

Guidance and Control Systems Console Handbook

Mission Operations Directorate
Space Transportation Vehicle Division
Guidance and Propulsion Systems Branch
DS62/Guidance and Control Systems Group

*To verify the latest version, refer to the DF Systems Division Master Document List at:
<http://stic.jsc.nasa.gov/dbase/iso9000/docs/DF/master.htm>*

Revision J, PCN-13
September 25, 2007

NASA

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

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MISSION OPERATIONS DIRECTORATE

GUIDANCE AND CONTROL SYSTEMS
CONSOLE HANDBOOK

REVISION J, PCN-13

September 25, 2007

PAGE CHANGE INSTRUCTIONS SHEET

Remove and replace the following pages and SCP's:

Cover	SCP 2.2	SCP 2.22
Letter	SCP 2.8	SCP 3.1
PCN Instructions Sheet	SCP 2.9	10.0-i
Signoff	SCP 2.11	SCP 11.19
Preface	SCP 2.18	Distribution
i-iv	SCP 2.19	
SCP 2.1	SCP 2.20	

Delete the following:

SCP 10.1

MISSION OPERATIONS DIRECTORATE

GUIDANCE AND CONTROL SYSTEMS
CONSOLE HANDBOOK

REVISION J, PCN-12

June 10, 2007

PAGE CHANGE INSTRUCTIONS SHEET

Remove and replace the following pages and SCP's:

Cover	i-iv	SCP 3.7
PCN Instructions Sheet	SCP 1.2	4.0-i
Signoff	SCP 1.4	Distribution
Preface	SCP 1.5	

Add the following:

SCP 4.19

MISSION OPERATIONS DIRECTORATE

GUIDANCE AND CONTROL SYSTEMS
CONSOLE HANDBOOK

REVISION J, PCN-11

November 13, 2006

PAGE CHANGE INSTRUCTIONS SHEET

Remove and replace the following pages and SCP's:

Cover	SCP 1.4	5.0-i
PCN Instructions Sheet	SCP 1.9	SCP 7.2
Signoff	SCP 2.2	SCP 7.4
Preface	SCP 2.3	SCP 8.1
i-iv	SCP 3.8	SCP 11.13
1.0-i	4.0-i	Distribution
SCP 1.1	SCP 4.10	
SCP 1.2	SCP 4.12	

Add the following:

SCP 1.11
SCP 4.18
SCP 5.9
SCP 5.10

Delete the following:

SCP 4.1

MISSION OPERATIONS DIRECTORATE

GUIDANCE AND CONTROL SYSTEMS
CONSOLE HANDBOOK

REVISION J, PCN-10

June 1, 2006

PAGE CHANGE INSTRUCTIONS SHEET

Remove and replace the following pages and SCP's:

Cover	SCP 2.18	SCP 9.1
PCN Instructions Sheet	SCP 2.19	SCP 9.3
Signoff	SCP 2.20	SCP 9.6
Preface	SCP 3.1	SCP 9.7
i-iv	SCP 3.5	SCP 9.9
SCP 1.1	SCP 3.7	SCP 9.14
SCP 1.5	SCP 4.8	SCP 11.16
SCP 1.9	SCP 4.16	Distribution
SCP 2.2	SCP 7.3	
SCP 2.11	SCP 8.2	

Add the following:

SCP 2.23

MISSION OPERATIONS DIRECTORATE

GUIDANCE AND CONTROL SYSTEMS
CONSOLE HANDBOOK

REVISION J, PCN-9

August 13th 2002

PAGE CHANGE INSTRUCTIONS SHEET

Remove and replace the following pages and SCP's:

Cover	SCP 2.3	SCP 4.15
PCN Instructions Sheet	SCP 2.7	SCP 4.16
Signoff	SCP 2.13	5.0-i
Preface	SCP 2.18	SCP 7.5
i-iv	SCP 3.2	SCP 8.1
SCP 1.1	SCP 3.6	SCP 8.3
SCP 1.2	SCP 4.2	SCP 9.10
SCP 1.3	SCP 4.4	11.0-i
SCP 1.4	SCP 4.5	SCP 11.10
SCP 1.5	SCP 4.6	SCP 11.11
SCP 1.6	SCP 4.9	SCP 11.14
SCP 1.8	SCP 4.10	SCP 11.19
2.0-i	SCP 4.12	Distribution
SCP 2.1	SCP 4.14	

Add the following:

SCP 2.22, SCP 5.8, SCP 11.3

Delete the following:

SCP 11.23

MISSION OPERATIONS DIRECTORATE

GUIDANCE AND CONTROL SYSTEMS
CONSOLE HANDBOOK

REVISION J, PCN-8

October 4th 2002

PAGE CHANGE INSTRUCTIONS SHEET

Remove and replace the following pages:

Cover	2.2	7.6
PCN Instructions Sheet	2.3	8.5
Signoff	2.8	9.6
Preface	2.9	9.10
i-iv	2.11	10.0-i
1.1	2.19	11.2
1.2	4.0-i	11.13
1.4	4.16	11.16
1.5	4.17	Distribution
2.0-i	5.7	
2.1	6.1	

Add the following:

2.14, 2.21, 4.8, 10.8

Delete the following pages:

none

MISSION OPERATIONS DIRECTORATE

GUIDANCE AND CONTROL SYSTEMS
CONSOLE HANDBOOK

REVISION J, PCN-7

May, 4th 2001

PAGE CHANGE INSTRUCTIONS SHEET

Remove and replace the following pages:

Cover	2.11	7.4
PCN Instructions	2.13	8.1
Sheet	2.16	8.5
Signoff	2.18	9.2
Preface	2.19	9.6
i-iv	3.0-i	9.10
1.3	3.1	10.0-i
1.4	3.3	10.1
2.0-i	3.4	10.6
2.2	3.5	10.10
2.4	4.0-i	10.11
2.5	4.4	11.0-i
2.6	4.7	11.10
2.7	5.7	11.7
2.8	6.0-i	Distribution
2.10	6.3	

Add the following:

4.17

Delete the following pages:

2.4A, 2.5A, 2.10A, 2.13A, 2.16A, 2.18A, 3.5A, 4.7A, 6.3A, 10.11A, 11.3

TITLE

STANDARD CONSOLE PROCEDURES CHANGE PROCESS

PURPOSE

This Standard Console Procedure (SCP) provides instructions for making changes to the Guidance and Control Systems Console Handbook (G&C CH).

PROCEDURE

To make changes to any of the SCP's in this handbook, the change initiator needs to fill out an SCP change request (CR) form and submit it to the JSC/DF62 Group Lead for change implementation. An SCP CR form is shown in Figure 1.0-1. A copy of the SCP CR form is also available in the front of the G&C CH immediately following the cover page. A copy of this page should be used when submitting an SCP CR.

If the CR includes changes related to command procedures, a Command Procedures Handbook (CPH) CR will be written and the SCP CR attached to it. Contact the Communications Systems Group Lead at NASA/JSC mail code DF24 for a CPH CR.

Instructions on how to fill out the SCP CR are provided below.

Initiated by: Indicate the name of the change initiator in this field.

Submit Date: Indicate the date the CR is being submitted.

CR #: The CR tracking number is determined by the G&C CH Book Manager. Leave this field blank.

Title: Provide a brief descriptive title that indicates why the change is being proposed.

Description of Change or Addition: This field includes a detailed description of the change, rationale for the change, and the initiator's organization/name.

Technical Author, Technical Reviewer, Assigned Completion Date, Assigned PCN, Authorization Signatures:

These fields are for administrative use only and will be completed by the G&C CH Book Manager and Group Lead.

Standard Console Procedures Change Request (CR) Form

Initiated by:	Submit Date:	CR #
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For Administrative Use Only

Title:

Description of Change or Addition:

For Administrative Use Only

Technical Author:	Assigned Completion Date:
Technical Reviewer:	Assigned PCN:

Group Lead Authorization Signatures

IMPLEMENT	CLOSE Completion Date: PCN =
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Figure 1.0-1 SCP CR Form

Standard Console Procedures Change Request (CR) Form

Initiated by: Melinda C. Ceccacci	Submit Date: 7/24/97	CR # J-5
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For Administrative Use Only

Title: Revision of Guidance and Control Console Handbook (G&C CH) to meet ISO9000 standards and consolidation of SCP Volumes I and II.
Description of Change or Addition:
<p>The G&C CH cover page was updated to include the ISO9000 web site address, the mail code for the G&C Systems Group, the PCN number (Revision J, PCN-1) and the PCN date. In addition, reference to Volumes I and II on the cover page and Table of Contents was deleted since Volumes I and II have been consolidated into one book (the G&C CH).</p> <p>In accordance with ISO9000 standards, a copy of the SCP change request (CR) form was included behind the cover page with instructions provided in a new SCP, SCP 1.0 STANDARD CONSOLE PROCEDURES CHANGE PROCESS. The Table of Contents was updated to reflect the addition of SCP 1.0.</p> <p>The signoff sheet was updated to identify the Book Manager by name and to reflect the change in organizational structure (“Group” instead of “Section”).</p>

For Administrative Use Only

Technical Author: Melinda C. Ceccacci	Assigned Completion Date: July 31, 1997
Technical Reviewer: Stanley J. Schaefer	Assigned PCN: Revision J, PCN-1
Group Lead Authorization Signatures	
IMPLEMENT	CLOSE Completion Date: PCN =

TITLE

GNC MDM/BUS LOSS TABLES

PURPOSE

This SCP provides a quicklook reference to determine what GNC equipment or redundancy is lost for given power bus, control bus, or Multiplexer/Demultiplexer (MDM) failures. The following tables contain only component losses.

PROCEDURE

The first set of tables contains all the subbuses which power GNC equipment for each main bus. The layout of these tables indicates bus hierarchy. For example, the first table shows that FMC1, FLC1, and AC1 are all subbuses of FPC1, which is itself a subbus of Main A. The loss of a higher bus will lose all subbuses powered by that bus. Components are listed below each bus basis with complete component losses in bold letters, redundancy losses in normal text. For example, if MPC 3 fails then ORB RGA 3 power is lost completely, but only redundant power for ORB RGA 4 is lost.

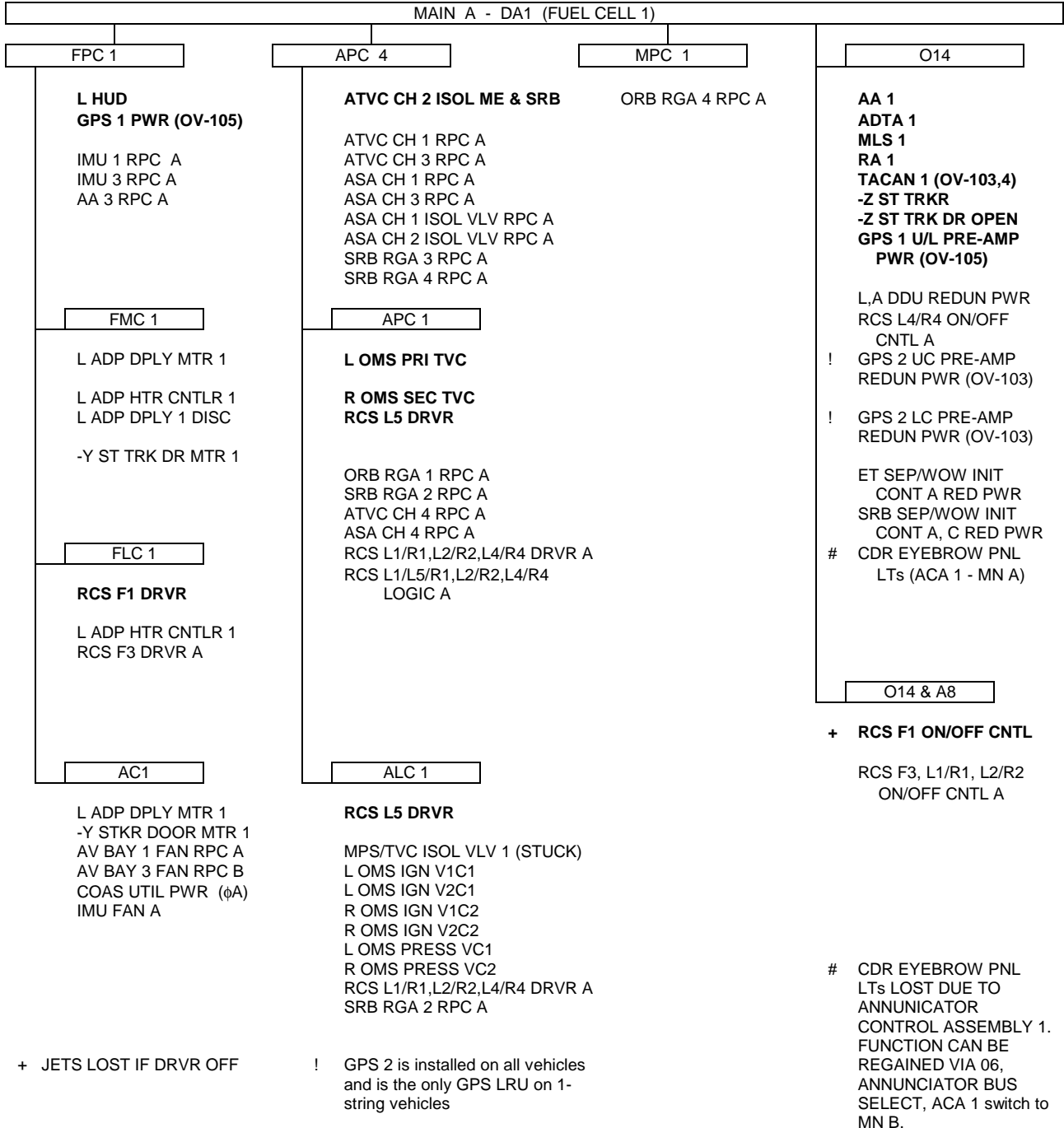
The next set of tables lists all components lost per each of the nine control and three essential buses. Again, components are presented according to loss severity. Complete losses are listed first, followed by one of two type redundancy losses. Next are listed any one of three type losses and, finally, any one of four type redundancy losses.

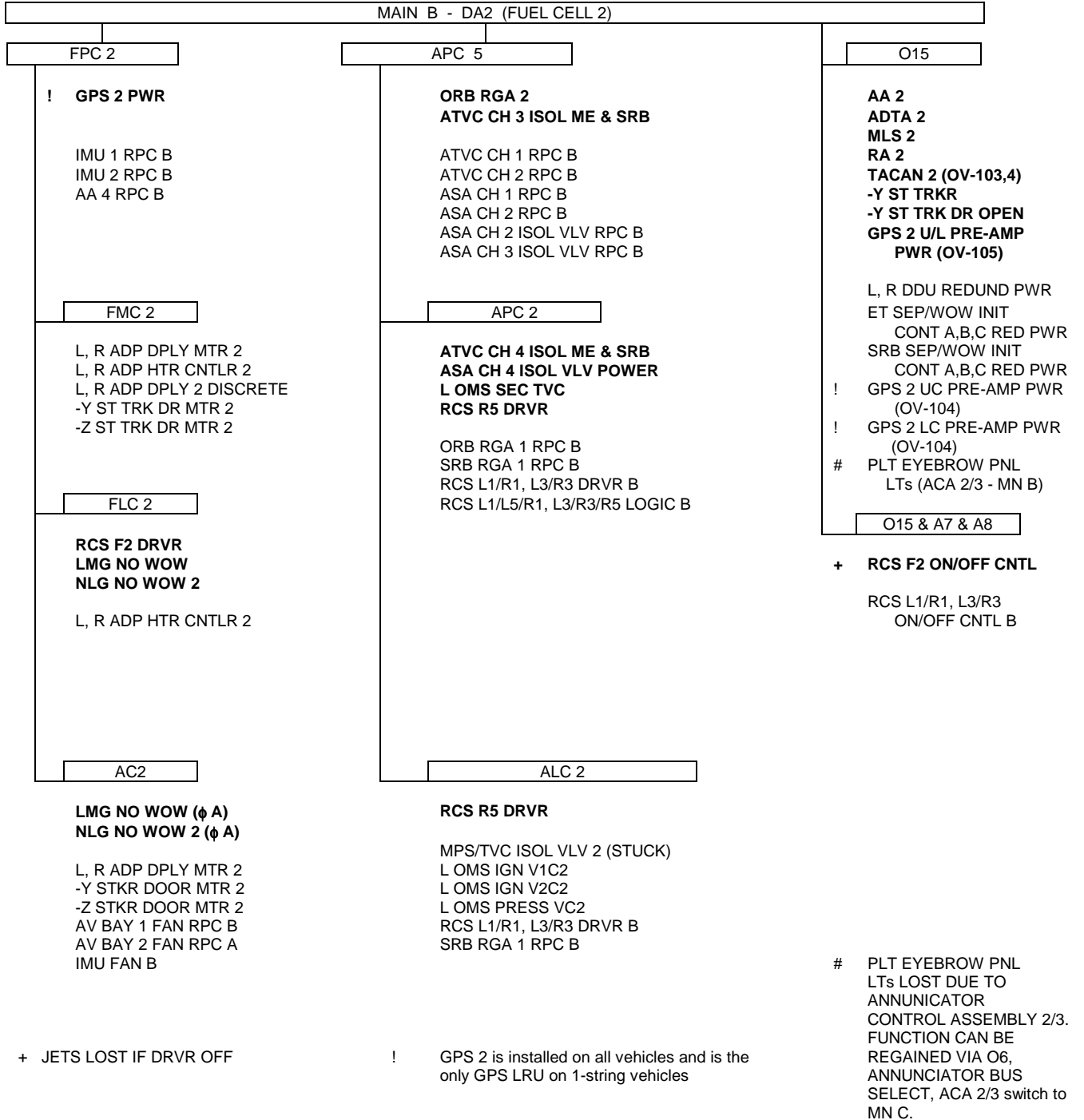
The last set of tables lists all GNC components connected to each of the flight-critical and payload MDM's. As before, complete losses are shown first, followed by one of two, then one of three, and finally one of four type redundancy losses.

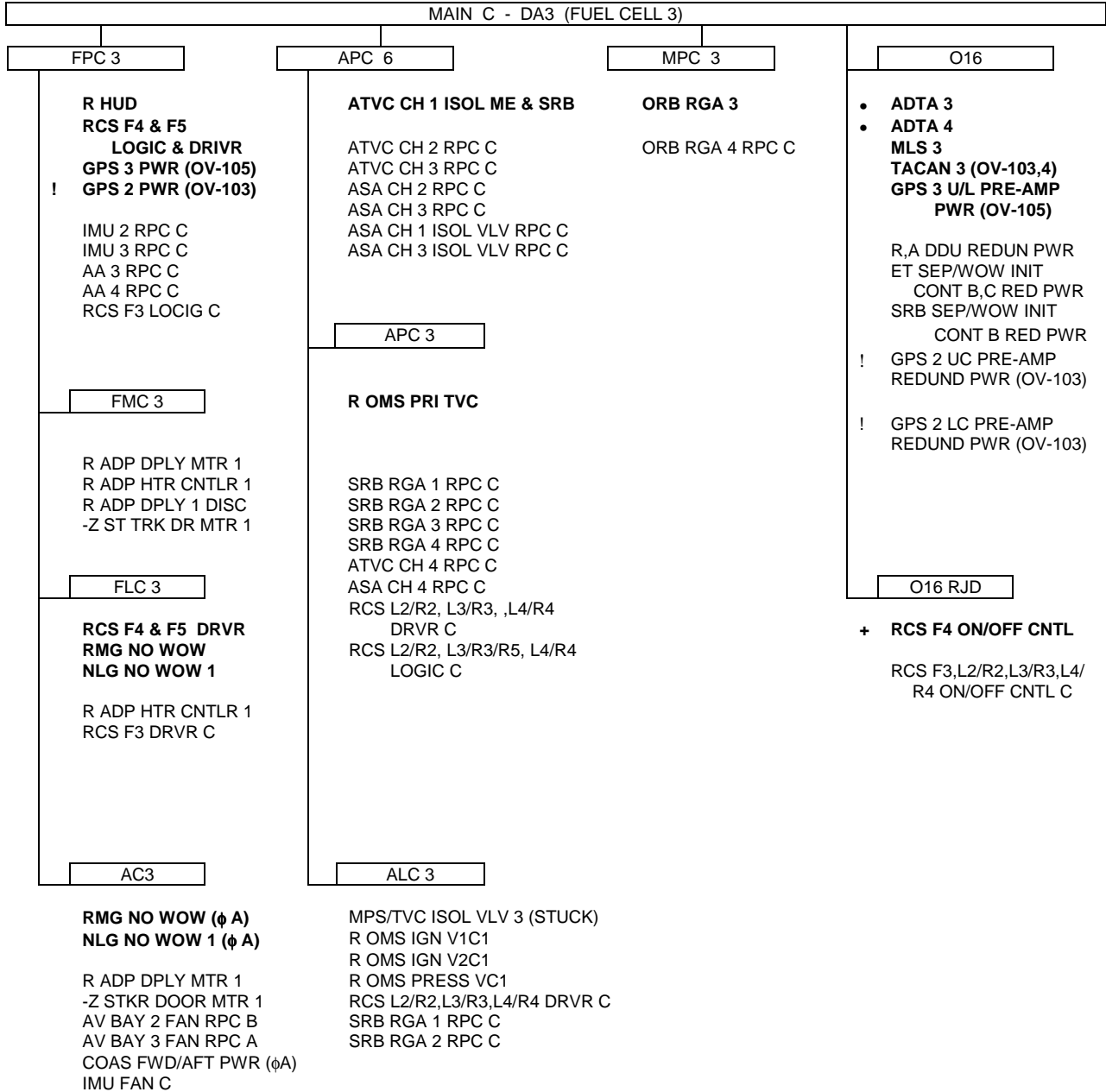
In the tables, symbols before some entries are used to remind users of flight rules impacts, secondary losses, and available actions. Specifically, a "•" indicates that the GNC flight rules call for minimum duration flight. A "+" instructs the user to check the status of the RJD DRVR switch. If it is in the "OFF" position, the RCS jets associated with that driver are lost. Switch contacts deselectable in OPS 8 are preceded by a "*" symbol.

REFERENCES

1. STS Flight Mandatory Instrumentation List and OI MDM/DSC Failure Impacts, JSC-16983, Basic, rev B, Jan. 1987.

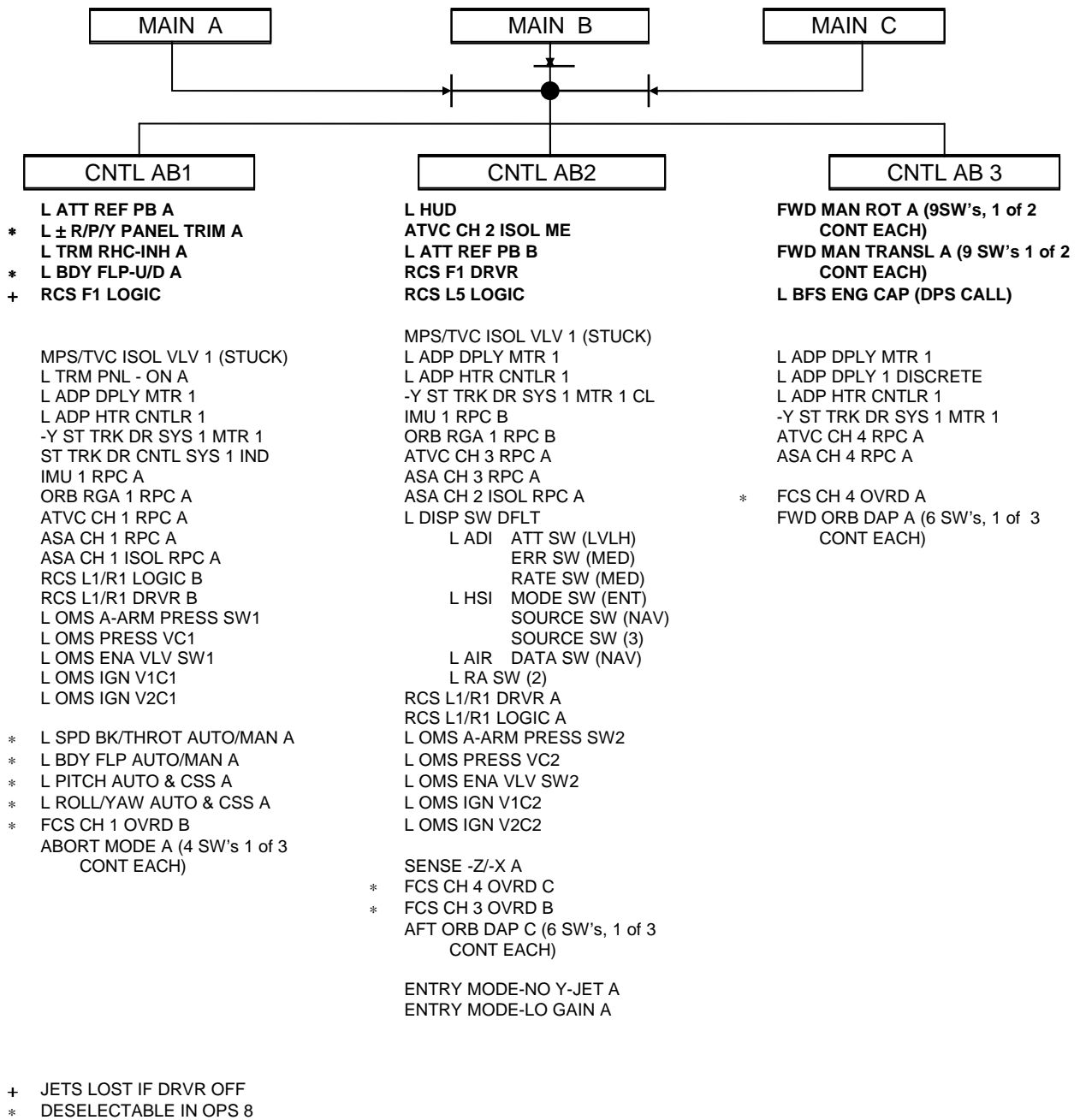


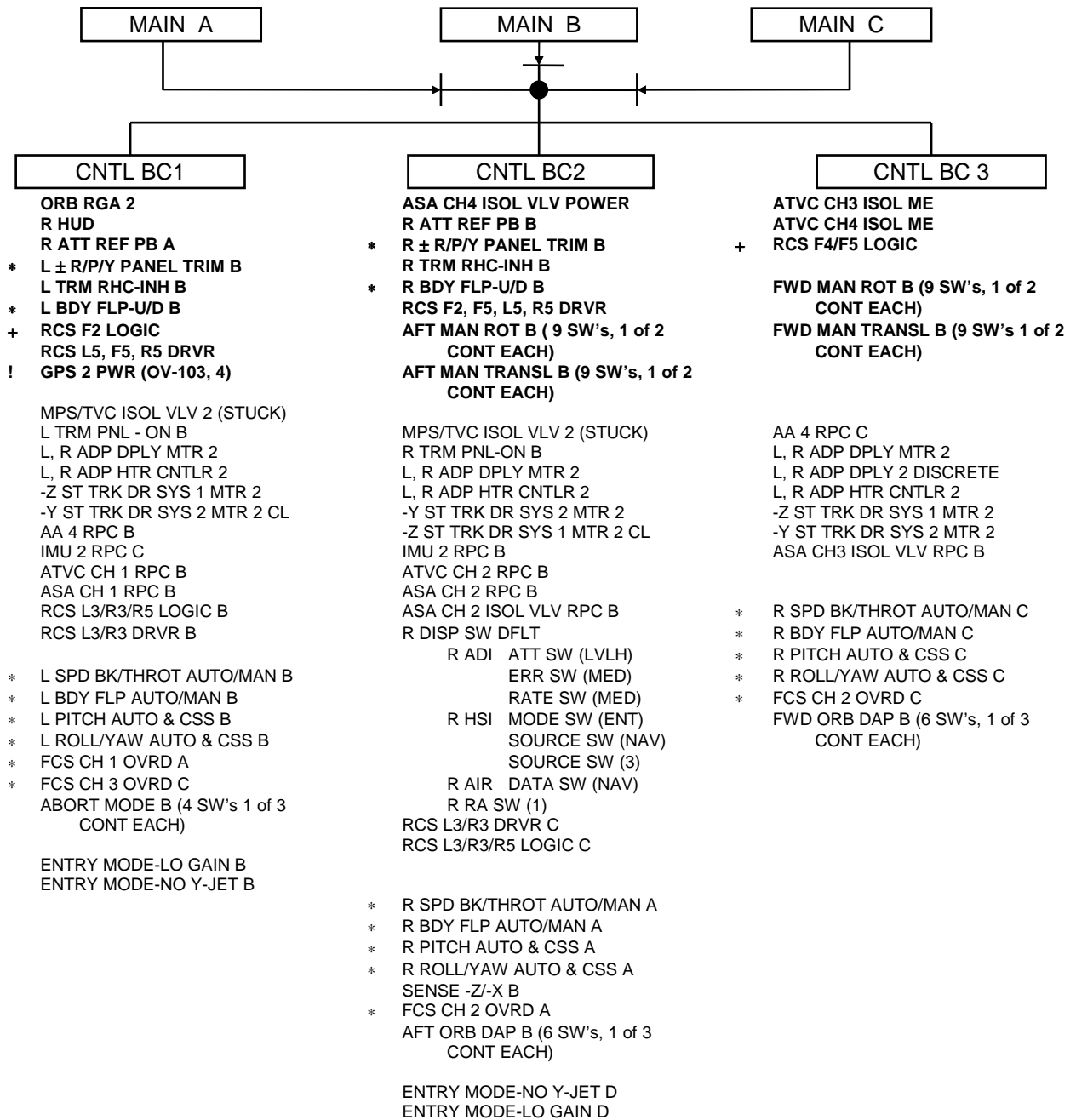




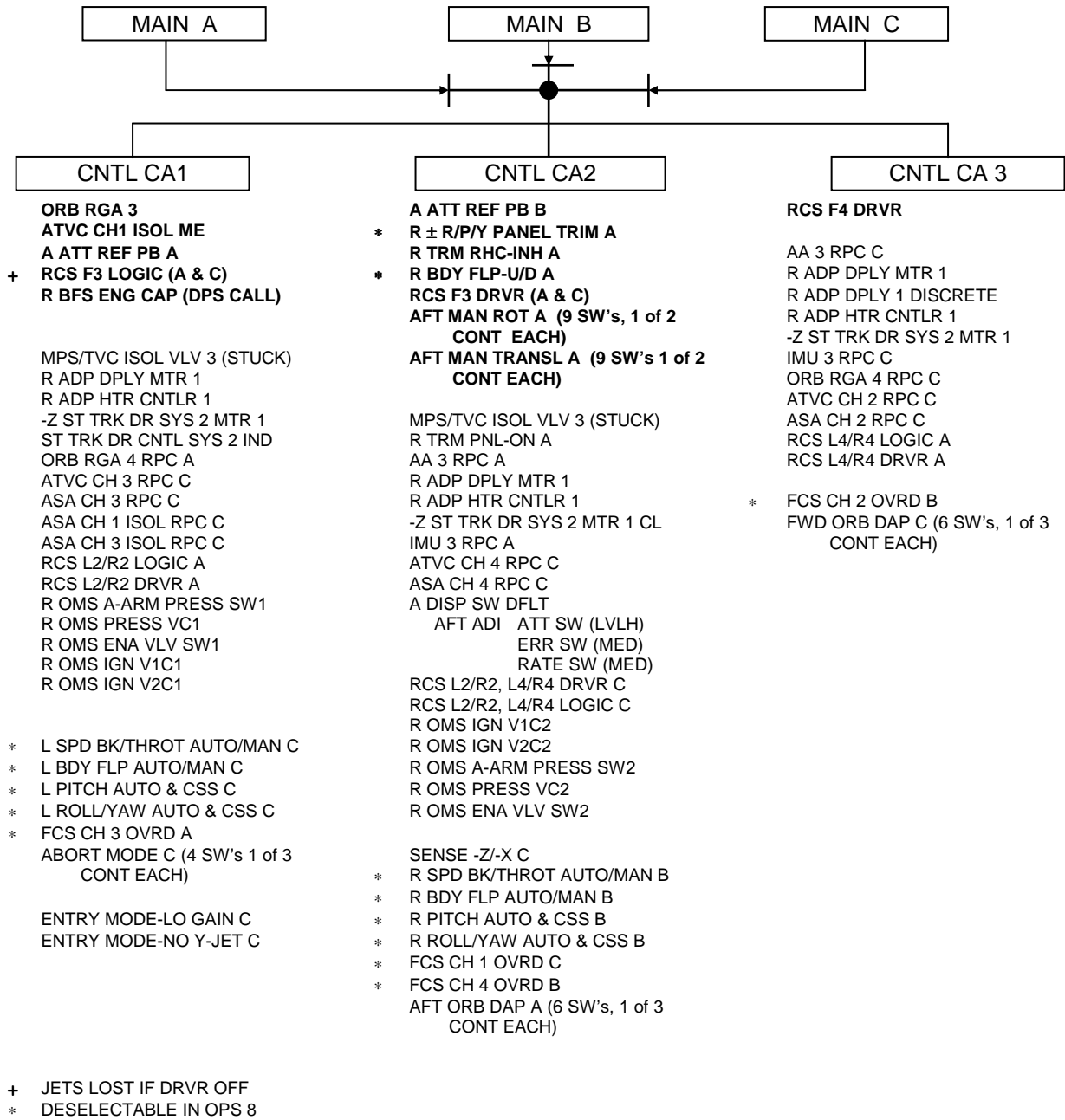
- INVOKE MINIMUM DURATION FLIGHT
- + JETS LOST IF DRVR OFF

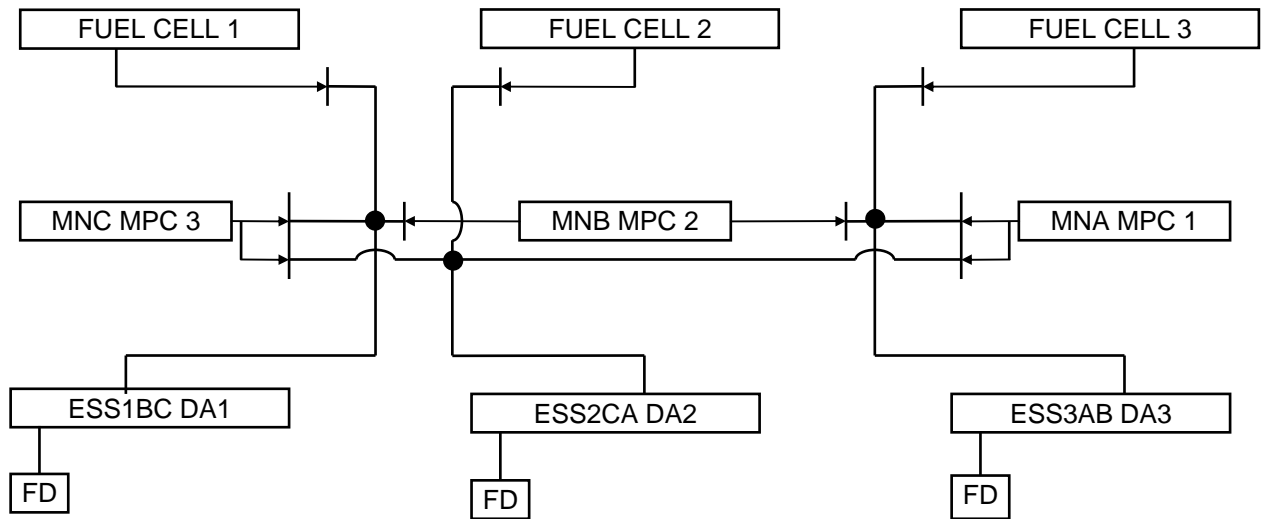
! GPS 2 is installed on all vehicles and is the only GPS LRU on 1-string vehicles





+ JETS LOST IF DRVR OFF
* DESELECTABLE IN OPS 8
! GPS 2 is installed on all vehicles and is the only GPS LRU on 1-string vehicles





GPS 1 PWR (OV-105)

TAC 1 AUTO SELF TEST (OV-103,4)
TAC 1 SW ON IND (OV-103,4)
MLS 1 SW ON IND
RA 1 PWR ON IND

GPS 2 PWR (OV-105)

TAC 2 AUTO SELF TEST (OV-103,4)
TAC 2 SW ON IND (OV-103,4)
MLS 2 SW ON IND
RA 2 PWR ON IND

**L & R BFS ENG CAP (DPS CALL)
GPS 3 PWR (OV-105)**

TAC 3 AUTO SELF TEST (OV-103,4)
TAC 3 SW ON IND (OV-103,4)
MLS 3 SW ON IND
SRB RGA 1 RPC C
SRB RGA 2 RPC C

MDM FF1

AA 1
IMU 1
ADTA 1
RA 1
MLS 1
TACAN 1 (OV-103,4)
-Z STAR TRACKER
RCS F1 CMD & DRVR
SPI-RUD POSN, SPD BK CMD & POSN, ELVN POSN,
VALID FLAG
FWD ORB DAP LTS (6)
FWD MAN TRANSL/ROT LTS (18)
L SPD BK/THROT AUTO LT
L BODY FLAP AUTO LT
L PITCH & ROLL/YAW AUTO LTS
L ATT REF PB
L OMS PRI TVC ENA
GPS 1 (OV-105)
L DDU POWER SUPPLY A, B, C (GND IND ONLY)
L ADP DPLY 1 DISCRETE
L DISP SW DFLT
L ADI ATT SW (LVLH)
ERR SW (MED)
RATE SW (MED)
L HSI MODE SW (ENT)
SOURCE SW (NAV)
SOURCE SW (3)
L AIR DATA SW (NAV)
L RA SW (2)
FWD MAN ROT A (9 SW's, 1 OF 2 CONT EACH)
FWD MAN TRANSL A (9 SW's, 1 OF 2 CONT EACH)
RCS CMD LTS A
L BODY FLAP - U/D A
L TRIM PNL - ON A
L +/- R/P/Y PANEL TRIM A
L RHC +/- ROLL/PITCH TRIM A
L TRIM RHC - INH A
-Z ST TRK DR OP & CL DSCT SYS 1 M2 (GND ONLY)
-Y ST TRK DR OP & CL DSCT SYS 1 M1 (GND ONLY) •

FCS CH 1,3(4) OVRD B(C)
ABORT MODE A (4 SW's, 1 OF 3 CONT EACH)
AFT ORB DAP C (6 SW's, 1 OF 3 CONT EACH)
FWD ORB DAP A (6 SW's, 1 OF 3 CONT EACH)
L BODY FLAP AUTO/MAN A
L PITCH AUTO & CSS A
L ROLL/YAW AUTO & CSS A
L SPD BK/THROT AUTO/MAN A
ET SEP/WOW INIT A
SRB SEP/WOW INIT A
FWD & AFT THC +/-XYZ A
L,A RHC ROLL/PITCH/YAW CMD A
SENSE -Z & -X A
L RPTA CMD A
L SBTC CMD/TAKEOVER A

ENTRY MODE - LO GAIN A
ENTRY MODE - NO Y JET A

! GPS 2 is installed in all vehicles and is the only GPS LRU on 1-string vehicles

MDM FF2

AA 2
IMU 2
ADTA 2
RA 2
MLS 2
TACAN 2 (OV-103,4)
RCS F2 CMD & DRVR
SPI - AILERON & BODY FLAP POSN's
L SPD BK/THROT MAN LT
L BODY FLAP MAN LT
L PITCH & ROLL/YAW CSS LTS
R ATT REF PB
L OMS SEC TVC ENA
NLG NO WOW 2
! GPS 2 RCVR (OV-103, 4, 5)
R DDU POWER SUPPLY A, B, C (GND IND ONLY)

R ADP DPLY 1 DISCRETE
R DISP SW DFLT
R ADI ATT SW (LVLH)
ERR SW (MED)
RATE SW (MED)
R HSI MODE SW (ENT)
SOURCE SW (NAV)
SOURCE SW (3)
R AIR DATA SW (NAV)
R RA SW (1)
FWD MAN ROT B (9 SW's, 1 OF 2 CONT EACH)
FWD MAN TRANSL B (9 SW's, 1 OF 2 CONT EACH)
L BODY FLAP - U/D B
L TRIM PANEL - ON B
L +/- R/P/Y PANEL TRIM B
L RHC +/- ROLL/PITCH TRIM B
L TRIM RHC - INH B

FCS CH 1,2(3) OVRD A(C)
ABORT MODE B (4 SW's, 1 OF 3 CONT EACH)
FWD ORB DAP B (6 SW's, 1 OF 3 CONT EACH)
L(R) BODY FLAP AUTO/MAN B(A)
L(R) SPD BK/THROT AUTO/MAN B(A)
L(R) PITCH AUTO & CSS B(A)
L(R) ROLL/YAW AUTO & CSS B(A)
L(R) RHC ROLL/PITCH/YAW CMD B(A)
A RHC PITCH/YAW CMD B
SENSE -Z & -X B
L(R) RPTA CMD B(A)
L(R) SBTC CMD/TAKEOVER B(A)
FWD, AFT THC +/- XYZ B

ENTRY MODE - LO GAIN B
ENTRY MODE - NO Y JET B

• INVOKE MINIMUM DURATION FLIGHT

MDM FF3

AA 3
IMU 3
ADTA 3
MLS 3
TACAN 3 (OV-103,4)
-Y STAR TRACKER
RCS F4, F5 CMD DRVR
C&W LIGHTS
RCS FAIL
FCS CH FAIL
FCS SAT
OMS TVC
L, R, OMS PC
L, R, A RHC FAIL
IMU, ADTA, RGA/AA
AFT ORB DAP LTS (6)
AFT MAN TRANSL/ROT LTS (18)
R PITCH & ROLL/YAW AUTO LTS
R BODY FLAP AUTO LT
R SPD BK/THROT AUTO LT
AFT ATT REF PB
R OMS SEC TVC ENA
NLG NO WOW 1
GPS 3 (OV-105)
A DDU POWER SUPPLY A, B, C (GND IND ONLY)

L ADP DPLY 2 DISCRETE
AFT DISP SW DFLT
AFT ADI ATT SW (LVLH)
ERR SW (MED)
RATE SW (MED)
AFT MAN ROT A (9 SW'S, 1 OF 2 CONT EACH)
AFT MAN TRANSL A (9 SW'S, 1 OF 2 CONT EACH)
R BODY FLAP - U/D A
R TRIM PANEL - ON A
R +/- R/P/Y PANEL TRIM A
R RHC +/- ROLL/PITCH TRIM A
R TRIM RHC - INH A
-Z ST TRK DR OP & CL DISCT SYS 2 M1 (GND ONLY)
-Y ST TRK DR OP & CL DSCT SYS 2 M2 (GND ONLY)

- RCS CMD LTS B (6 LIGHTS, 1 OF 2 BULBS EACH)
FCS CH 1(2,4) OVRD C (B)
ABORT MODE C (4 SW'S, 1 OF 3 CONT EACH)
AFT ORB DAP A (6 SW'S, 1 OF 3 CONT EACH)
FWD ORB DAP C (6 SW'S, 1 OF 3 CONT EACH)
- L(R) BODY FLAP AUTO/MAN C(B)
L(R) SPD BK/THROT AUTO/MAN C(B)
L(R) PITCH AUTO & CSS C(B)
L(R) ROLL/YAW AUTO & CSS C(B)
FWD, AFT THC +/- XYZ C
L, A(R) RHC ROLL/PITCH/YAW CMD C(B)
SENSE -Z & -X C
L(R) RPTA CMD C(B)
L(R) SBTC CMD/TAKEOVER C(B)
SENSE -Z & -X C
L(R) RPTA CMD C(B)
L(R) SBTC CMD/TAKEOVER C(B)
SRB SEP/WOW INIT C
ET SEP/WOW INIT C

ENTRY MODE - LO GAIN C
ENTRY MODE - NO Y JET C

MDM FF4

AA 4
ADTA 4
RCS F3 CMD & DRVR
R PITCH & ROLL/YAW CSS LTS
R BODY FLAP MAN LT
R OMS PRI TVC ENA

R ADP DPLY 2 DISCRETE
AFT MAN ROT B (9 SW'S, 1 OF 2 CONT EACH)
AFT MAN TRANSL B (9 SW'S, 1 OF 2 CONT EACH)
R BODY FLAP - U/D B
R TRIM PANEL - ON B
R +/- R/P/Y PANEL TRIM B
R RHC +/- ROLL/PITCH TRIM B
R TRIM RHC - INH B

FCS CH 2(3,4) OVRD C(A)
AFT ORB DAP B (6 SW'S, 1 OF 3 CONT EACH)
R BODY FLAP AUTO/MAN C
R SPD BK/THROT AUTO/MAN C
R PITCH AUTO & CSS C
R RHC ROLL/PITCH/YAW CMD C
A RHC ROLL CMD B
R SBTC CMD/TAKEOVER C
R RPTA CMD C
SRB SEP/WOW INIT B
ET SEP/WOW INIT B

ENTRY MODE - LO GAIN D
ENTRY MODE - NO Y JET D

- **INVOKE MINIMUM DURATION FLIGHT**

MDM FA1

ORB RGA 1
SRB RGA 1
L OMS PRI TVC
ATVC CH 1 CMDS, OVRD, FAIL
ASA CH 1 CMDS, OVRD, FAIL
ASA CH 1 BF UP/DOWN ENABLE, POS FDBK
ASA CH 1 ELVN PRI ΔP
ASA CH 1 LOB, LIB, RIB, ROB ELVN POS FDBK
ASA CH 1 SPD BK & RUDDER POS FDBK
RCS L1/L5/R1 CMD & DRVR

L OMS V1C2
R OMS V1C2
L OMS A - ARM/PRESS SW 2
HYD PRESS 1A, 2B*

MDM FA2

ORB RGA 2
SRB RGA 2
L OMS SEC TVC
ATVC CH 2 CMDS, OVRD, FAIL
ASA CH 2 CMDS, OVRD, FAIL
ASA CH 2 BF UP/DOWN ENABLE, POS FDBK
ASA CH 2 ELVN PRI ΔP
ASA CH 2 LOB, LIB, RIB, ROB ELVN POS FDBK
ASA CH 2 SPD BK & RUDDER POS FDBK
RCS L3/R3/R5 CMD & DRVR

L OMS V2C2
R OMS V2C2
R OMS A - ARM/PRESS SW 2
HYD PRESS 1B*, 2A, 3C

DSC OA1⁺

SSME 1,2,3 P,Y ACTR POSNs
LIB, LOB, RIB, ROB PRI SW VLV POSNs
LIB, LOB SEC SW VLV POSNs
RUD, SPBK PRI SW VLV POSNs

HYD PRESS 1A, 2B*

DSC OA2⁺

SSME 1,2,3 P,Y SW VLV POSNs
RUD, SPBK SEC SW VLV POSNs

HYD PRESS 1B*, 2A, 3C

MDM FA3

ORB RGA 3
SRB RGA 3
R OMS SEC TVC
ATVC CH 3 CMDS, OVRD, FAIL
ASA CH 3 CMDS, OVRD, FAIL
ASA CH 3 BF UP/DOWN ENABLE, POS FDBK
ASA CH 3 ELVN PRI ΔP
ASA CH 3 LOB, LIB, RIB, ROB ELVN POS FDBK
ASA CH 3 SPD BK & RUDDER POS FDBK
L OMS PC - FDI
RCS L2/R2 CMD & DRVR

L OMS V2C1
R OMS V1C1
L OMS A - ARM/PRESS SW 1
HYD PRESS 2C, 3A

MDM FA4

ORB RGA 4
SRB RGA 4
R OMS PRI TVC
ATVC CH 4 CMDS, OVRD, FAIL
ASA CH 4 CMDS, OVRD, FAIL
ASA CH 4 BF POS FDBK
ASA CH 4 ELVN PRI ΔP
ASA CH 4 LOB, LIB, RIB, ROB ELVN POS FDBK
ASA CH 4 SPD BK & RUDDER POS FDBK
R OMS PC - FDI
RCS L4/R4 CMD & DRVR

L OMS V1C1
R OMS V2C1
R OMS A - ARM/PRESS SW 1
HYD PRESS 1C, 3B*

MDM PF1

ABORT LT A

MDM PF2

L,R BFC LTS
ABORT LT B

DSC OA3⁺

RIB, ROB SEC SW VLV POSNs

HYD PRESS 1C, 2C, 3A, 3B*

- INVOKE MINIMUM DURATION FLIGHT
- * GPC "B" MEASUREMENTS ARE USED BY PRL BUT ARE NOT ON TLM. OI "B" MEASUREMENTS ARE ON TLM AND USED FOR MCC DISPLAY
- + DATA WILL NOT BE COMMFAULTED ON MCC DISPLAYS

MDM OF1

AA 3 RPC A ON IND
IMU 1,3 RPC A ON INDs
L ADP MAST,T-0, ALPHA HEATER ON, CURR INDs
L RPTA OUTPUT A, B, C INDs
GPS 1 RECEIVER STATUS (OV-105)
GPS 1 RPC A ON IND (OV-105)

MDM OF2

COAS FWD, AFT STATION PWR ON INDs (DSC OF2)
AA 4 RPC B ON IND
IMU 1,2 RPC B ON INDs
L,R ADP MAST,T-0, ALPHA HEATER ON, CURR INDs
TACAN 1,2,3 AGC INDs
R RPTA OUTPUT A, B, C INDs
! GPS 2 RECEIVER STATUS
GPS 2 RPC B ON IND (OV-105)

MDM OF3

AA 3,4 RPC C ON INDs
AA 3,4 PWR ON CMD INDs
IMU 2,3 RPC C ON INDs
R ADP HAST, T-0, ALPHA HEATER ON, CURR INDs
GPS 3 RECEIVER STATUS (OV-105)
GPS 3 RPC C ON IND (OV-105)

MDM OF4

STAR TRKR DR CONT SYS 1,2 OFF INDs
L,R ADP STOW, DPLY/HEAT GND INDs
L,R PANEL TRIM PWR ON A INDs
L,R HUD ELECTRONICS UNIT GOOD INDs
L,R HUD PDU GOOD INDs
MLS 1,2,3 PWR ON INDs
TACAN 1,2,3 PWR ON INDs
RA 1,2 PWR ON INDs
AA 1,2 PWR ON CMD INDs
GPS 1 PRE AMPL UP RH PWR ON IND (OV-105)
GPS 1 PRE AMPL LWR LH PWR ON IND (OV-105)
! GPS 2 PRE AMPL UP PWR ON IND
! GPS 2 PRE AMPL LWR PWR ON IND
GPS 3 PRE AMPL UP LH PWR ON IND (OV-105)
GPS 3 PRE AMPL LWR RH PWR ON IND (OV-105)

SRB DSC A4

L,R,ROCK,TILT ACTR POSNS

DSC OF1

ET SEP/WOW INIT A
SRB SEP/WOW INIT A

DSC OF2

ET SEP/WOW INIT B
SRB SEP/WOW INIT B

DSC OF3

ET SEP/WOW INIT C

! GPS 2 is installed in all vehicles and is the only GPS LRU on 1-string vehicles

MDM OA1

L,R ROCK,TILT CH 1 SEC ΔPs
L,R ROCK,TILT CH 1 DRVR OUTPUTs
RUD,SPBK,ELVN CH 1 POSNs
RUD,SPBK,ELVN CH 1 SEC ΔPs
RUD,SPBK,ELVN CH 1 DRVR OUTPUTs
BDY FLP CH 1 ENA,UP,DN OUTPUTs
SSME 1,2,3 P,Y CH 1 SEC ΔPs
SSME 1,2,3 P,Y CH 1 DRVR OUTPUTs
ASA 1,2,3,4 RPC A ON INDs
ASA 1 PWR ON CMD IND
ATVC 1,3,4 RPC A ON INDs
ATVC 1 PWR ON CMD IND
RGA 1,4 RPC A ON INDs
RGA 1 PWR ON CMD IND
MPS/TVC Isol Valve 1

MDM OA2

L,R ROCK,TILT CH 2 SEC ΔPs
L,R ROCK,TILT CH 2 DRVR OUTPUTs
RUD,SPBK,ELVN CH 2 POSNs
RUD,SPBK,ELVN CH 2 SEC ΔPs
RUD,SPBK,ELVN CH 2 DRVR OUTPUTs
BODY FLAP CH 2 ENA,UP,DN OUTPUTs
SSME 1,2,3 P,Y CH 2 SEC ΔPs
SSME 1,2,3 P,Y CH 2 DRVR OUTPUTs
ASA 1,2,3, RPC B ON INDs
ASA 2 PWR ON CMD IND
ATVC 1,2 RPC B ON INDs
ATVC 2 PWR ON GND IND
RGA 1 RPC B ON INDs
RGA 2 PWR ON CMD IND
MPS/TVC Isol Valve 2

MDM OA3

L,R ROCK,TILT CH 3,4 SEC ΔPs
L,R ROCK,TILT CH 3,4 DRVR OUTPUTs
RUD,SPBK,ELVN CH 3,4 POSNs
RUD,SPBK,ELVN CH 3,4 DRVR OUTPUTs
RUD,SPBK,ELVN CH 3,4 SEC ΔPs
BODY FLP CH 3 ENA,UP,DN OUTPUTs
SSME 1,2,3 P,Y CH 3,4 SEC ΔPs
SSME 1,2,3 P,Y CH 3,4 DRVR OUTPUTs
ASA 1,2,3,4 RPC C ON INDs
ASA 3,4 PWR ON CMD INDs
ATVC 2,3,4 RPC C ON INDs
ATVC 3,4 PWR ON CMD INDs
RGA 4 RPC C ON INDs
RGA 3,4 PWR ON CMD INDs
MPS/TVC Isol Valve 3

DSC OM1

SRB SEP/WOW INIT C

SHUTTLE OPS
GNC/JSC-12843

ORIG: F. E. TRLICA
11/13/06: REVISION J, PCN-11

MDM/BUS LOSS
SCP 1.1

TITLE

TROUBLESHOOTING CONTROL BUS SHORTS/PARTIAL LOSSES

PURPOSE

This SCP provides a quick-look reference to determine the GNC systems and redundancy losses associated with the partial loss of a given control bus. For the purposes of troubleshooting to determine which switch panels are affected by the control bus short(s), this SCP provides a quick-look reference for the equipment associated with each panel powered by the control bus.

DESCRIPTION

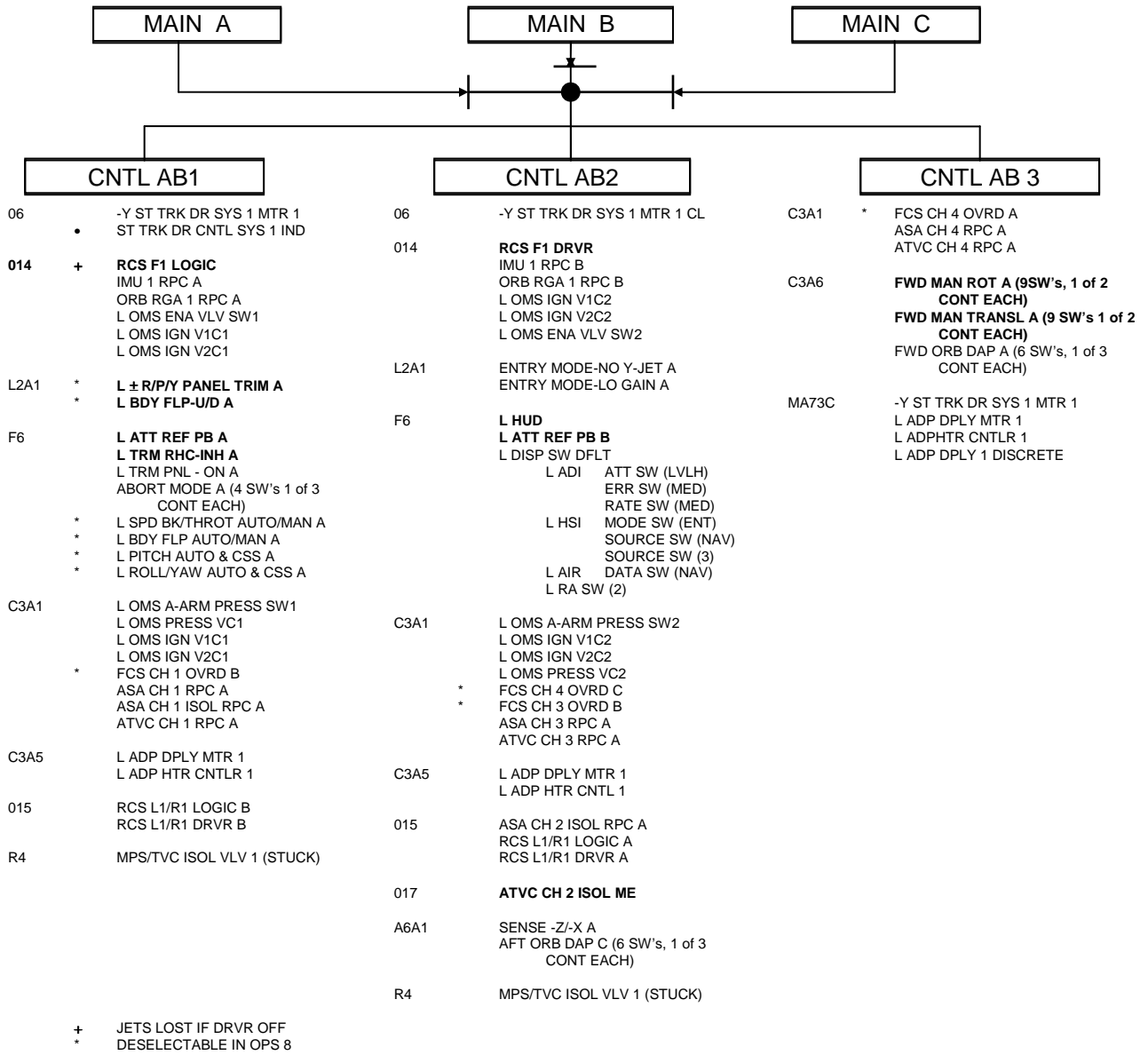
The nine control buses provide power to various switches and RPC's for GNC equipment, as well as numerous other systems. A short in one of the buses will cause a partial loss of that bus and at least two shorts are required for a total loss of the bus. The partial loss will manifest itself by affecting one or more panels powered by the bus. Studies show that for most shorts, the voltage will generally degrade across the length of the bus as the resistance builds from one panel to the next. Also, it is possible for a given panel to have a voltage gradient across it, since the control buses are wired in series (vice parallel) through the panel. The equipment at one end of the panel might have sufficient voltage, while the middle of the panel has somewhat degraded voltage, and the opposite end of the panel has even less voltage. For example, a short in CNTL AB1 at panel L2A1 may cause a voltage gradient across panel 014, such that there is sufficient voltage to maintain RGA 1 RPC A to the ON state, but not sufficient voltage to maintain IMU 1 RPC A to the ON state (ref. SSSH DWG 20.1, Sheet 3 of 4, SSSH DWG 2.2, Sheet 1 of 2, and SCP 1.1, CNTL AB1 redundancy losses).

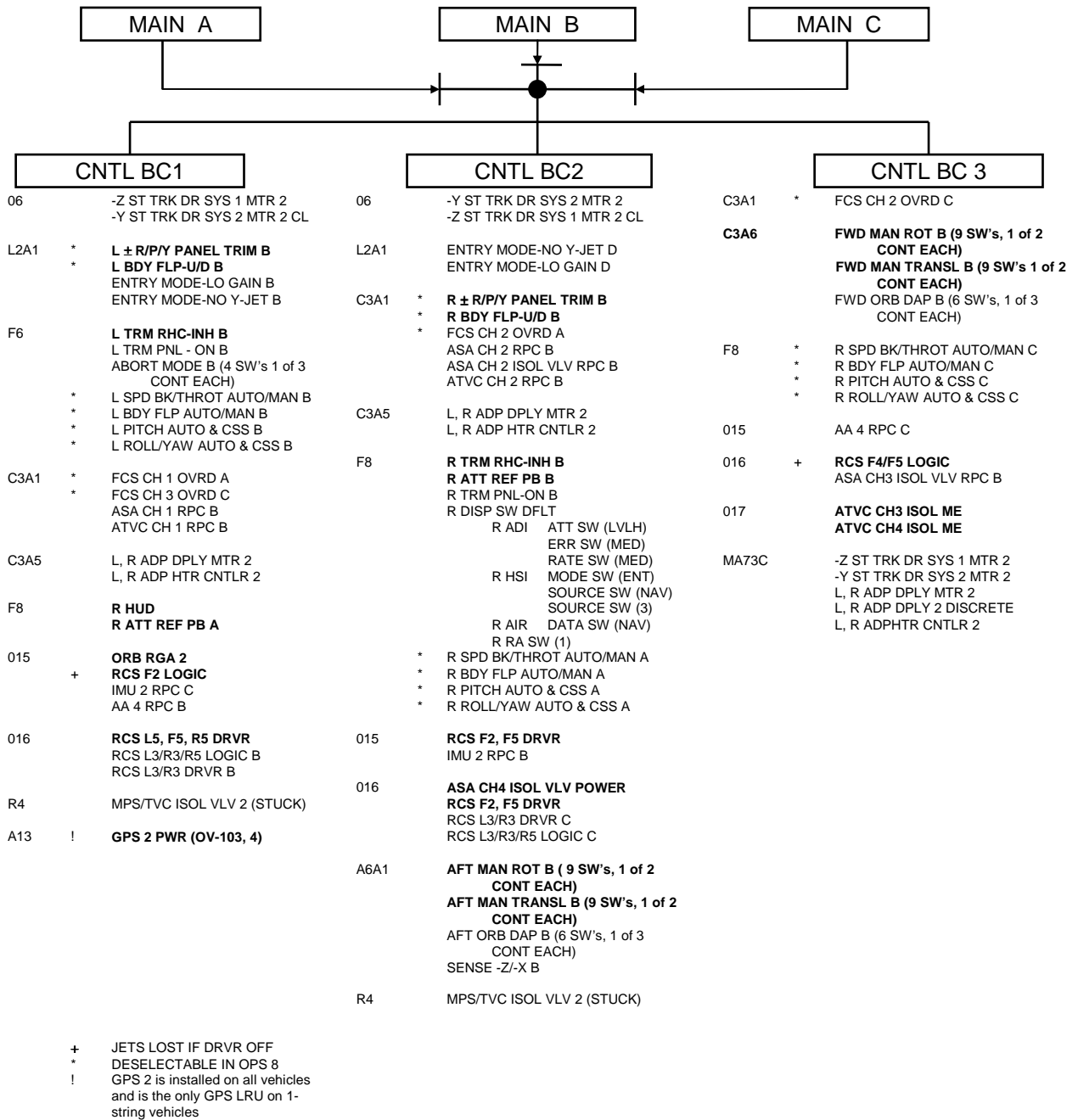
PROCEDURE

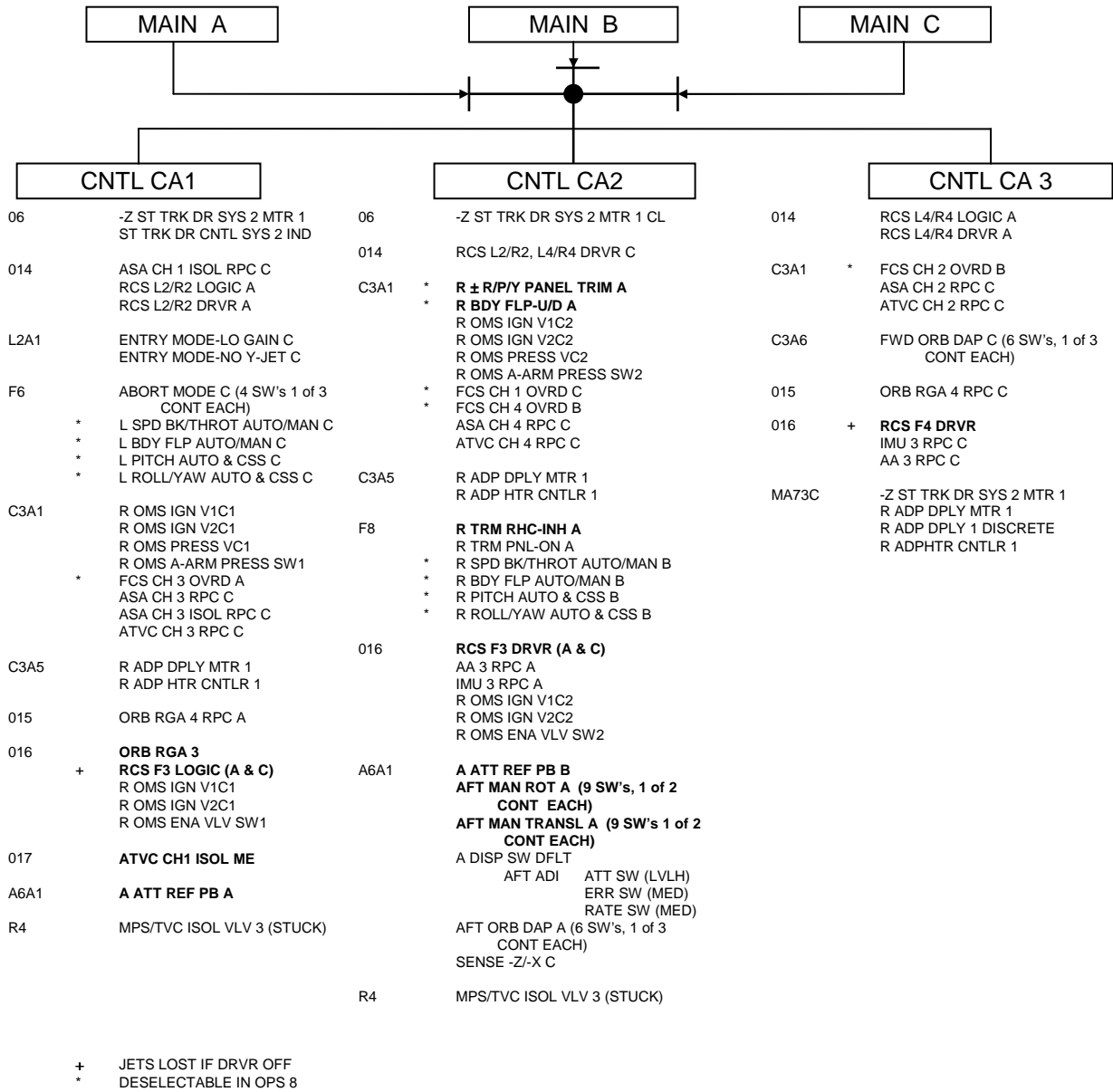
For a known short in one of the control buses, the Electrical Generation Integrated Loading (EGIL) officer will coordinate with other disciplines to determine the panels that are known to be affected by the short. For the GNC systems, the control buses provide power to systems that are powered ON for the orbit phase and other phases of the flight. However, during OPS 2 on-orbit operations there are several GNC systems (RGA's, AA's, FCS switches, etc.) which are not powered, and therefore, the impacts will be unknown. For these systems, the procedures will be to develop Flight Notes which provide the appropriate crew actions required to check out these systems. It is possible that some of the panels will be totally lost with respect to the affected bus.

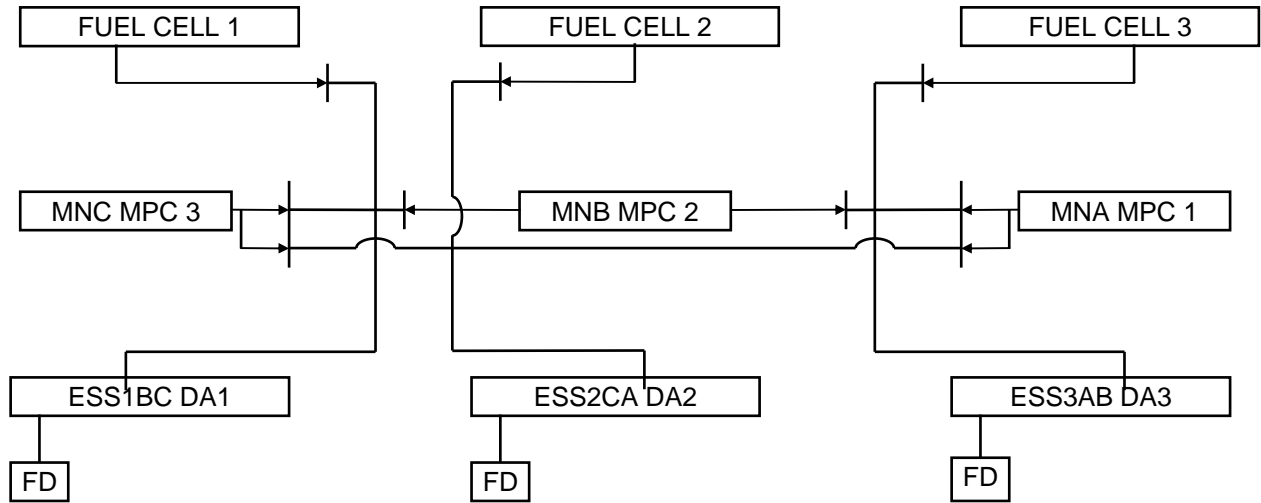
It is obvious for these cases that any functionality or redundancy not verifiable on these panels can be assumed lost and should not be included in checkout procedures, unless convenient. The GNC operators should use the tables provided in this SCP to verify the functional losses (bold type) and the redundancy losses that are associated with the affected control bus. Another useful tool in troubleshooting panels affected by a short is the Electrical Power Distribution Main Bus DC Distribution SSSH (ref. SSSH DWG 2.2, Sheet 1 of 2). This drawing illustrates the "daisy chain" for each control bus and shows the serial wiring of the bus through the associated panels. Note that the tables provided in this SCP list each bus and the GNC

equipment powered by that bus (grouped in panels), where the panels are listed in the order that they exist in the "daisy chain" of that bus.









GPS 1 PWR (OV-105)

TAC 1 AUTO SELF TEST (OV-103,4)
TAC 1 SW ON IND (OV-103,4)
MLS 1 SW ON IND
RA 1 PWR ON IND

GPS 2 PWR (OV-105)

TAC 2 AUTO SELF TEST (OV-103,4)
TAC 2 SW ON IND (OV-103,4)
MLS 2 SW ON IND
RA 2 PWR ON IND

**L & R BFS ENG CAP (DPS CALL)
GPS 3 PWR (OV-105)**

TAC 3 AUTO SELF TEST (OV-103,4)
TAC 3 SW ON IND (OV-103,4)
MLS 3 SW ON IND
SRB RGA 1 RPC C
SRB RGA 2 RPC C

TITLE

GNC HEXADECIMAL WORDS

PURPOSE

This SCP contains GNC hexadecimal words showing their nominal (where applicable) values. By transforming from hexadecimal to binary notation, it is possible to determine the state (0, 1) of each of the 16 bits which make up the hexadecimal word.

DESCRIPTION

A. HEX, DECIMAL, AND BINARY EQUIVALENTS

The hexadecimal system is a numbering system consisting of the alphanumeric values, 0 through 9 and A through F. The hexadecimal characters have the following decimal and binary equivalents:

Hex	Decimal	Binary	Hex	Decimal	Binary	Hex	Decimal	Binary
0	= 0	= 0000	6	= 6	= 0110	C	= 12	= 1100
1	= 1	= 0001	7	= 7	= 0111	D	= 13	= 1101
2	= 2	= 0010	8	= 8	= 1000	E	= 14	= 1110
3	= 3	= 0011	9	= 9	= 1001	F	= 15	= 1111
4	= 4	= 0100	A	= 10	= 1010			
5	= 5	= 0101	B	= 11	= 1011			

B. TWO'S COMPLEMENT OF BINARY NUMBERS

Several GNC hex words make use of two's complements of binary numbers. IMU command words 1 and 13, containing the pulse torquing commands, are given in two's complement if the sign bits (bits 0, 5, 10) are equal to 1. The magnitude of these pulse torquing commands are in binary if the sign bits are equal to 0.

The two's complement of binary number is derived by replacing 0 digits with 1 digits and 1 digits with 0 digits, then adding 1 to the least significant bit. For example:

- Bit 0 = 1
- Bit 1 = 0
- Bit 2 = 1
- Bit 3 = 0
- Bit 4 = 0

Bit 0 indicates the number is negative.

Original number (bits 1,2,3,4)	0 1 0 0
Replace 1's and 0's	1 0 1 1
Add 1	<u> + 1</u>
Two's complement	1 1 0 0

In two's complement:

- Bit 1 = 1
- Bit 2 = 1
- Bit 3 = 0
- Bit 4 = 0

C. GNC HEX WORD EXAMPLES

The following examples show how to take a hex word, convert the hex to binary (16 bits), and then use the breakdown of the hex words in this section to identify what the value of each bit represents.

- Example 1: The nominal value of the left ADI control word (V72M0895P) in hex form is

F F F 8

Each hex character can be converted into four binary characters as follows:

$$F = 15 = 1 * 2^3 + 1 * 2^2 + 1 * 2^1 + 1 * 2^0$$

so: F = 1 1 1 1

and

$$8 = 1 * 2^3 + 0 * 2^2 + 0 * 2^1 + 0 * 2^0$$

so: 8 = 1 0 0 0

The binary value of V72M0895P are shown below:

Bit #	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bit value	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0

2. Example 2: The nominal value of the IMU 1 mode status word, data word 1 (V71M2020P) in hex is

8000

Each hex character can be converted into four binary characters as follows:

$$8 = 1 * 2^3 + 0 * 2^2 + 0 * 2^1 + 0 * 2^0$$

so: 8 = 1 0 0 0

and

$$0 = 0 * 2^3 + 0 * 2^2 + 0 * 2^1 + 0 * 2^0$$

so: 0 = 0 0 0 0

The binary values of V71M2020P are shown below:

Bit #	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bit value	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Suppose the hex word was the following:

39AE

In binary the word becomes:

$$3 = 0 * 2^3 + 0 * 2^2 + 1 * 2^1 + 1 * 2^0 = 0011$$

$$9 = 1 * 2^3 + 0 * 2^2 + 0 * 2^1 + 1 * 2^0 = 1001$$

$$A = 1 * 2^3 + 0 * 2^2 + 1 * 2^1 + 0 * 2^0 = 1010$$

$$E = 1 * 2^3 + 1 * 2^2 + 1 * 2^1 + 0 * 2^0 = 1110$$

so that:

Bit #	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
39AE =	0	0	1	1	1	0	0	1	1	0	1	0	1	1	1	0

Referring to figure 1.3-1, V71M2020P, the status of IMU 1 then becomes:

- Bit 0 indicates IMU failure
- Bit 2 indicates A/D failure
- Bit 3 indicates Platform failure
- Bit 4 indicates Digital Subsystem failure
- Bit 7 indicates Resolver failure
- Bit 8 indicates Circuit Card overtemp
- Bit 10 indicates Transfer Word 2 failure
- Bit 12 indicates D2 is set
- Bit 13 indicates D3 is set
- Bit 14 indicates D4 is set

With this information, the conclusion could be made that IMU 1 has failed.

D. GNC HEX WORD NOMINAL VALUES

The figures in this section identify hex words for the following GNC subsystems: IMU, star tracker, TACAN, ADTA, MLS, RA, and dedicated displays (ADI, AMI, HSI, AVVI). Table 1.3-I lists the hex words by subsystem.

← - - - Formatted: Centered

TABLE 1.3-I. - GNC HEX WORDS (BY SYSTEM)

SUBSYSTEM	HEX WORDS	MSID#	FIGUR E NUM.
IMU 1(2,3)	Mode status word (data word 1)	V71M2020P(3020P,4020P)	1
	CMD WD 1 & Data WD13 (echo WD 1)	V71M2520P(3520P,4520P)	2
	CMD WD 2 & Data WD14 (echo WD 2)	V71M2260P(3260P,4260P) V71M2540P(3540P,4540P)	3
	HAINS startup sequence	V71M2280P(3280P,4280P)	4
	Reserved		5,6,7,8
Star tracker -Y(-Z)	Mode status word	V71M5520P(5020P)	9
	Command word	V71M5820P(5320P)	10
	Status	V95J4930C(4929C)	11
	Horizontal data and status word	V71M5540P(5040P)	12
	Vertical data and status word	V71M5560P(5060P)	13
TACAN 1(2,3)	Control word	V74M1510P(1610P,1710P)	14
	Bearing word 1	V74M1530P(1630P,1730P)	15
	Bearing word 2	V74M1531P(1631P, 1731P)	16
	Range word 1st half	V74M1549P(1649P,1749P)	17
	Range word 2nd half	V74M1549P(1649P,1749P)	18
ADTA	1,3 mode/status	V71M7020P(8020P)	19
	2,4 mode/status	V71M7520P(8520P)	20
MLS 1(2,3)	Azimuth word	V74M1010P(1110P,1210P)	21
	Elevation word	V74M1030P(1130P,1230P)	22
	Range word	V74M1050P(1150P,1250P)	23
RA 1(2)	Data word	V74M1801P(1851P)	24
Dedicated displays	ADI control word LH(RH,AFT)	V72M0895P(0995P,1095P)	25
	AMI control word LH(RH)	V72M7240P(7280P)	26
	HSI control word LH(RH)	V72M8799P(8849P)	27
	AVVI control word LH(RH)	V72M5340P(5380P)	28
GPS 1(2,3)	NAV Mode word 1	V74M2319P(1921P,2380P)	29
	NAV Mode word 2	V74M2320P(1934P,2381P)	30
	PPS Status	V74M4459P(1459P,3459P)	31
	Status FOM GDOP word 1	V74M4461P(1461P,3461P)	32
	Channel status word 1	V74M4960P(1960P,5960P)	33
	Channel status word 2	V74M4961P(1961P,5961P)	34
	Channel status word 3	V74M4962P(1962P,5962P)	35
	Channel status word 4	V74M4963P(1963P,5963P)	36
	Channel status word 5	V74M4964P(1964P,5964P)	37
	Channel status word 6	V74M4965P(1965P,5965P)	38
	Channel status word 7	V74M4966P(1966P,5966P)	39
Channel status word 8	V74M4967P(1967P,5967P)	40	

IMU 1 (2, 3) HAINS MODE STATUS WORD (DATA WORD 1)
V71M2020P (M3020P, M4020P)

MSID NOMENCLATURE	B I T	N O M		N O M	
V71X2021B IMU 1 (2,3) HAINS GOOD (X3021B, X4021B)	0	1		8	
V71X2022B IMU 1 (2,3) MUX FAIL (X3022B, X4023B)	1	0			
V71X2023B IMU 1 (2,3) A/D FAIL (X3023B, X4023B)	2	0			
V71X2024B IMU 1 (2,3) PLATFORM FAIL (X3024B, X4024B)	3	0			
V71X2025B IMU 1 (2,3) DIGITAL SUBSYSTEM FAIL (X3025B, X4025B)	4	0		0	
V71X2026B IMU 1 (2,3) DC/DC FAIL (X3026B, X4026B)	5	0			
V71X2027B IMU 1 (2,3) DISCRETE POWER SUPPLY FL (X3027B, X4027B)	6	0			
V71X2028B IMU 1 (2,3) RESLVR FAIL (X3028B, X4028B)	7	0			
V71X2029B IMU 1 (2,3) CIRCUIT CARD OVERTEMP (X3029B, X4029B)	8	0		0	
V71X2030B IMU 1 (2,3) TRANS WD 1 FAIL (X3030B, X4030B)	9	0			
V71X2031B IMU 1 (2,3) TRANS WD 2 FAIL (X3031B, X4031B)	10	0			
V71X2032B IMU 1 (2,3) D1 + D8 SEQUENCE DISCRETE (X3032B, X4032B)	11	0			
V71X2033B IMU 1 (2,3) D2 SEQUENCE DISCRETE (X3033B, X4033B)	12	0		0	
V71X2034B IMU 1 (2,3) D3 SEQUENCE DISCRETE (X3034B, X4034B)	13	0			
V71X2035B IMU 1 (2,3) D4 SEQUENCE DISCRETE (X3035B, X4035B)	14	0			
V71X2036B IMU 1 (2,3) D5 SEQUENCE DISCRETE (X3036B, X4036B)	15	0			

Figure 1.3-1. - HAINS Mode Status word (Data Word 1)

COMMAND WORD 1 (IN 2'S COMPLEMENT) V71M2520P (M3520P, M4520P)

AND

DATA WD 13 (ECHO WD 1) (IN 2'S COMPLEMENT) V71M2260P (M3260P, M4260P)

MSID NOMENCLATURE	CMD WD 1 IMU 1 IMU 2 IMU 3	DATA WD 13 IMU 1 IMU 2 IMU 3	B I T	N O M		N O M	
TORQUE X SIGN BIT (1 = POSITIVE ROTATION; 0 = NEGATIVE ROTATION)	V71K2521B, V71K3521B, V71K4521B	V71H2261B, V71H3261B, V71H4261B	0				
TORQUE X MSB (MAGNITUDE BIT)	V71K2521B, V71K3521B, V71K4521B	V71H2261B, V71H3261B, V71H4261B	1				
TORQUE X X (MAGNITUDE BIT)	V71K2521B, V71K3521B, V71K4521B	V71H2261B, V71H3261B, V71H4261B	2				
TORQUE X X (MAGNITUDE BIT)	V71K2521B, V71K3521B, V71K4521B	V71H2261B, V71H3261B, V71H4261B	3				
TORQUE X LSB (MAGNITUDE BIT) (1 = 0.5 arcsec; 0 = 0 arcsec)	V71K2521B, V71K3521B, V71K4521B	V71H2261B, V71H3261B, V71H4261B	4				
TORQUE Y SIGN BIT (1 = POSITIVE ROTATION; 0 = NEGATIVE ROTATION)	V71K2526B, V71K3526B, V71K4526B	V71H2266B, V71H3266B, V71H4266B	5				
TORQUE Y MSB (MAGNITUDE BIT)	V71K2526B, V71K3526B, V71K4526B	V71H2266B, V71H3266B, V71H4266B	6				
TORQUE Y X (MAGNITUDE BIT)	V71K2526B, V71K3526B, V71K4526B	V71H2266B, V71H3266B, V71H4266B	7				
TORQUE Y X (MAGNITUDE BIT)	V71K2526B, V71K3526B, V71K4526B	V71H2266B, V71H3266B, V71H4266B	8				
TORQUE Y LSB (MAGNITUDE BIT) (1 = 0.5 arcsec; 0 = 0 arcsec)	V71K2526B, V71K3526B, V71K4526B	V71H2266B, V71H3266B, V71H4266B	9				
TORQUE Z SIGN BIT (1 = POSITIVE ROTATION; 0 = NEGATIVE ROTATION)	V71K2531B, V71K3531B, V71K4531B	V71H2271B, V71H3271B, V71H4271B	10				
TORQUE Z MSB (MAGNITUDE BIT)	V71K2531B, V71K3531B, V71K4531B	V71H2271B, V71H3271B, V71H4271B	11				
TORQUE Z X (MAGNITUDE BIT)	V71K2531B, V71K3531B, V71K4531B	V71H2271B, V71H3271B, V71H4271B	12				
TORQUE Z X (MAGNITUDE BIT)	V71K2531B, V71K3531B, V71K4531B	V71H2271B, V71H3271B, V71H4271B	13				
TORQUE Z LSB (MAGNITUDE BIT) (1 = 0.5 arcsec; 0.5 = 0 arcsec)	V71K2531B, V71K3531B, V71K4531B	V71H2271B, V71H3271B, V71H4271B	14				
SPARE		SPARE	15				

Figure 1.3-2 - IMU mode CMD word 1 and Data Word 13

IMU 1 (2, 3) CMD WD 2 (Slew Commands) V71M2540P (M3540P, M4540P)

And

IMU 1 (2, 3) Data WD 14 (Echo WD 2) V71M2280P (M3280P, M4280P)

MSID NOMENCLATURE	CMD WD 2 IMU 1, IMU 2, IMU 3	DATA WD 14 IMU 1, IMU 2, IMU 3	B I T		N O M*	
CAPRI SF (1 = ON)	V71K2541B, V71K3541B, V71K4541B	V71X2281B, V71X3281B, V71X4281B	0		0	
SLEW X POS (1 = POS)	V71K2542B, V71K3542B, V71K4542B	V71X2282B, V71X3282B, V71X4282B	1			
SLEW X NEG (1 = NEG)	V71K2543B, V71K3543B, V71K4543B	V71X2283B, V71X3283B, V71X4283B	2			
SLEW Y POS (1 = POS)	V71K2544B, V71K3544B, V71K4544B	V71X2284B, V71X3284B, V71X4284B	3			
SLEW Y NEG (1 = NEG)	V71K2545B, V71K3545B, V71K4545B	V71X2285B, V71X3285B, V71X4285B	4		0	
SLEW Z POS (1 = POS)	V71K2546B, V71K3546B, V71K4546B	V71X2286B, V71X3286B, V71X4286B	5			
SLEW Z NEG (1 = NEG)	V71K2547B, V71K3547B, V71K4547B	V71X2287B, V71X3287B, V71X4287B	6			
SPARE			7			
SPARE			8		0	
SPARE			9			
SPARE			10			
SPARE			11			
SPARE			12		0	
SPARE			13			
SPARE			14			
SPARE			15			

*EXCEPT DURING IMU ALIGNMENTS AND GROUND (HANGAR) CALIBRATIONS

Figure 1.3-3 - IMU CMD word 2 (slew) & Data word 14 (Echo Word 2)

MAX TIME (MIN)	AMBIENT TEMP (DEG F)	INLET AIR TEMP (DEG F)
T* = 50	75	75
T* = 120	35	35

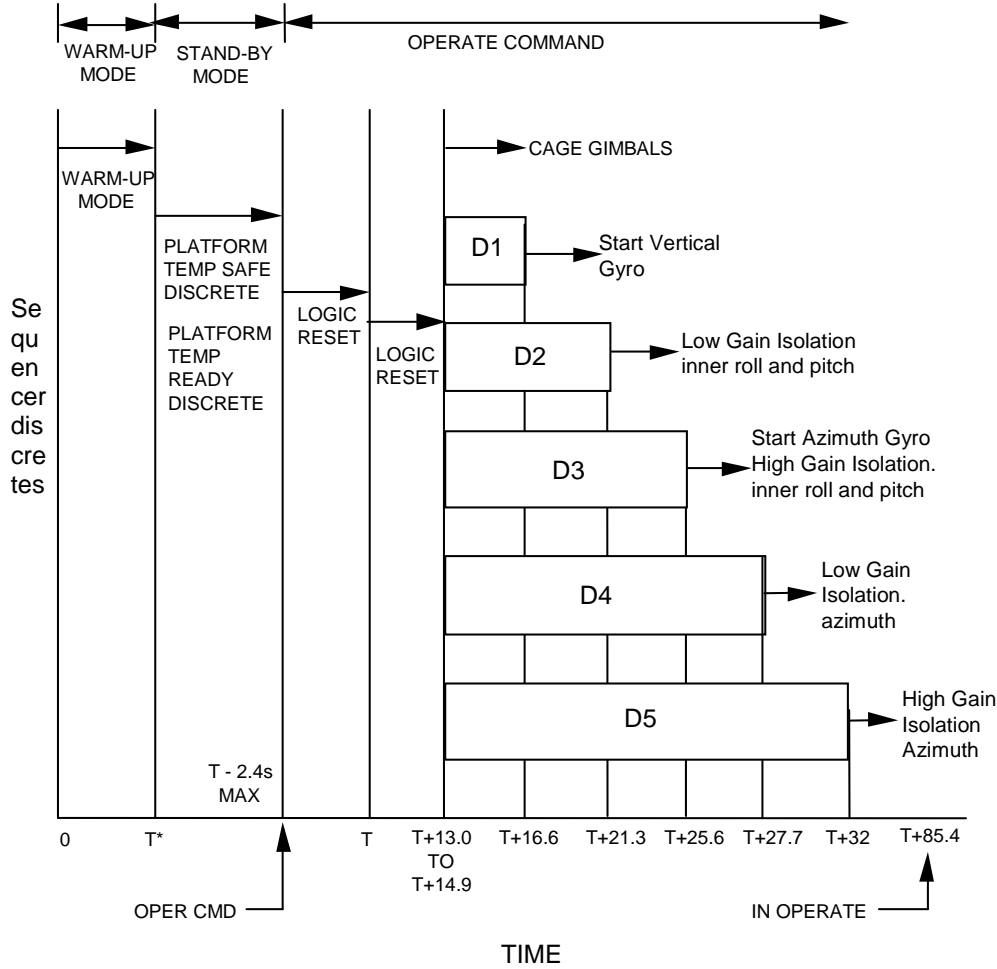


Figure 1.3-4 HAINS Startup Sequence

BITE WD -Y (-Z) [-Y (-Z) ST MODE STATUS]
V71M5520P (M5020P)

MSID NOMENCLATURE	B I T	N O M	ST		N O M	ST
V71X5521B (X5021B) -Y (-Z) ST TRACKER GOOD 1 = GOOD	0	1	$\frac{1}{0}$		A	$\frac{B}{3}$
V71X5522B (X5022B) -Y (-Z) ST TARGET SUPPRESSED/HI BACKGRD 1 = SUPPRESSED/HIGH BACKGROUND	1	0	0			
V71X5523B (X5023B) -Y (-Z) ST TRANSMISSION WORD GOOD 1 = GOOD	2	1	1			
V71X5524B (X5024B) -Y (-Z) ST SHUTTER CLOSED 1 = CLOSED	3	0	1			
V71X5525B (X5025B) -Y (-Z) SELF-TEST ENGAGED 1 = SELF-TEST	4	0	1			
V71X5526B (X5026B) -Y (-Z) STAR PRESENT 1 = STAR PRESENT (1 AND 0 DURING SELF-TEST)	5	$\frac{1}{0}$	$\frac{1}{0}$			
V71X5527B (X5027B) -Y (-Z) HV RNG MSB* - CCD TEMP MSB ALWAYS 1 - 1 = FAIL	6	1	$\frac{1}{0}$			
V71X5528B (X5028B) -Y (-Z) HV RNG LSB* - CCD TEMP LSB ALWAYS 0 - 1 = FAIL	7	0	0			
V71Q5529B (Q5029B) -Y (-Z) ST STAR INTENSITY MSB	8	X	X		X	X
V71Q5529B (Q5029B) -Y (-Z) ST STAR INTENSITY X	9	X	X			
V71Q5529B (Q5029B) -Y (-Z) ST STAR INTENSITY X	10	X	X			
V71Q5529B (Q5029B) -Y (-Z) ST STAR INTENSITY X	11	X	X			
V71Q5529B (Q5029B) -Y (-Z) ST STAR INTENSITY X	12	X	X		X	X
V71Q5529B (Q5029B) -Y (-Z) ST STAR INTENSITY X	13	X	X			
V71Q5529B (Q5029B) -Y (-Z) ST STAR INTENSITY X	14	X	X			
V71Q5529B (Q5029B) -Y (-Z) ST STAR INTENSITY LSB	15	X	X			

* For IDT star tracker S/N 8 and higher, bits 7 and 8 of Hardware Word 1 will not be latched, but are used to monitor the tracker's temperature.

Figure 1.3-9.- Star tracker mode status word

CMD WD -Y (-Z)
V71M5820P (M5320P)

MSID NOMENCLATURE	B I T	N O M	S- T		N O M	S- T	
V71K5821B (K5321B) -Y (-Z) ST OFFSET MODE CMD 1 = ON (1 AND 0 DURING SELF-TEST)	0	X	1/0		X	C/4	
V71K5822B (K5322B) -Y (-Z) ST SELF-TEST CMD 1 = ON	1	0	1				
V71K5823B (K5323B) -Y (-Z) ST BREAK TRACK CMD 1 = ON	2	0	0				
V71K5824B (K5324B) -Y (-Z) ST SHUTTER OPEN CMD 1 = ON	3	0	0				
V71K5825B (K5325B) -Y (-Z) ST THRESHOLD SET 1 MSB	4	0	0		X	X	
V71K5826B (K5326B) -Y (-Z) ST THRESHOLD SET 2 LSB	5	0	0				
V71K5827B (K5327B) -Y (-Z) ST HORIZ OFFSET CMD (SELF-TEST VALUE DEPENDS ON ST)	6	0	0				
V71K5827B (K5327B) -Y (-Z) ST HORIZ OFFSET CMD	7	0	0				
V71K5827B (K5327B) -Y (-Z) ST HORIZ OFFSET CMD	8	X	X		X	X	
V71K5827B (K5327B) -Y (-Z) ST HORIZ OFFSET CMD	9	X	X				
V71K5827B (K5327B) -Y (-Z) ST HORIZ OFFSET CMD	10	X	X				
V71K5832B (K5332B) -Y (-Z) ST VERT OFFSET CMD (SELF-TEST VALUE DEPENDS ON ST)	11	X	X				
V71K5832B (K5332B) -Y (-Z) ST VERT OFFSET CMD	12	X	X		X	X	
V71K5832B (K5332B) -Y (-Z) ST VERT OFFSET CMD	13	X	X				
V71K5832B (K5332B) -Y (-Z) ST VERT OFFSET CMD	14	X	X				
V71K5832B (K5332B) -Y (-Z) ST VERT OFFSET CMD	15	X	X				

Figure 1.3-10. - ST tracker command word

STATUS -Y (-Z)
V95J4930C (J4929C)

MSID NOMENCLATURE			B I T	N O M	S- T		N O M	S- T	
CREW DISPLAY= BIT = HEX			0	0	0		0	0	
		SPARE	1	0	0				
		SPARE	2	0	0				
BLANK = 0000 = 0		SPARE	3	0	0				
ST FAIL =0001 =1		SPARE	4	0	0		0	0	
ST PASS =0010 =2		SPARE	5	0	0				
FALSE TRACK =0011 =3		SPARE	6	0	0				
OUT OF FOV =0100 =4		SPARE	7	0	0				
HIGH RATE =0101 =5		SPARE	8	0	0		0	0	
NO TARGET =0110 =6		SPARE	9	0	0				
NOT DEFINED =0111 =7		SPARE	10	0	0				
NOT DEFINED =1000 =8		SPARE	11	0	0				
NOT DEFINED =1001 =9		SPARE	12	X	0		X	2/1	
NOT DEFINED =1010 =A			13	X	0				
NOT DEFINED =1011 =B			14	X	1/0				
NOT DEFINED =1100 =C			15	X	0/1				

Figure 1.3-11. - Star tracker status

-Y (-Z) HORIZONTAL WD [-Y (-Z) ST HORIZONTAL DATA & STATUS WD]
V71M5540P (M5040P)

MSID NOMENCLATURE	B I T	N O M	S- T	N O M	S- T
V71H5541B (H5041B) -Y (-Z) ST HORIZONTAL POS SIGN BIT 0 = - 1 = +	0	X	X	X	X
V71H5541B (H5041B) -Y (-Z) ST HORIZONTAL POS MSB (SELF-TEST VALUE DEPENDS ON S TRKR)	1	X	X		
V71H5541B (H5041B) -Y (-Z) ST HORIZONTAL POS X	2	X	X		
V71H5541B (H5041B) -Y (-Z) ST HORIZONTAL POS X	3	X	X		
V71H5541B (H5041B) -Y (-Z) ST HORIZONTAL POS X	4	X	X	X	X
V71H5541B (H5041B) -Y (-Z) ST HORIZONTAL POS X	5	X	X		
V71H5541B (H5041B) -Y (-Z) ST HORIZONTAL POS X	6	X	X		
V71H5541B (H5041B) -Y (-Z) ST HORIZONTAL POS X	7	X	X		
V71H5541B (H5041B) -Y (-Z) ST HORIZONTAL POS X	8	X	X	X	X
V71H5541B (H5041B) -Y (-Z) ST HORIZONTAL POS X	9	X	X		
V71H5541B (H5041B) -Y (-Z) ST HORIZONTAL POS X	10	X	X		
V71H5541B (H5041B) -Y (-Z) ST HORIZONTAL POS X	11	X	X		
V71X5553B (X5053B) 1 = ERROR -Y (-Z) ST BIT CNT ERR - EEPROM ERROR	12	0	0	0	0
V71X5554B (X5054B) 1 = ERROR -Y (-Z) ST MANCHESTER ERR - RAM/ROM FL	13	0	0		
V71X5555B (X5055B) 1 = ERROR -Y (-Z) ST PARITY ERR - WATCHDOG ERR	14	0	0		
V71X5556B (X5056B) 1 = FAIL -Y (-Z) ST PRESSURE FAIL	15	0	0		

Figure 1.3-12.- Star tracker horizontal data/status word

-Y (-Z) VERTICAL WD [-Y (-Z) ST VERTICAL DATA & STATUS WD]
V71M5560P (M5060P)

MSID NOMENCLATURE	B I T	N O M	S-T	S-T	S-T	N O M	S-T	S-T	S-T
V71H5561B (H5061B) -Y (-Z) ST VERTICAL POS SIGN BIT 0 = - 1 = +	0	X	X			X			
V71H5561B (H5061B) -Y (-Z) ST VERTICAL POS (SELF-TEST VALUE DEPENDS ON ST)	1	X	X						
V71H5561B (H5061B) -Y (-Z) ST VERTICAL POS X	2	X	X						
V71H5561B (H5061B) -Y (-Z) ST VERTICAL POS X	3	X	X						
V71H5561B (H5061B) -Y (-Z) ST VERTICAL POS X	4	X	X			X			
V71H5561B (H5061B) -Y (-Z) ST VERTICAL POS X	5	X	X						
V71H5561B (H5061B) -Y (-Z) ST VERTICAL POS X	6	X	X						
V71H5561B (H5061B) -Y (-Z) ST VERTICAL POS X	7	X	X						
V71H5561B (H5061B) -Y (-Z) ST VERTICAL POS X	8	X	X			X			
V71H5561B (H5061B) -Y (-Z) ST VERTICAL POS X	9	X	X						
V71H5561B (H5061B) -Y (-Z) ST VERTICAL POS X	10	X	X						
V71H5561B (H5061B) -Y (-Z) ST VERTICAL POS LSB	11	X	X						
V71X5573B (X5073B) -Y (-Z) ST SELF-TEST ANGLE ERROR 1 = ERROR	12	0	0	1	1	3	6	A	E
V71X5574B (X5074B) -Y (-Z) ST SELF-TEST MAGNITUDE ERROR 1 = ERROR	13	0	1	0	1				
V71X5575B (X5075B) -Y (-Z) ST POWER SUPPLY GOOD 1 = GOOD	14	1	1	1	1				
V71X5576B (X5076B) -Y (-Z) ST BRIGHT OBJECT ALERT OFF 1 = NO BRIGHT OBJECT ALERT	15	1	1	0	0	0			

Figure 1.3-13.- Star tracker vertical data/status word

TACAN 1 (2, 3) CONTROL WORD
V74M1510P (M1610P, M1710P)

MSID NOMENCLATURE	B I T	N O M		N O M	
SYNC BIT (ALWAYS EQUAL TO '1')	0	1		8	
ALWAYS EQUAL TO '0'	1	0			
V74K1511B (K1611B, K1711B) X/Y MODE (1 = Y, 0 = X)	2	0			
V74K1512B (K1612B, K1712B) A/A MODE	3	0			
V74K1513B (K1613B, K1713B) T/R/RCV MODE (1 = T/R)	4	1		X	
ALWAYS EQUAL TO '0'	5	0			
ALWAYS EQUAL TO '0'	6	0			
V74K1514B (K1614B, K1714B) CHANNEL SELECT (CH. = \sum BIT WEIGHTS) 1	7	X			
V74K1514B (K1614B, K1714B) CHANNEL SELECT (CH. = \sum BIT WEIGHTS) 2	8	X		X	
V74K1514B (K1614B, K1714B) CHANNEL SELECT (CH. = \sum BIT WEIGHTS) 4	9	X			
V74K1514B (K1614B, K1714B) CHANNEL SELECT (CH. = \sum BIT WEIGHTS) 8	10	X			
V74K1514B (K1614B, K1714B) CHANNEL SELECT (CH. = \sum BIT WEIGHTS) 10	11	X			
V74K1514B (K1614B, K1714B) CHANNEL SELECT (CH. = \sum BIT WEIGHTS) 20	12	X		X	
V74K1514B (K1614B, K1714B) CHANNEL SELECT (CH. = \sum BIT WEIGHTS) 40	13	X			
V74K1514B (K1614B, K1714B) CHANNEL SELECT (CH. = \sum BIT WEIGHTS) 80	14	X			
V74K1515B (K1615B, K1715B) SELFTEST (1 = SELF TEST ACTIVE)	15	0			

Figure 1.3-14.- TACAN control word

TACAN 1 (2, 3) BEARING WD 1
V74M1530P (M1630P, M1730P)

MSID NOMENCLATURE	B I T	N O M		N O M	
V74X1532B (X1632B, X1732B) PARITY BIT	0	X		X	
V74H1534B (H1634B, H1734B) BEARING STATUS	1	X			
V74H1534B (H1634B, H1734B) BEARING STATUS	2	X			
V74H1535B (H1635B, H1735B) BEARING DATA	3	X			
V74H1535B (H1635B, H1735B) BEARING DATA	4	X		X	
V74H1535B (H1635B, H1735B) BEARING DATA	5	X			
V74H1535B (H1635B, H1735B) BEARING DATA	6	X			
V74H1535B (H1635B, H1735B) BEARING DATA	7	X			
V74H1535B (H1635B, H1735B) BEARING DATA	8	X		X	
V74H1535B (H1635B, H1735B) BEARING DATA	9	X			
V74H1535B (H1635B, H1735B) BEARING DATA	10	X			
V74H1535B (H1635B, H1735B) BEARING DATA	11	X			
V74H1535B (H1635B, H1735B) BEARING DATA	12	X		X	
V74H1535B (H1635B, H1735B) BEARING DATA	13	X			
V74H1535B (H1635B, H1735B) BEARING DATA	14	X			
ALWAYS EQUAL TO '0'	15	0			

Figure 1.3-15.- TACAN bearing word 1

TACAN 1 (2, 3) BEARING WD 2
V74M1531P (M1631P, M1731P)

MSID NOMENCLATURE	B I T	N O M		N O M	
ALWAYS EQUAL TO '0'	0	0		0	
ALWAYS EQUAL TO '0'	1	0			
ALWAYS EQUAL TO '0'	2	0			
ALWAYS EQUAL TO '0'	3	0			
V74J1536B (J1636B, J1736B) ALWAYS EQUAL TO '0'	4	0		X	
V74J1536B (J1636B, J1736B) 00 = NOT IN SELF-TEST BEARING SELF-TEST STATUS 11 = IN BRG SELF-TEST	5	X			
V74J1536B (J1636B, J1736B) 01 = NOT DEFINED BEARING SELF-TEST STATUS 10 = NOT DEFINED	6	X			
V74J1536B (J1636B, J1736B) ALWAYS EQUAL TO '0'	7	0			
ALWAYS EQUAL TO '0'	8	0		0	
ALWAYS EQUAL TO '0'	9	0			
ALWAYS EQUAL TO '0'	10	0			
ALWAYS EQUAL TO '0'	11	0			
ALWAYS EQUAL TO '0'	12	0		1	
ALWAYS EQUAL TO '0'	13	0			
ALWAYS EQUAL TO '0'	14	0			
ALWAYS EQUAL TO '1'	15	1			

Figure 1.3-16.- TACAN bearing word 2

TACAN 1 (2, 3) RANGE WD - 1st half
V74M1549P (M1649P, M1749P)

MSID NOMENCLATURE		B I T	N O M		N O M	
V74J1552B (J1652B, J1752B) RANGE STATUS	00 = VALID DATA 01 = RNG SELF-TEST FAILURE	0	X		X	
V74J1552B (J1652B, J1752B) RANGE STATUS	10 = NO COMPUTED DATA 11 = NOT USED	1	X			
V74U1553B (U1653B, U1753B) RANGE DATA	100's NM 300 (MAX)	2	X			
V74U1553B (U1653B, U1753B) RANGE DATA	100's NM 300 (MAX)	3	X			
V74U1553B (U1653B, U1753B) RANGE DATA	10's NM 90 (MAX)	4	X		X	
V74U1553B (U1653B, U1753B) RANGE DATA	10's NM 90 (MAX)	5	X			
V74U1553B (U1653B, U1753B) RANGE DATA	10's NM 90 (MAX)	6	X			
V74U1553B (U1653B, U1753B) RANGE DATA	10's NM 90 (MAX)	7	X			
V74U1553B (U1653B, U1753B) RANGE DATA	1's NM 9 (MAX)	8	X		X	
V74U1553B (U1653B, U1753B) RANGE DATA	1's NM 9 (MAX)	9	X			
V74U1553B (U1653B, U1753B) RANGE DATA	1's NM 9 (MAX)	10	X			
V74U1553B (U1653B, U1753B) RANGE DATA	1's NM 9 (MAX)	11	X			
V74U1553B (U1653B, U1753B) RANGE DATA	1/10's NM 0.9 (MAX)	12	X		X	
V74U1553B (U1653B, U1753B) RANGE DATA	1/10's NM 0.9 (MAX)	13	X			
V74U1553B (U1653B, U1753B) RANGE DATA	1/10's NM 0.9 (MAX)	14	X			
V74U1553B (U1653B, U1753B) RANGE DATA	1/10's NM 0.9 (MAX)	15	X			

Figure 1.3-17.- TACAN range word (1st. half)

TACAN 1 (2, 3) RANGE WD - 2nd half
V74M1549P (M1649P, M1749P)

MSID NOMENCLATURE	B I T	N O M		N O M	
V74U1553B (U1653B, U1753B) RANGE DATA	16	X		X	
V74U1553B (U1653B, U1753B) RANGE DATA	17	X			
V74U1553B (U1653B, U1753B) RANGE DATA	18	X			
V74U1553B (U1653B, U1753B) RANGE DATA	19	X			
V74X1558B (X1658B, X1758B) BITE STATUS	20	0		X	
V74J1559B (J1659B, J1759B) RANGE SELF-TEST STATUS	21	X			
V74J1559B (J1659B, J1759B) RANGE SELF-TEST STATUS	22	X			
V74X1560B (X1660B, X1760B) BLANKING PULSE	23	X			
ALWAYS EQUAL TO '0'	24	0		0	
ALWAYS EQUAL TO '0'	25	0			
ALWAYS EQUAL TO '0'	26	0			
ALWAYS EQUAL TO '0'	27	0			
ALWAYS EQUAL TO '0'	28	0		0	
ALWAYS EQUAL TO '0'	29	0			
ALWAYS EQUAL TO '0'	30	0			
ALWAYS EQUAL TO '0'	31	0			

Figure 1.3-18.- TACAN range word (2nd. half)

ADTA 1 (3) MODE STATUS
V71M7020P (M8020P)

MSID NOMENCLATURE	B I T	N O M		N O M	
V71X7021B (X8021B) ADTA 1 (3) GOOD 1 = GOOD	0	1		8	
V71X7022B (X8022B) ADTA 1 (3) RADIATE CIRCUIT GOOD *	1	0			
V71X7023B (X8023B) ADTA 1 (3) HIGH TEST MODE 1 = ON	2	0			
V71X7024B (X8024B) ADTA 1 (3) LOW TEST MODE 1 = ON	3	0			
V71X7025B (X8025B) ADTA 1 (3) P?L GOOD 1 = GOOD	4	1		F	
V71X7026B (X8026B) ADTA 1 (3) P?U GOOD 1 = GOOD	5	1			
V71X7027B (X8027B) ADTA 1 (3) P?C GOOD 1 = GOOD	6	1			
V71X7028B (X8028B) ADTA 1 (3) PS GOOD 1 = GOOD	7	1			
V71X7029B (X8029B) ADTA 1 (3) A/D CONV GOOD 1 = GOOD	8	1		F	
V71X7030B (X8030B) ADTA 1 (3) ELEC GOOD 1 = GOOD	9	1			
V71X7031B (X8031B) ADTA 1 (3) TEMP CKT GOOD 1 = GOOD	10	1			
V71X7032B (X8032B) ADTA 1 (3) CODE MEMORY CRC 1 = GOOD	11	1			
V71X7033B (X8033B) ADTA 1 (3)PWR SUP GOOD 1 = GOOD	12	1		C	
V71X7034B (X8034B) ADTA 1 (3) DISC INPUTS GOOD 1 = GOOD	13	1			
V71X7035B (X8035B) ADTA 1 (3) RAM MEMORY GOOD * 1 = FAIL	14	0			
V71X7036B (X8036B) ADTA 1 (3) F/D GOOD * 1 = FAIL	15	0			

* NOTE: Data bits only valid for new Allied Signal ADTA units

Figure 1.3-19.- ADTA 1,3 mode/status

ADTA 2 (4) MODE STATUS
V71M7520P (M8520P)

MSID NOMENCLATURE	B I T	N O M		N O M	
V71X7521B (X8521B) ADTA 2 (4) GOOD	0	1		8	
V71X7522B (X8522B) ADTA 2 (4) RADIATE GOOD CIRCUIT *	1	0			
V71X7523B (X8523B) ADTA 2 (4) HIGH TEST MODE	2	0			
V71X7524B (X8524B) ADTA 2 (4) LOW TEST MODE	3	0			
V71X7525B (X8525B) ADTA 2 (4) P?L GOOD	4	1		F	
V71X7526B (X8526B) ADTA 2 (4) P?U GOOD	5	1			
V71X7527B (X8527B) ADTA 2 (4) P?C GOOD	6	1			
V71X7528B (X8528B) ADTA 2 (4) PS GOOD	7	1			
V71X7529B (X8529B) ADTA 2 (4) A/D CONV GOOD	8	1		F	
V71X7530B (X8530B) ADTA 2 (4) ELEC GOOD	9	1			
V71X7531B (X8531B) ADTA 2 (4) TEMP CKT GOOD	10	1			
V71X7532B (X8532B) ADTA 2 (4) CODE MEMORY CRC	11	1			
V71X7533B (X8533B) ADTA 2 (4)PWR SUP GOOD	12	1		C	
V71X7534B (X8534B) ADTA 2 (4) DISC INPUTS GOOD	13	1			
V71X7535B (X8535B) ADTA 2 (4) RAM MEMORY GOOD *	14	0			
V71X7536B (X8536B) ADTA 2 (4) F/D GOOD *	15	0			

* NOTE: Data bits only valid for new Allied Signal ADTA units

Figure 1.3-20.- ADTA 2,4 mode/status

MLS 1 (2,3) AZIMUTH WORD
V74M1010P (M1110P, M1210P)

MSID NOMENCLATURE	B I T	N O M		N O M	
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA 1 = MINUS = FLY RIGHT (LEFT OF CENTERLINE)	0	X		X	
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA 16.0000 DEG	1	X			
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA 8.0000 DEG	2	X			
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA 4.0000 DEG	3	X			
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA 2.0000 DEG	4	X		X	
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA 1.0000 DEG	5	X			
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA .5000 DEG	6	X			
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA .2500 DEG	7	X			
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA .1250 DEG	8	X		X	
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA .0625 DEG	9	X			
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA .0312 DEG	10	X			
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA .0156 DEG	11	X			
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA .0078 DEG	12	X		X	
V74H1012B (H1112B, H1212B) MLS 1 (2,3) AZ DATA .0039 DEG	13	X			
V74X1013B (X1113B, X1213B) MLS 1 (2,3) AZ TEST 1 = IN SELF TEST	14	0			
V74X1014B (X1114B, X1214B) MLS 1 (2,3) AZ VALIDITY 0 = VALID DATA	15	0			

Figure 1.3-21.- MLS azimuth word

MLS 1 (2,3) ELEVATION WORD
V74M1030P (M1130P, M1230P)

MSID NOMENCLATURE		B I T	N O M		N O M	
V74X1031B (X1131B, X1231B) MLS 1 (2,3) EL XT CUR FAIL	1 = XTAL CUR FAILURE, AND AGC FAIL DURING S/T.	0	X		X	
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	16.0000 DEG	1	X			
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	8.0000 DEG	2	X			
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	4.0000 DEG	3	X			
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	2.0000 DEG	4	X		X	
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	1.0000 DEG	5	X			
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	.5000 DEG	6	X			
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	.2500 DEG	7	X			
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	.1250 DEG	8	X		X	
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	.0625 DEG	9	X			
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	.0312 DEG	10	X			
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	.0156 DEG	11	X			
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	.0078 DEG	12	X		X	
V74H1032B (H1132B, H1232B) MLS 1 (2,3) EL DATA	.0039 DEG	13	X			
V74X1033B (X1133B, X1233B) MLS 1 (2,3) EL TEST	1 = IN SELF TEST	14	0			
V74X1034B (X1134B, X1234B) MLS 1 (2,3) EL VALIDITY	0 = VALID DATA	15	0			

Figure 1.3-22.- MLS elevation word

MLS 1 (2,3) RANGE WORD
V74M1050P (M1150P, M1250P)

MSID NOMENCLATURE		B I T	N O M		N O M	
V74X1051B (X1151B, X1251B) MLS 1 (2,3) RNG XT CUR FAIL	1 = XTAL CUR FAILURE, AND AGC FAIL DURING S/T	0	X		X	
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	10.3600 NM	1	X			
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	5.1800 NM	2	X			
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	2.5900 NM	3	X			
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	1.2950 NM	4	X		X	
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	.6475 NM	5	X			
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	.3237 NM	6	X			
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	.1619 NM	7	X			
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	.0809 NM	8	X		X	
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	.0405 NM	9	X			
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	.0202 NM	10	X			
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	.0101 NM	11	X			
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	.0051NM	12	X		X	
V74H1052B (H1152B, H1252B) MLS 1 (2,3) RNG DATA	.0025 NM	13	X			
V74X1053B (X1153B, X1253B) MLS 1 (2,3) RNG TEST	1 = IN SELF TEST	14	0			
V74X1054B (X1154B, X1254B) MLS 1 (2,3) RNG VALIDITY	0 = VALID DATA	15	0			

Figure 1.3-23.- MLS RANGE word

RA 1 (RA2) DATA WORD
V74M1801P (M1851P)

MSID NOMENCLATURE	B I T	N O M		N O M	
V74X1803B (X1853B) ODD PARITY RA1 (RA2) PARITY BIT	0	1		X	
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 4096 FT	1	1			
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 2048 FT	2	1			
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 1024 FT	3	1			
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 512 FT	4	1		X	
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 256 FT	5	1			
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 128 FT	6	1			
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 64 FT	7	1			
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 32 FT	8	1		X	
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 16 FT	9	1			
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 8 FT	10	1			
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 4 FT	11	1			
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 2 FT	12	1		X	
V74H1804B (H1854B) RA1 (RA2) ALTITUDE DATA 1 FT	13	0			
V74X1805B (X1855B) 1 = VALID (LOCK-ON) RA1 (RA2) VALIDITY BIT	14	0			
V74X1806B (X1856B) ALWAYS = 1 RA1 (RA2) CONTROL BIT	15	0			

Figure 1.3-24.- RA data word

LH (RH , AFT) ADI CONTROL WORD
V72M0895P (M0995P, M1095P)

MSID NOMENCLATURE	IF INVALID	B I T	N O M		N O M	
V72X0896B (X0996B, X1096B) ALWAYS = 1 LH (RH, AFT) ADI TEST WD CNTL		0	1		F	
V72X0897B (X0997B, X1097B) 1 = VALID LH (RH, AFT) ADI ROLL SINE CNTL		1	1			
V72X0898B (X0998B, X1098B) 1 = VALID LH (RH, AFT) ADI ROLL COSINE CNTL		2	1			
V72X0899B (X0999B, X1099B) 1 = VALID LH (RH, AFT) ADI PITCH SINE CNTL		3	1			
V72X0900B (X1000B, X1100B) 1 = VALID LH (RH, AFT) ADI PITCH COSINE CNTL		4	1		F	
V72X0901B (X1001B, X1101B) 1 = VALID LH (RH, AFT) ADI YAW SINE CNTL		5	1			
V72X0902B (X1002B, X1102B) 1 = VALID LH (RH, AFT) ADI YAW COSINE CNTL		6	1			
V72X0903B (X1003B, X1103B) 1 = VALID LH (RH, AFT) ADI ROLL RATE CNTL		7	1			
V72X0904B (X1004B, X1104B) 1 = VALID LH (RH, AFT) ADI PITCH RATE CNTL		8	1		F	
V72X0905B (X1005B, X1105B) 1 = VALID LH (RH, AFT) ADI YAW RATE CNTL		9	1			
V72X0906B (X1006B, X1106B) 1 = VALID LH (RH, AFT) ADI ROLL ERROR CNTL		10	1			
V72X0907B (X1007B, X1107B) 1 = VALID LH (RH, AFT) ADI PITCH ERROR CNTL		11	1			
V72X0908B (X1008B, X1108B) 1 = VALID LH (RH, AFT) ADI YAW ERROR CNTL		12	1		8	
SPARE = 0		13	0			
SPARE = 0		14	0			
SPARE = 0		15	0			

Figure 1.3-25.- ADI control word

LH (RH) AMI CONTROL WORD
V72M7240P (M7280P)

MSID NOMENCLATURE	IF INVALID	B I T	N O M		N O M	
V72X7241B (X7281B) LH (RH) AMI TEST WD CNTL	ALWAYS = 1	0	1		F	
V72X7242B (X7282B) LH (RH) AMI MACH NUMBER CNTL	1 = VALID	M/VEL OFF FLAG	1	1		
V72X7243B (X7283B) LH (RH) AMI ALPHA CNTL	1 = VALID	ALPHA OFF FLAG	2	1		
V72X7244B (X7284B) LH (RH) AMI EQUIV AIRSPEED CNTL	1 = VALID	EAS OFF FLAG	3	1		
V72X7245B (X7285B) LH (RH) AMI VEH ACCEL CNTL	1 = VALID	ACCEL OFF FLAG	4	1	8	
SPARE = 0		5	0			
SPARE = 0		6	0			
SPARE = 0		7	0			
SPARE = 0		8	0		0	
SPARE = 0		9	0			
SPARE = 0		10	0			
SPARE = 0		11	0			
SPARE = 0		12	0		0	
SPARE = 0		13	0			
SPARE = 0		14	0			
SPARE = 0		15	0			

Figure 1.3-26.- AMI control word

LH (RH) HSI CONTROL WORD
V72M8799P (M8849P)

MSID NOMENCLATURE	IF INVALID	B I T	N O M		N O M	
V72X8800B (X8850B) LH (RH) HSI TEST WD CNTL	ALWAYS = 1	0	1		F	
V72X8801B (X8851B) LH (RH) HSI SEL COURSE CNTL	1 = VALID	BRG FLAG	1	1		
V72X8802B (X8852B) LH (RH) HSI HEADING CNTL	1 = VALID	BRG FLAG	2	1		
V72X8803B (X8853B) LH (RH) HSI PRI BEARING CNTL	1 = VALID	BRG FLAG	3	1		
V72X8804B (X8854B) LH (RH) HSI SEC BEARING CNTL	1 = VALID	BRG FLAG	4	1	F	
V72X8805B (X8855B) LH (RH) HSI PRI DISTANCE CNTL	1 = VALID	BARS	5	0		
V72X8806B (X8856B) LH (RH) HSI SEC DISTANCE CNTL	1 = VALID	BARS	6	0		
V72X8807B (X8857B) LH (RH) HSI COURSE DEVN CNTL	1 = VALID	CDI FLAG	7	0		
V72X8810B (X8860B) LH (RH) HSI GLIDESLOPE DEVN CNTL	1 = VALID	GS FLAG	8	0	8	
SPARE = 0			9	0		
SPARE = 0			10	0		
SPARE = 0			11	0		
SPARE = 0			12	0	0	
SPARE = 0			13	0		
SPARE = 0			14	0		
SPARE = 0			15	0		

Figure 1.3-27.- HSI control word

LH (RH) AVVI CONTROL WORD
V72M5340P (M5380P)

MSID NOMENCLATURE	IF INVALID	B I T	N O M		N O M	
V72X5341B (X5381B) LH (RH) AVVI TEST WD CNTL	ALWAYS = 1	0	1		F	
V72X5342B (X5382B) LH (RH) AVVI IND ALT CNTL	1 = VALID	1	1			
V72X5343B (X5383B) LH (RH) AVVI VERT VEL CNTL	1 = VALID	2	1			
V72X5344B (X5384B) LH (RH) AVVI RADAR ALT CNTL	1 = VALID	3	1			
V72X5345B (X5385B) LH (RH) AVVI VERT ACCEL CNTL	1 = VALID	4	1		8	
SPARE = 0		5	0			
SPARE = 0		6	0			
SPARE = 0		7	0			
SPARE = 0		8	0		0	
SPARE = 0		9	0			
SPARE = 0		10	0			
SPARE = 0		11	0			
SPARE = 0		12	0		0	
SPARE = 0		13	0			
SPARE = 0		14	0			
SPARE = 0		15	0			

Figure 1.3-28.- AVVI control word

GPS1(2,3) NAV MODE WORD 1
V74M2319P (M1921P, M2380P)

MSID NOMENCLATURE	B I T	N A V	INIT	S/T	N A V	INIT	S/T
V74X4922B (1922,5922) GPS1 DATA VALID 1 = VALID	0	1	0	0	C	2	0
V74U4923B (1923,5923) GPS1 RCVR MODE MSB 00 = TEST 01 = INIT 10 = NAV 11 = Not Used	1	1	0	0			
V74U4923B (1923,5923) GPS1 RCVR MODE LSB	2	0	1	0			
V74X4925B (1925,5925) GPS1 BIT IN PROGRESS H/W 1 = ON	3	0	0	0			
V74X4926B (1926,5926) GPS1 PRELAUNCH STANDBY MODE 1 = ON	4	0	0	0	1/3	0/1/ 4/5	0
V74X4927B (1927,5927) GPS1 INIT REQUEST 1 = Needs INIT Data (When RCVR in INIT MODE)	5	0	0/1	0			
V74X4928B (1928,5928) GPS1 ALMANAC DOWNLOADED 1 = Needs Data (in INIT MODE) / Almanac updated (in NAV MODE)	6	0/1	0	0			
V74X4929B (1929,5929) GPS1 PPS OR SPS 1 = PPS 0 = SPS	7	1	1/0	0			
V74X4930B (1930,5930) GPS1 UTC DATA VALID 1 = VALID	8	1	1	0	C	8	0
V74X4931B (1931,5931) GPS1 LEVER ARM CORRECTION 1 = Correction Used	9	1	0	0			
SPARE	10	0	0	0			
SPARE	11	0	0	0			
SPARE	12	0	0	0	2	0	0
V74U4932B (1932,5932) GPS1 FILTER MODE MSB 00 = PVA 01 = INS10 and 11 Not Used	13	0	0	0			
V74U4932B (1932,5932) GPS1 FILTER MODE LSB	14	1	0	0			
SPARE	15	0	0	0			

Figure 1.3-29.- GPS NAV Mode Word 1

GPS1(2,3) NAV MODE WORD 2
V74M2320P (M1934P, M2381P)

MSID NOMENCLATURE	B I T	N A V	INIT	S/T	N A V	INIT	S/T
V74X4935B (1935,5935) GPS1 ANNCD RESET CMPLT 1 = COMPLETE	0	0/1	0	0	0/8	0/4	0
V74X4936B (1936,5936) GPS1 INIT STATES CMPLT 1 = ON	1	0	0/1	0			
V74X4937B (1937,5937) GPS1 IMU RECONFIG CMPLT (NOT USED) 1 = COMPLETE	2	0	0	0			
V74X4938B (1938,5938) GPS1 FILTER RESTART CMPLT 1 = COMPLETE	3	0	0	0			
V74X4939B (1939,5939) GPS1 SELF RESET 1 = ON (If Receiver Resets Without GPC Command)	4	0	0	0	0	0	0
SPARE	5	0	0	0			
SPARE	6	0	0	0			
SPARE	7	0	0	0			
SPARE	8	0	0	0	0	0	0
SPARE	9	0	0	0			
SPARE	10	0	0	0			
SPARE	11	0	0	0			
SPARE	12	0	0	0	1	2	3/0
SPARE	13	0	0	0			
V74U4940B (1940,5940) GPS1 RCVR MODE COMMAND CHECK MSB 10 = INIT 01 = NAV	14	0	1	1/0			
V74U4940B (1940,5940) GPS1 RCVR MODE COMMAND CHECK LSB 11 = SELF TEST MODE 00 = DURING SELF TEST	15	1	0	1/0			

Figure 1.3-30.- GPS NAV Mode Word 2

GPS1(2,3) PPS STATUS
V74M4459P (M1459P, M3459P)

MSID NOMENCLATURE	B I T	N A V	INIT	N A V	INIT
V74X4467B (1467,3467) GPS1 PPS DAILY KEY IN USE VERIFIED 1 = VERIFIED	0	1	1	8	8
V74X4468B (1468,3468) GPS1 PPS DAILY KEY IN USE UNVERIF 1 = NOT VERIFIED	1	0	0		
V74X4469B (1469,3469) GPS1 PPS DAILY KEY IN USE INCORR 1 = INCORRECT KEY	2	0	0		
V74X4470B (1470,3470) GPS1 PPS KEY FAILED PARITY 1 = PARITY ERROR	3	0	0		
V74X4471B (1471,3471) GPS1 PPS GUV USER 1 = USING GUV	4	1	1	8	8
V74X4472B (1472,3472) GPS1 PPS 2 HOUR ALERT 1 = ON (2 hrs or less before expiration of current and last key)	5	0	0		
V74X4473B (1473,3473) GPS1 PPS INSUFFICIENT KEYS 1 = INSUFFICIENT KEYS	6	0	0		
V74X4476B (1476,3476) GPS1 PPS-ERASE KEY FAIL 1 = Failed to Erase or Zeroize a portion of Memory	7	0	0		
V74X4474B (1474,3474) GPS1 PPS RECEIVER CONTAINS KEYS 1 = ON	8	1	1	X	X
V74W4475B (1475,3475) GPS1 PPS MISSION DURATION FOR KEYS MSB MAX Value = 44 MIN Value = 0	9	X	X		
V74W4475B (1475,3475) GPS1 PPS MISSION DURATION FOR KEYS (number of consecutive days has keys)	10	X	X		
V74W4475B (1475,3475) GPS1 PPS MISSION DURATION FOR KEYS	11	X	X		
V74W4475B (1475,3475) GPS1 PPS MISSION DURATION FOR KEYS	12	X	X	X	X
V74W4475B (1475,3475) GPS1 PPS MISSION DURATION FOR KEYS	13	X	X		
V74W4475B (1475,3475) GPS1 PPS MISSION DURATION FOR KEYS	14	X	X		
V74W4475B (1475,3475) GPS1 PPS MISSION DURATION FOR KEYS LSB	15	X	X		

Figure 1.3-31.- GPS PPS Status

GPS1(2,3) STATUS FOM GDOP WORD 1
V74M4461P (M1461P, M3461P)

MSID NOMENCLATURE	B I T	N A V		N A V	
SPARE	0	0		0	
SPARE	1	0			
V74X4462B (1462,3462) GPS1(2,3) INCORP LESS THAN 4 MEAS 1 = (<4 Measurements)	2	0			
V74X4463B (1463,3463) GPS1(2,3) RPU FAIL 1 = FAIL	3	0			
SPARE	4	0		X	
V74X4464B (1464,3464) GPS1(2,3) BATTERY LOW 1 = ON (≤ 3.3 VDC) 0 = RESET (≥ 3.4 VDC)	5	0			
SPARE	6	0			
V74U4465B (1465,3465) GPS1(2,3) GEOMETRIC DILUTION OF PREC MSB MAX Value = 15 MIN Value = 1	7	X			
V74U4465B (1465,3465) GPS1(2,3) GEOMETRIC DILUTION OF PREC	8	X		X	
V74U4465B (1465,3465) GPS1(2,3) GEOMETRIC DILUTION OF PREC	9	X			
V74U4465B (1465,3465) GPS1(2,3) GEOMETRIC DILUTION OF PREC LSB	10	X			
V74U4466B (1466,3466) GPS1(2,3) FIGURE OF MERIT MSB MAX Value = 9 MIN Value = 1	11	X			
V74U4466B (1466,3466) GPS1(2,3) FIGURE OF MERIT	12	X		X	
V74U4466B (1466,3466) GPS1(2,3) FIGURE OF MERIT	13	X			
V74U4466B (1466,3466) GPS1(2,3) FIGURE OF MERIT LSB	14	X			
SPARE	15	0			

Figure 1.3-32.- GPS Status FOM GDOP Word 1

GPS1(2,3) CHAN STATUS WD 1
V74M4960P (M1960P, M5960P)

MSID NOMENCLATURE	B I T	N A V		N A V	
V74X4971B (1971,5971) GPS1(2,3) CHAN 1 FAULT FLAG 1 = CHANNEL FAULT	0	0		1/3/5/ 7	
V74X4972B (1972,5972) GPS1(2,3) CHAN 1 ANTENNA SELECT 1 = TOP 0 = BOTTOM	1	0/1			
V74X4973B (1973,5973) GPS1(2,3) CHAN 1 FREQUENCY 1 = L2 0 = L1	2	0/1			
V74X4974B (1974,5974) GPS1(2,3) CHAN 1 EPHEM DOWNLOAD FLAG 1 = EPHEMERIS DOWNLOADED	3	1			
V74U4975B (1975,5975) GPS1(2,3) CHAN 1 STATE MSB MAX Value = 7 MIN Value = 1	4	X		X	
V74U4975B (1975,5975) GPS1(2,3) CHAN 1 STATE	5	X			
V74U4975B (1975,5975) GPS1(2,3) CHAN 1 STATE LSB	6	X			
V74U4976B (1976,5976) GPS1(2,3) CHAN 1 HDWARE CHAN NUMBER MSB MAX Value = 5 MIN Value = 1	7	X			
V74U4976B (1976,5976) GPS1(2,3) CHAN 1 HDWARE CHAN NUMBER	8	X		X	
V74U4976B (1976,5976) GPS1(2,3) CHAN 1 HDWARE CHAN NUMBER LSB	9	X			
V74U4977B (1977,5977) GPS1(2,3) CHAN 1 SATELLITE NUMBER MSB MAX Value = 63 MIN Value = 1	10	X			
V74U4977B (1977,5977) GPS1(2,3) CHAN 1 SATELLITE NUMBER	11	X			
V74U4977B (1977,5977) GPS1(2,3) CHAN 1 SATELLITE NUMBER	12	X		X	
V74U4977B (1977,5977) GPS1(2,3) CHAN 1 SATELLITE NUMBER	13	X			
V74U4977B (1977,5977) GPS1(2,3) CHAN 1 SATELLITE NUMBER	14	X			
V74U4977B (1977,5977) GPS1(2,3) CHAN 1 SATELLITE NUMBER LSB	15	X			

Figure 1.3-33.- GPS Channel Status Word 1

GPS1(2,3) CHAN STATUS WD 2
V74M4961P (M1961P, M5961P)

MSID NOMENCLATURE	B I T	N A V		N A V	
V74E4978B (1978,5978) GPS1(2,3) CHAN 1 SIGNAL TO NOISE RATIO MSB MAX Value = 63 MIN Value = 0	0	X		X	
V74E4978B (1978,5978) GPS1(2,3) CHAN 1 SIGNAL TO NOISE RATIO	1	X			
V74E4978B (1978,5978) GPS1(2,3) CHAN 1 SIGNAL TO NOISE RATIO	2	X			
V74E4978B (1978,5978) GPS1(2,3) CHAN 1 SIGNAL TO NOISE RATIO	3	X			
V74E4978B (1978,5978) GPS1(2,3) CHAN 1 SIGNAL TO NOISE RATIO	4	X		1/5/9/ D	
V74E4978B (1978,5978) GPS1(2,3) CHAN 1 SIGNAL TO NOISE RATIO LSB	5	X			
V74U4979B (1979,5979) GPS1(2,3) CHAN 1 CODE TRACKING STATUS MSB 00 = P CODE 01 = Y CODE 10 = C/A CODE 11 = not used	6	0			
V74U4979B (1979,5979) GPS1(2,3) CHAN 1 CODE TRACKING STATUS LSB	7	1			
V74E4980B (1980,5980) GPS1(2,3) CHAN 2 SIGNAL TO NOISE RATIO MSB MAX Value = 63 MIN Value = 0	8	X		X	
V74E4980B (1980,5980) GPS1(2,3) CHAN 2 SIGNAL TO NOISE RATIO	9	X			
V74E4980B (1980,5980) GPS1(2,3) CHAN 2 SIGNAL TO NOISE RATIO	10	X			
V74E4980B (1980,5980) GPS1(2,3) CHAN 2 SIGNAL TO NOISE RATIO	11	X			
V74E4980B (1980,5980) GPS1(2,3) CHAN 2 SIGNAL TO NOISE RATIO	12	X		1/5/9/ D	
V74E4980B (1980,5980) GPS1(2,3) CHAN 2 SIGNAL TO NOISE RATIO LSB	13	X			
V74U4981B (1981,5981) GPS1(2,3) CHAN 2 CODE TRACKING STATUS MSB 00 = P CODE 01 = Y CODE 10 = C/A CODE 11 = not used	14	0			
V74U4981B (1981,5981) GPS1(2,3) CHAN 2 CODE TRACKING STATUS LSB	15	1			

Figure 1.3-34.- GPS Channel Status Word 2

GPS1(2,3) CHAN STATUS WD 3
V74M4962P (M1962P, M5962P)

MSID NOMENCLATURE	B I T	N A V		N A V	
V74X4982B (1982,5982) GPS1(2,3) CHAN 2 FAULT FLAG 1 = CHANNEL FAULT	0	0		1/3/5/ 7	
V74X4983B (1983,5983) GPS1(2,3) CHAN 2 ANTENNA SELECT 1 = TOP 0 = BOTTOM	1	0/1			
V74X4984B (1984,5984) GPS1(2,3) CHAN 2 FREQUENCY 1 = L2 0 = L1	2	0/1			
V74X4985B (1985,5985) GPS1(2,3) CHAN 2 EPHEM DOWNLOAD FLAG 1 = EPHEMERIS DOWNLOADED	3	1			
V74U4986B (1986,5986) GPS1(2,3) CHAN 2 STATE MSB MAX Value = 7 MIN Value = 1	4	X		X	
V74U4986B (1986,5986) GPS1(2,3) CHAN 2 STATE	5	X			
V74U4986B (1986,5986) GPS1(2,3) CHAN 2 STATE LSB	6	X			
V74U4987B (1987,5987) GPS1(2,3) CHAN 2 HDWARE CHAN NUMBER MSB MAX Value = 5 MIN Value = 1	7	X			
V74U4987B (1987,5987) GPS1(2,3) CHAN 2 HDWARE CHAN NUMBER	8	X		X	
V74U4987B (1987,5987) GPS1(2,3) CHAN 2 HDWARE CHAN NUMBER LSB	9	X			
V74U4988B (1988,5988) GPS1(2,3) CHAN 2 SATELLITE NUMBER MSB MAX Value = 63 MIN Value = 1	10	X			
V74U4988B (1988,5988) GPS1(2,3) CHAN 2 SATELLITE NUMBER	11	X			
V74U4988B (1988,5988) GPS1(2,3) CHAN 2 SATELLITE NUMBER	12	X		X	
V74U4988B (1988,5988) GPS1(2,3) CHAN 2 SATELLITE NUMBER	13	X			
V74U4988B (1988,5988) GPS1(2,3) CHAN 2 SATELLITE NUMBER	14	X			
V74U4988B (1988,5988) GPS1(2,3) CHAN 2 SATELLITE NUMBER LSB	15	X			

Figure 1.3-35.- GPS Channel Status Word 3

GPS1(2,3) CHAN STATUS WD 4
V74M4963P (M1963P, M5963P)

MSID NOMENCLATURE	B I T	N A V		N A V	
V74E4989B (1989,5989) GPS1(2,3) CHAN 3 SIGNAL TO NOISE RATIO MSB MAX Value = 63 MIN Value = 0	0	X		X	
V74E4989B (1989,5989) GPS1(2,3) CHAN 3 SIGNAL TO NOISE RATIO	1	X			
V74E4989B (1989,5989) GPS1(2,3) CHAN 3 SIGNAL TO NOISE RATIO	2	X			
V74E4989B (1989,5989) GPS1(2,3) CHAN 3 SIGNAL TO NOISE RATIO	3	X			
V74E4989B (1989,5989) GPS1(2,3) CHAN 3 SIGNAL TO NOISE RATIO	4	X		1/5/9/ D	
V74E4989B (1989,5989) GPS1(2,3) CHAN 3 SIGNAL TO NOISE RATIO LSB	5	X			
V74U4990B (1990,5990) GPS1(2,3) CHAN 3 CODE TRACKING STATUS MSB 00 = P CODE 01 = Y CODE 10 = C/A CODE 11 = not used	6	0			
V74U4990B (1990,5990) GPS1(2,3) CHAN 3 CODE TRACKING STATUS LSB	7	1			
V74E4991B (1991,5991) GPS1(2,3) CHAN 4 SIGNAL TO NOISE RATIO MSB MAX Value = 63 MIN Value = 0	8	X		X	
V74E4991B (1991,5991) GPS1(2,3) CHAN 4 SIGNAL TO NOISE RATIO	9	X			
V74E4991B (1991,5991) GPS1(2,3) CHAN 4 SIGNAL TO NOISE RATIO	10	X			
V74E4991B (1991,5991) GPS1(2,3) CHAN 4 SIGNAL TO NOISE RATIO	11	X			
V74E4991B (1991,5991) GPS1(2,3) CHAN 4 SIGNAL TO NOISE RATIO	12	X		1/5/9/ D	
V74E4991B (1991,5991) GPS1(2,3) CHAN 4 SIGNAL TO NOISE RATIO LSB	13	X			
V74U4992B (1992,5992) GPS1(2,3) CHAN 4 CODE TRACKING STATUS MSB 00 = P CODE 01 = Y CODE 10 = C/A CODE 11 = not used	14	0			
V74U4992B (1992,5992) GPS1(2,3) CHAN 4 CODE TRACKING STATUS LSB	15	1			

Figure 1.3-36.- GPS Channel Status Word 4

GPS1(2,3) CHAN STATUS WD 5
V74M4964P (M1964P, M5964P)

MSID NOMENCLATURE	B I T	N A V		N A V	
V74X4993B (1993,5993) GPS1(2,3) CHAN 3 FAULT FLAG 1 = CHANNEL FAULT	0	0		1/3/5/ 7	
V74X4994B (1994,5994) GPS1(2,3) CHAN 3 ANTENNA SELECT 1 = TOP 0 = BOTTOM	1	0/1			
V74X4995B (1995,5995) GPS1(2,3) CHAN 3 FREQUENCY 1 = L2 0 = L1	2	0/1			
V74X4996B (1996,5996) GPS1(2,3) CHAN 3 EPHEM DOWNLOAD FLAG 1 = EPHEMERIS DOWNLOADED	3	1			
V74U4997B (1997,5997) GPS1(2,3) CHAN 3 STATE MSB MAX Value = 7 MIN Value = 1	4	X		X	
V74U4997B (1997,5997) GPS1(2,3) CHAN 3 STATE	5	X			
V74U4997B (1997,5997) GPS1(2,3) CHAN 3 STATE LSB	6	X			
V74U4998B (1998,5998) GPS1(2,3) CHAN 3 HDWARE CHAN NUMBER MSB MAX Value = 5 MIN Value = 1	7	X			
V74U4998B (1998,5998) GPS1(2,3) CHAN 3 HDWARE CHAN NUMBER	8	X		X	
V74U4998B (1998,5998) GPS1(2,3) CHAN 3 HDWARE CHAN NUMBER LSB	9	X			
V74U4999B (1999,5999) GPS1(2,3) CHAN 3 SATELLITE NUMBER MSB MAX Value = 63 MIN Value = 1	10	X			
V74U4999B (1999,5999) GPS1(2,3) CHAN 3 SATELLITE NUMBER	11	X			
V74U4999B (1999,5999) GPS1(2,3) CHAN 3 SATELLITE NUMBER	12	X		X	
V74U4999B (1999,5999) GPS1(2,3) CHAN 3 SATELLITE NUMBER	13	X			
V74U4999B (1999,5999) GPS1(2,3) CHAN 3 SATELLITE NUMBER	14	X			
V74U4999B (1999,5999) GPS1(2,3) CHAN 3 SATELLITE NUMBER LSB	15	X			

Figure 1.3-37.- GPS Channel Status Word 5

GPS1(2,3) CHAN STATUS WD 6
V74M4965P (M1965P, M5965P)

MSID NOMENCLATURE	B I T	N A V		N A V	
V74E8080B (2080,3080) GPS1(2,3) CHAN 5 SIGNAL TO NOISE RATIO MSB MAX Value = 63 MIN Value = 0	0	X		X	
V74E8080B (2080,3080) GPS1(2,3) CHAN 5 SIGNAL TO NOISE RATIO	1	X			
V74E8080B (2080,3080) GPS1(2,3) CHAN 5 SIGNAL TO NOISE RATIO	2	X			
V74E8080B (2080,3080) GPS1(2,3) CHAN 5 SIGNAL TO NOISE RATIO	3	X			
V74E8080B (2080,3080) GPS1(2,3) CHAN 5 SIGNAL TO NOISE RATIO	4	X		1/5/9/ D	
V74E8080B (2080,3080) GPS1(2,3) CHAN 5 SIGNAL TO NOISE RATIO LSB	5	X			
V74U8081B (2081,3081) GPS1(2,3) CHAN 5 CODE TRACKING STATUS MSB 00 = P CODE 01 = Y CODE 10 = C/A CODE 11 = not used	6	0			
V74U8081B (2081,3081) GPS1(2,3) CHAN 5 CODE TRACKING STATUS LSB	7	1			
SPARE	8	0		0	
SPARE	9	0			
SPARE	10	0			
SPARE	11	0			
SPARE	12	0		0	
SPARE	13	0			
SPARE	14	0			
SPARE	15	0			

Figure 1.3-38.- GPS Channel Status Word 6

GPS1(2,3) CHAN STATUS WD 7
V74M4966P (M1966P, M5966P)

MSID NOMENCLATURE	B I T	N A V		N A V	
V74X8084B (2084,3084) GPS1(2,3) CHAN 4 FAULT FLAG 1 = CHANNEL FAULT	0	0		1/3/5/ 7	
V74X8085B (2085,3085) GPS1(2,3) CHAN 4 ANTENNA SELECT 1 = TOP 0 = BOTTOM	1	0/1			
V74X8086B (2086,3086) GPS1(2,3) CHAN 4 FREQUENCY 1 = L2 0 = L1	2	0/1			
V74X8087B (2087,3087) GPS1(2,3) CHAN 4 EPHEM DOWNLOAD FLAG 1 = EPHEMERIS DOWNLOADED	3	1			
V74U8088B (2088,3088) GPS1(2,3) CHAN 4 STATE MSB MAX Value = 7 MIN Value = 1	4	X		X	
V74U8088B (2088,3088) GPS1(2,3) CHAN 4 STATE	5	X			
V74U8088B (2088,3088) GPS1(2,3) CHAN 4 STATE LSB	6	X			
V74U8089B (2089,3089) GPS1(2,3) CHAN 4 HDWARE CHAN NUMBER MSB MAX Value = 5 MIN Value = 1	7	X			
V74U8089B (2089,3089) GPS1(2,3) CHAN 4 HDWARE CHAN NUMBER	8	X		X	
V74U8089B (2089,3089) GPS1(2,3) CHAN 4 HDWARE CHAN NUMBER LSB	9	X			
V74U8090B (2090,3090) GPS1(2,3) CHAN 4 SATELLITE NUMBER MSB MAX Value = 63 MIN Value = 1	10	X			
V74U8090B (2090,3090) GPS1(2,3) CHAN 4 SATELLITE NUMBER	11	X			
V74U8090B (2090,3090) GPS1(2,3) CHAN 4 SATELLITE NUMBER	12	X		X	
V74U8090B (2090,3090) GPS1(2,3) CHAN 4 SATELLITE NUMBER	13	X			
V74U8090B (2090,3090) GPS1(2,3) CHAN 4 SATELLITE NUMBER	14	X			
V74U8090B (2090,3090) GPS1(2,3) CHAN 4 SATELLITE NUMBER LSB	15	X			

Figure 1.3-39.- GPS Channel Status Word 7

GPS(2,3) CHAN STATUS WD 8
V74M4967P (M1967P, M5967P)

MSID NOMENCLATURE	B I T	N A V		N A V	
V74X8091B (2091,3091) GPS1(2,3) CHAN 5 FAULT FLAG 1 = CHANNEL FAULT	0	0		1/3/5/ 7	
V74X8092B (2092,3092) GPS1(2,3) CHAN 5 ANTENNA SELECT 1 = TOP 0 = BOTTOM	1	0/1			
V74X8093B (2093,3093) GPS1(2,3) CHAN 5 FREQUENCY 1 = L2 0 = L1	2	0/1			
V74X8094B (2094,3094) GPS1(2,3) CHAN 5 EPHEM DOWNLOAD FLAG 1 = EPHEMERIS DOWNLOADED	3	1			
V74U8095B (2095,3095) GPS1(2,3) CHAN 5 STATE MSB MAX Value = 7 MIN Value = 1	4	X		X	
V74U8095B (2095,3095) GPS1(2,3) CHAN 5 STATE	5	X			
V74U8095B (2095,3095) GPS1(2,3) CHAN 5 STATE LSB	6	X			
V74U8096B (2096,3096) GPS1(2,3) CHAN 5 HDWARE CHAN NUMBER MSB MAX Value = 5 MIN Value = 1	7	X			
V74U8096B (2096,3096) GPS1(2,3) CHAN 5 HDWARE CHAN NUMBER	8	X		X	
V74U8096B (2096,3096) GPS1(2,3) CHAN 5 HDWARE CHAN NUMBER LSB	9	X			
V74U8097B (2097,3097) GPS1(2,3) CHAN 5 SATELLITE NUMBER MSB MAX Value = 63 MIN Value = 1	10	X			
V74U8097B (2097,3097) GPS1(2,3) CHAN 5 SATELLITE NUMBER	11	X			
V74U8097B (2097,3097) GPS1(2,3) CHAN 5 SATELLITE NUMBER	12	X		X	
V74U8097B (2097,3097) GPS1(2,3) CHAN 5 SATELLITE NUMBER	13	X			
V74U8097B (2097,3097) GPS1(2,3) CHAN 5 SATELLITE NUMBER	14	X			
V74U8097B (2097,3097) GPS1(2,3) CHAN 5 SATELLITE NUMBER LSB	15	X			

Figure 1.3-40.- GPS Channel Status Word 8

TITLE

PRELAUNCH SENSOR/CONTROL CONSOLE OPERATIONS

PURPOSE

The purpose of this SCP is to define those tasks and responsibilities assigned to the Sensors and Control console operators during the period preceding a Shuttle launch.

BACKGROUND

During the 11-hour period prior to shuttle lift-off, KSC is in charge of the countdown and vehicle processing; however, there are numerous responsibilities assigned to the Sensor and Control operators on both the planning and ascent teams. In many cases those tasks may only involve tracking of Kennedy Space Center (KSC) activities per the Operation and Maintenance Instruction (OMI) documents related to activation of GNC hardware; in other cases there are visual signs of compliance that can be used to verify KSC operations. There are also some isolated cases where MCC computations afford a greater insight into the performance of our hardware than that available to KSC; these will be defined in the text.

PROCEDURE

The Sensors and Control operators should monitor the prelaunch activities using table 1.4-I as a guideline. OMI S0007 Volume 2 (S0007.200) is used during actual launch countdowns and OMI S0017 is used for Terminal Countdown Demonstration Tests (TCDT's). These documents and their supporting documentation can be found on the OMD web page which is linked off the GNC Documents page. Be sure that "show published documents" is checked while searching, and keep in mind that even though the document is pronounced "soo-seven" the document number contains zeros not the letter o's.

Table 1.4-II is a checklist which should be handed over from the Planning Team to the Ascent Team. It lists the activities which must be performed prelaunch in order to ready the team for the mission.

Included in the checklist is a review of the L - 1 day crew debriefing. This will alert the operator to any off-nominal conditions that should be closely monitored. Systems monitoring should be done as soon as possible. The Launch Commit Criteria (LCC) summary in table 1.4-III can be used as a guide.

TABLE 1.4-I.- PRELAUNCH COUNTDOWN TIMELINE

T-Time	Event
1D 17H 40	Transition to OPS 9
1D 06H 30	DDU/FLT CNTL Pwr/HUD Self Test
1D 06H 30	Manual Controller Test, OMI V1123
1D 06H 30	NAVAIDS Prep
1D 06H 00	NAVAIDS Activation/Self Test/Deactivation
1D 06H 30	Abort SW Test
1D 05H 15	RHC Panel Switch Test
19H 00	IMU Power Up, OMI V1123
19H 00	Star Tracker Power Up/Self Test/Power Down
17H 45	RCS Logic Activation, OMI V1123
15H 00	ADTA, RGA, AA, ASA, ATVC Activation, OMI V1123
14H 30	Air Data Transducer Assembly Self Test, OMI V1123
14H 30	RGA/AA Sensor Self Test, OMI V1123
14H 30	Landing Gear No WOW Status Check
14H 20	Pre-Ingress Switchlist
11H 00*	Hold (11 hours)
9H 00	SRB Power Up
9H 00	SRB TVC Power Up
9H 00	Landing Gear No WOW Status Check
7H 30	OMS Gimbal Profile (S007.400 operation 43)
6H 45	IMU Operate & Attitude Determination, OMI V1123
6H 00	LCC Verification
5H 22	IMU Preflight Calibration (2H15M), OMI V1123
3H 00	Hold (1 hour)
3H 00	SRB RGA Power Up & Torque Test, OMI V1123
3H 00	Landing Gear No WOW Status Check
3H 00**	IMU Preflight Calibration #2 (if required)
3H 00	Landing Sites Status
3H 00	NAVAIDS Activation/Configuration (TACAN's & RA's)
3H 00	Star Tracker Door Close Verification
2H 45	LCC Verification
2H 25	Flight Crew Ingress
2H 10	TACAN Thumbwheel Settings for TAL

* Planning Team on Console

** Ascent Team on console

TABLE 1.4-I.- CONCLUDED

T-Time	Event
2H 00	GLS Initialization
1H 40	TACAN/MSBLS Ground Station Status
1H 35	Crew Module Closeout
1H 30	Controllability Light Test
1H 20	Launch Polynomial Update (if required) (DOLILU)
1H 20	GPS Delta Time Update (if required; see nav018b)
3H 00	IMU Preflight Calibration Completed
1H 15	IRAMS Activation
1H 57	IMU Attitude Determination (4 minutes), OMI V1123
1H 47	IMU Preflight Align (38 minutes), OMI V1123
1H 00	TACAN/MSBLS Ground Station Status
22M 00	PASS/BFS Transfer
20M 00	Hold (10 minutes)
20M 00	Star Tracker Door Close Verification
20M 00	Extended Hold Time (contingency)
20M 00	IMU Preflight Align Complete
20M 00	IMU Continuous Align Started
20M 00	RH SBTC Check
20M 00	Landing Gear No WOW Status Check
20M 00	OPS 1 Transition
19M 00	BFS to OPS 101
17M 00	Flight Controls Driver Current and Position Checks
17M 00	HORIZ SIT Config.
9M 00	Hold (10 minutes)
9M 00	G1 Launch Polynomial Update (if required) (DOLILU)
9M 00	MLS Channel Update (if required)
9M 00	Resume Count
9M 00	GLS Auto Sequence Start
6M 00	APU Pre-Start
5M 00	APU Start
4M 00	IMU's to Inertial Mode
3M 55	Aerosurface Slew
3M 30	SSME TVC Slew
0M 31	Redundant Set Launch Sequencer (RSLS) Start
0M 21	SRB TVC Slew
0M 06	Main Engine Start
0M 00	SRB Ignition/Liftoff/Tower Clear

TABLE 1.4-II. - PRELAUNCH CHECKLIST

Flight _____ Vehicle _____ Operator _____
Date _____ GMT _____ Team _____

Status	Action
	<ul style="list-style-type: none"> • Log onto the Workstation Flight Activity: Call up appropriate displays • Start ELOG, be sure to clear ELOG at start up so preflight sim data is not retained in ELOG. • Start RTPLOT, Channelization, CRANS, Publish CRANS, Dracula, and GPS YETI (YETI 2 for single-string; 1, 2, and 3 for three-string) • Initialize limit manager with Ascent limits • Start Ascent LOC program (FCR)
	<p>Verify the flight directories on all workstations have been cleaned out. Sim data should be moved or deleted.</p> <ul style="list-style-type: none"> • /users/gnc/Data/SSPXXX/* • ODRC directories: /mcc/rw_remote/common/mews/iss/flights/STS-XXX/data/gnc/* • local workstation files (/mcc/rw_local and /mcc/rw_temp) <u>on each workstation.</u>
	Review the L - 1 day crew debriefing
	Incorporate all Flight Data File and Flight Rules Updates
	Check active telemetry according to table 1.4-III
	<p>Verify IMU roll-to-roll matrices for OV10X are sent to the ISP server via ispvalue</p> <p>Send a copy of IMU roll-to-roll matrices for OV10X to ODRC and verify they have been correctly entered into ODRC.</p>
	<p>Following the IMU Preflight Calibration:</p> <ul style="list-style-type: none"> • Obtain IMU Preflight Cal results (from MOIR/IMU) • Load IMU gyro and accel biases into the GCS • Record IMU biases in the IMU log (format x.xxxx deg/hr)
	<p>Following IMUs to Inertial (T-4 min):</p> <ul style="list-style-type: none"> • Load IMU REFSMMATs into the GCS

SUBSYSTEM	AUTO HOLD	TIME PERIOD	LCC NUMBER	Contingency Procedure / Comments
AA POWER: 4 of 4 required RPC's and 2 of 2 pwr ON cmd (Go for confirmed inst failure) No RM fails	YES/GLS at T-31 YES/GLS at T-31	ET tanking to RLSL start (T-31) From OPS 1 transition to RLSL start (T-31)	GNC-09 GNC-13	Verify status of switches and cbs Confirm inst failure by dropping CNTL bus (prior to OPS 1; see General Notes in this SCP for full constraints)
AIR DATA Deploy disc: 4 of 4 Stow disc: 4 of 4 ADTA BITE's: No BITE's (A/D Converter Good and Discrete Inputs Good BITE's acceptable for launch) BCE STRG: No bypasses ADTA pressures: LRU to LRU comparisons within limits (Like pressures must track within 0.064 in-Hg, RM limit for static pressure)	NO/GNC console NO/GNC console YES/GLS at T-31 NO/GNC console	From OPS 1 transition (T-19 min) to GLS start (T-9 min) From ET tanking to OPS 1 transition (T-20 min) ET tanking to RLSL start (T-31) From ET tanking to OPS 1 transition (T-20 min)	AFW-15 GNC-73 DPS-15 GNC-74	Go for confirmed inst failure. Check for "deploy" inst failure by monitoring drive time during probe deploy. Refer to contingency procedure for "stow" inst failure verification. Perform self-test for continuing A/D Converter Good failure. After confirmation of correct pressure data and successful self-test, continue count. Loss of air data on one side could make air data calculations beta sensitive Acceptable if experiencing wind turbulence
GPS (OV-105) 2 of 3 if C-band scheduled for EOM (otherwise 3 of 3) To be operational, each GPS must meet following req: - GPS Data Valid On - GPS RPU Fail Off - MDM GPS Bypass: No Bypasses	NO YES/T-9m to T-31s YES/GLS at T-31	GPS Activation + 30m to T-9m GPS Activation to T-31s GPS Activation to T-31s	CT-11 DPS-28	Transient dropouts of GPS Data Valid permitted per LCC CT-11. GPS BCE Bypasses not allowed unless CT-11 not violated (DPS-28).
IMU IMU GOOD: No BITE's (One time transient allowed if re-cal, re-alignment OK) IMU TEMP: No BITE's (Platform Safe/Ready, Temp Safe/Ready) (One time transient allowed if re-cal, re-alignment OK) IMU FAIL: No RM fails SOFTWARE BITEs: No BITE's GYROCOMPASS FAIL: No fails	YES/GLS at T-31 YES/GLS at T-31 YES/GLS at T-31 NO/GNC console	From ET tanking to RLSL start (T-31) From ET tanking to RLSL start (T-31) From platform release (T-4 min) to RLSL start (T-31) From ET tanking to RLSL start (T-31) One time verify after preflight alignment	GNC-56 GNC-58 GNC-59 GNC-60 GNC-61 GNC-62 GNC-63 GNC-66 GNC-64 GNC-57 GNC-67	Platform Ready BITE – performance degradation may be delayed Platform Safe BITE – power off IMU to prevent damage Temp Safe/Ready BITE – indicates power supply problem Before T-5 min: Analyze data, if no substantiating data, then GO After T-5 min: Hold and evaluate Repeat gyrocompass alignment Continue alignment and analyze data For a transient, repeat cal; if good then GO Refer to flight rule A8-57 Verify status of power switches Can perform CNTL bus drop to test for inst failure (refer to Sensor Console General Note K for "no-later-than" times to perform the control bus drop in order to recover a caged IMU prior to launch). A COMM BITE by itself indicates an MDM problem A COMM BITE along with other BITEs (Echo word 13 & 14, inner rsrvr fail, rsrvr null fail) indicate a HAINS IMU problem
ALIGN CORRECTION LIMITED: No fails TRANSMISSION WORD FAIL: No fails IMU MISALIGNMENT W/IRAMS: No redline violations RPC's: 5 of 6 required (RPC considered good for confirmed inst failure) IMU COMM BITE (One time transient allowed if re-cal, re-alignment OK)	NO/GNC console YES/GLS at T-31 NOMER, KSC up to T-31 YES/GLS at T-31 NO/GNC console	From ET tanking to RLSL start (T-31) From gyrocompass align to RLSL start (T-31) From ET tanking to RLSL start (T-31) From ET tanking to RLSL start (T-31)		

TABLE 1.4-III. - LAUNCH COMMIT CRITERIA

SUBSYSTEM	AUTO HOLD	TIME PERIOD	LCC NUMBER	Contingency Procedure / Comments
MLS 2 of 3 if both RAs good 3 of 3 if 1 RA failed 3 of 3 if no C-band tracking scheduled for night EOM	NO	Self-tested at L = 1 day	Append H Sect 04	No active data Refer to Flight Rules A3-2 and A3-202
RA Ready: 1 of 2 ON (2 of 2 if less than 3 MLS)	NO/GNC console	From LRU power up (T-3 hrs) to go for GLS start (T-9 min)	CT-08	RA's criticality 1 for night landings (loss of visual depth perception at night requires increased safety margin provided by RAs) Loss of Ready indication causes software to inhibit RA processing
No Bypasses (BCE STRG 1(2) TAC Fault Message)	NO	T-6 hrs to T-31 sec	DPS-17	Loss of Serial MDM card interface for TACAN 1(2) and RAT(2)
RGAs/Orbiter RPCs: RGA 1 RPC A - ON RGA 4 RPC A & C - ON (GO for confirmed inst failure)	YES/GLS at T-31	ET tanking to RLSL start (T-31)	GNC-08	Verify status of RGA power switches Confirm inst failure by dropping CNTL bus (prior to OPS 1; see General Notes in this SCP for full constraints)
SMRD: No SMRD's	YES/GLS at T-31	From 2 min after powerup to RLSL start (T-31)	GNC-11	RGA w/SMRD will have degraded gyro performance Need 4 of 4 RGAs to be 2 fault tolerant
No RM Fails	YES/GLS at T-31	From OPS 1 transition to RLSL start (T-31)	GNC-12	
RGAs (SRB) RPCs: 2 of 2 for L,R bus C RPC A 2 of 2 for L,R bus C RPC C (Go for confirmed inst failure)	YES/GLS at T-31	From SRGA power application (T-3 hours) to RLSL start (T-31)	GNC-10	No telemetry Confirm inst failure by commanding off alternate RPC for affected bus
SMRD: None	YES/GLS at T-31	From 10 seconds after powerup (T-3 hr) to RLSL start (T-31)	GNC-15	
RGAs: Rates = $0 \pm 0.22^\circ/s$	NO	From completion of torque test (T-3 hours) to OPS 1 transition	GNC-16	Redlines are set to protect the OPS 1 FDIR limit of 0.45 deg/sec (-0.22 and +0.22 express the widest range of acceptable outputs) RGA RM fail discretes are used for LCC evaluation post OPS 1 trans.
No RM Fails	YES/GLS at T-31	From OPS 1 transition to RLSL start (T-31)	GNC-14	Fail flag cannot be reset w/o GPC IPL and resultant loss of redundant set
STAR TRACKER 2 of 2 are required	NO	Self-tested at -L-1 day	Append H Sect 04	No active data
Door Motors: 3 of 4	NO		Append H Sect 04	No active data
Door discretes: 7 of 8 open & close discretes req. (<7 may be acceptable. See reqmts in redline derivation)	NO/CAFM console	OPS 1 transition complete (T-19 min) to GLS start (T-9 min)	AFM-14	Attempt to drive door in direction of failed switch and monitor MCA currents (see contingency procedure in LCC)
TACAN (OV-103 & OV-104) 2 of 3 if C-band scheduled for EOM or TACAN 2 failed with GPS 2 operational * 3 of 3 if no C-band scheduled for EOM To be operational, each TACAN must meet following req: - Power ON (go for confirmed ground inst failure) - Range Status = 0 - Bearing Status = 0 or 3 - Range BITE = OFF - Range Supp. Pulse = ON * OV-104 only	Yes (T-31) NO NO YES (T-31) YES (T-31)	From TACAN activation (T-3 hrs) to: RLSL start (T-31 sec) GLS start (T-9 min) GLS start (T-9 min) RLSL start (T-31 sec) RLSL start (T-31 sec)	CT-01 DPS-17 Append H Sect 04	Extensive contingency procedures provided in LCC GPS 2 is an acceptable replacement for TACAN 2 on OV-104 only. Monitor range/bearing for reasonableness

TABLE 1.4-III. - LAUNCH COMMIT CRITERIA (CONT)

SUBSYSTEM	AUTO HOLD	TIME PERIOD	LCC NUMBER	Contingency Procedure / Comments
ASA RPC's: All are required (GO for confirmed inst failure)	YES/GLS at T-31	ET tanking to RLSLS start (T-31)	GNC-32	Confirm inst failure: For ASA 1 RPC C, ASA 2 RPC A, or ASA 3 RPC B – turn off FCS channel and see if channel bypasses (Des/Res BF pos feedbacks) For all others – drop CNTL bus (prior to OPS 1; see General Notes in this SCP for full constraints)
ATVC RPC's: All are required (GO for confirmed inst failure)	YES/GLS at T-31	ET tanking to RLSLS start (T-31)	GNC-39	Confirm inst failure by dropping CNTL bus (prior to OPS 1; see General Notes in this SCP for full constraints)
BODY FLAP CMD's: ENA, UP, DN = 0 (No HOLD, CYCLE or FAIL fault messages allowed) POSN: ±1.85° (28.8 – 39.6%) (each of 4 ducers)	YES/GLS at T-31 YES/GLS at T-31	Post aerosurface slew to RLSLS start (T-31) Post aerosurface slew to RLSLS start (T-31)	GNC-29 GNC-30 GNC-31	No manual capability to drive body flap in OPS 1 Possible structural damage due to improper launch configuration Verify feedbacks during aerosurface slew (tested at T-3 min 55 sec)
DDU (L/R) PWR SUP A,B,C: No Fails AFT: Mission dependent	YES/GLS at T-31 NO	ET tanking to RLSLS start (T-31) N/A	GNC-85 See MEL	Deflect RHC through full range of motion & verify all 9 channels tracking. Loss of BFS engage capability if FBITE is real. No active data except at L-2 Controller and Switch Tests
DEDICATED DISPLAYS HUD's required for night landing	NO	N/A	Append H Sect 04	
ELEVONS POSN: LIB: 4 of 4 = -0.52° to 1.18° LOB: 4 of 4 = -0.36° to 1.34° RIB: 4 of 4 = -0.52° to 1.18° ROB: 4 of 4 = -0.36° to 1.34° (3 of 4 acceptable for confirmed inst failure) Pri ΔP: 4 of 4 = 0 ± 230 psi for each surface Sec ΔP: 4 of 4 = 0 ± 650 psi for each surface (3 of 4 acceptable for confirmed inst failure) Σ of 4 between -440 and +370 psi	YES/GLS at T-31 YES/GLS at T-31 YES/GLS at T-31	Post aerosurface slew (T-3 min) to RLSLS start (T-31) From hydraulic activation (T-5 min) to RLSLS start (T-31) Post aerosurface slew to RLSLS start (T-31) One time verify between slew complete and RLSLS start (T-31)	GNC-22 GNC-25 GNC-23 GNC-24 GNC-24	Confirm inst fail by repeating slew and confirming no channel anomaly and also by comparing FA and OI feedbacks (channel on & off) Possible structural damage if launch in improper configuration Verify feedbacks during aerosurface slew (test at T-3 min 55 sec) Pri ΔP required for load relief RM only in MM 102 Hold at T-31 sec and rerun slew to attempt clear. If clear, proceed, else scrub Confirm inst fail by repeating slew and confirming no channel anomaly
FCS CHANNEL All 4 channels required for all actuators	YES/GLS at T-31	Post APU start to SSME start (T-10). RLSLS monitors SSME ATVC from 90% thrust to T-0	GNC-38	See contingency procedures in LCC

TABLE 1.4-III. - LAUNCH COMMIT CRITERIA (CONT)

SUBSYSTEM	AUTO HOLD	TIME PERIOD	LCC NUMBER	Contingency Procedure / Comments
OMS POSN: LY 5.35° to 6.67° LP 5.14° to 6.16° RY -6.67° to -5.35° RP 5.14° to 6.16°	YES/GLS at T-9 min	Verify prior to GLS start (T-9 min)	GNC-43	Pri & Sec positions must track within 0.25 deg of each other
TVC: 3 of 4 pass gimbal ck (rate > 2.9 deg/sec) Pos ± 0.25° of steady state cmd	No/GNC console	During OMS gimbal check (T-7:30 hr)	GNC-44	The change in drive rate from previous test must be < 1°/sec Can launch with one actuator failed if no-back held on last flight and if selection of that actuator will not cause movement of 1.5° inward or upward
PRL No fails or dilemmas (1 of 2 duzers required, duzer A not in OPS 1 TLM)	YES/GLS at T-10 sec	Hydraulic activation (T-5 min) to SSME start (T-10 sec)	HYD-02	Supply pressure A available as backup on HYD/APU Display (data provided by A transducer)
RHC (L,R) Roll ± 6.8° (28.3%) Pitch ± 5.1° (21.2%) Yaw ± 2.8° (19.6%) AFT: Mission dependent	YES/GLS at T-31 NO	From OPS 1 transition to RLSL start (T-31) N/A	GNC-01 Append H	RM limits applied for LCCs If bias observed, ask crew to make input to verify no scale factor No active data except at L-2 Controller and Switch Tests
RPTA (L,R) All channels within 3.6° (16%) of each other (L & R RPTA mechanically linked)	YES/GLS at T-31	From OPS 1 transition (T-20 min) to RLSL start (T-31)	GNC-03	If bias observed, ask crew to make input to verify no scale factor (RPTA SOP in 304, 305, 602, 603) If 2 RPTA channels fail high prior to MECO, hardover rudder is commanded on an RTLS/TAL when CSS R/Y is selected below M5 No OPS 1 RM
RUDDER POSN: 4 of 4 = 0 ± 0.95° (3 of 4 acceptable for confirmed inst failure) Sec ΔP: 4 of 4 = 0 ± 850 psi (3 of 4 acceptable for confirmed inst failure) Σ of 4 between -440 and +370 psi	YES/GLS = T-5 min (pre APU start) YES/GLS at T-31 YES/GLS at T-31	Verify at this position prior to hyd sys activation and after aero slew to T-31 Post aerosurface slew to RLSL start (T-31) One time verify between slew complete and RLSL start	GNC-26 GNC-28 GNC-27 GNC-27	Confirm inst fail by repeating slew and confirming no channel anomaly and also by comparing FA and OI feedbacks (channel on & off) There is no feedback RM (FDIR or SF) in OPS 1 Verify feedbacks during aerosurface slew (test at T-3 min 55 sec) If outside limit, hold at T-31 and repeat aero slew. If clears, proceed, else scrub Confirm inst fail by repeating slew and confirming no channel anomaly Hold at T-31 and repeat aero slew. If clears, proceed, else scrub
SPEEDBRAKE POSN: 2.45° to 7.55° (2.8% to 8.7%) (3 of 4 acceptable for confirmed inst failure) 4 of 4 < 3° (3.4%) for launch (3 of 4 acceptable for confirmed inst failure) Sec ΔP: 4 of 4 = 0 ± 850 psi (3 of 4 acceptable for confirmed inst failure) Σ of 4 between -440 and +370 psi	YES/GLS = T-5 min (pre APU start) YES/GLS at T-10 sec YES/GLS at T-31 YES/GLS at T-31	Verify at this position prior to hyd sys activation and after aero slew From T-15 sec to SSME start (T-10 sec) Post aerosurface slew to RLSL start (T-31) One time verify between slew complete and RLSL start	GNC-26 GNC-28 GNC-26 GNC-27 GNC-27	Confirm inst fail by repeating slew and confirming no channel anomaly and also by comparing FA and OI feedbacks (channel on & off) Verify feedbacks during aerosurface slew (test at T-3 min 55 sec) Confirm inst fail by repeating slew and confirming no channel anomaly and also by comparing FA and OI feedbacks (channel on & off) If outside limit, hold at T-31 sec and repeat aero slew. If clears, proceed, else scrub

TABLE 1.4-III. - LAUNCH COMMIT CRITERIA (CONT)

SUBSYSTEM	AUTO HOLD	TIME PERIOD	LCC NUMBER	Contingency Procedure / Comments
SBTC (Right Only) 3 of 3 channels req'd for cmd and takeover discrete (cmds must track within 5.3° of each other)	NO/GNC console	One time verify prior to OPS 1 transition (T-20 min)	GNC-04	MDM BITE test 4 required to verify limits on CH B and C Format 42 has all measurements – ask for change if req Manual throttle is req for systems TAL aborts (allows time for OMS dump) L SBTC not functional in OPS 1 No OPS 1 RM
SRB TVC POSN: All actuators must follow gimbal check and return to 0° ± 0.4° (0 ± 0.5 in) Sec ΔP: 4 of 4 = 0 ± 237 psi for each actuator 4 of 4 = 0 ± 990 psi for each actuator (no time to verify instrumentation failure) Σ of 4 between -530 and +460 psi FCS CHANNEL: No Fails	YES/GLS at T-10 sec YES/GLS at T-9 YES/GLS at T-10 YES/GLS at T-10 YES/GLS at T-10	During gimbal test (- T-21 to T-17) One time verify prior to GLS start (T-9) One time verify between slew complete and SSME start One time verify between slew complete and SSME start From start of SRB gimbal test to SSME start (T-10)	BTV-14 BTV-11 BTV-13 BTV-13 BTV-12	
SSME TVC (IGN POSN) CP -0.32° ± 0.8° (-1.12°, 0.48°) CY +0.17° ± 0.8° (-0.43°, 0.77°) LP +0.32° ± 0.8° (-0.48°, 1.12°) LY +0.21° ± 0.8° (-0.39°, 0.81°) RP -0.32° ± 0.8° (-1.12°, 0.48°) RY +0.21° ± 0.8° (-0.39°, 0.81°) (5 of 6 acceptable for confirmed inst failure) Sec ΔP: 4 of 4 = 0 ± 1050 psi for each actuator (3 of 4 acceptable for confirmed inst failure) Σ of 4 between -440 and +370 psi	YES/GLS at T-31 YES/GLS at T-31 YES/GLS at T-31	Post gimbal profile to RLSLS start (T-31) Post gimbal profile to RLSLS start (T-31) One time verify between slew complete and RLSLS start	GNC-40 GNC-41 GNC-41	For inst failure, use driver current outputs and Sec ΔPs to verify proper operation during slew (eight additional measurements) RSLs will move LY and RY to launch position after SSME thrust > 90% If outside limits, hold at T-31 and repeat SSME slew. If clears, proceed, else scrub Redlines valid at actuator positions of 0.0 ± 2°
SWITCHES Refer to MEL Display Sw Default: Go for any/all switches green/dotted	NO NO	Monitor during prelaunch	Append H None	Refer to fault summary message, Appendix E
THC (Left) 3 of 3 contacts for ± X, ± Z 2 of 3 contacts for ± Y AFT: Mission dependent	YES/GLS at T-31 NO	From OPS 1 transition to RLSLS start (T-31) N/A	GNC-02 None	THC needed to backup or terminate ET sep sequence and for loss of forward RCS sep +/- Z contacts to backup ET sep +/- X contacts to backup OMS Switch RM in all OPS No active data except at L-2 Controller and Switch Tests

TABLE 1.4-III. - LAUNCH COMMIT CRITERIA (CONCLUDED)

GENERAL NOTES

In the event of off-nominal LRU power indications, GNC Launch Commit Criteria (LCC) 08, 09, 32, 39, and 57 drop a control bus to confirm instrumentation failure. The following constraints for control bus deactivation during a launch countdown are laid out in OMRS S00GEN.780, between ET tanking and T-31 seconds.

1. Control bus drops will only be performed when the vehicle is in a quiescent state. No other testing or hardware configurations will be performed during control bus drop operations.
2. CNTL Bus drops will NOT be performed during the following events:
 - a. ET cryogenic load operations up to LH2 and LO2 stable replenish
 - b. ET cryogenic drain operations
 - c. Vehicle flight software is in OPS mode 101
3. SCO or ASP is required for orbiter deconfiguration/reconfiguration to support a control bus drop. Side hatch will be open.
4. All other testing and configuration changes including GSE, facilities and payloads, will be suspended during control bus drops.

SENSOR CONSOLE

- A. When IMU's are moded from standby to operate, note that all gimbal resolver angles go to caged positions. Since the IMU drives the sine of the resolver angle to 0.0, the caged gimbal position can be zero or 180 degrees for the outer roll and azimuth gimbal (pitch and inner roll can not physically move to 180°). This can occur when the gimbal is near 180° when the caging process begins. This occurred during STS-115 pre-launch operations on the outer roll gimbal of IMU 2.

IMU BITE logic is active in all OPS modes in PASS, including OPS 9, anytime an IMU is in the OPERATE mode. No provision for crew annunciation of an IMU BITE is made in OPS 9, but the BITE parameters are available on downlist for ground monitoring.

- B. During the IMU preflight calibration, gimbal repositioning can be tracked; however, an interim error could not be detected prior to test completion. At that time, KSC will declare the pass or fail status of the calibration after comparing various IMU output parameters against predetermined "C" criteria (explained in SCP 2.15). Watchdog timer BITEs may annunciate during cal, these are not a real BITEs. This is a limitation of the BITE comp while in OPS9.
- C. Failure of the preflight alignment should cause a launch hold or scrub; however, that decision will likely depend upon the actual degree of violation above predetermined failure criteria (reference SCP 2.15), as well as IMU performance after platform release (T-4 minutes).

- D. At L-0:30 hr, the OPS 9/1 transition occurs; at this time the IMU's are continuously being aligned (GC_ALIGN1). Real time plots are started as soon as reliable data is visible (after T-4 minutes). The plots show the gyro deltas that are also being displayed in digital form on the SENSORS ASCENT/ENTRY display.

The purpose of these plots is twofold: (1) the digital display of IMU gyro drift rates is not reliable until it has run for a substantial length of time (20 to 30 min), whereas the plots allow detection of the trend of a gyro drift; (2) the plots clearly indicate the visual evaluation, while the digital comps will swallow the noise input. The noise input can dominate the computations early in the process. The determination of a satisfactory drift rate will depend on the slope of each plateau without regard for the resolver noise effect, as opposed to the average slope from the plot start, which is what the digital display output represents. Flight Rule A8-57 specifies restrictions on acceptable launch hold times based upon the 3-sigma guidelines.

- E. The IMU REFSMMAT's must be transferred to the GCS following platform release (T-4 minutes). Transfer is accomplished via DNAV using GNC/Realtime/Send Launch REFSMMAT/OV10x. REFSMMATs should match up to the last digit or two. Differences are caused by roundoff.
- F. If a failure of a TACAN, MSBLS, or RA unit occurs early in the countdown, (e.g., during self-test), the failed unit should be replaced. We should launch with a full complement of LRU's whenever possible. Thus, in the event of future failures in the LRU's, a launch scrub could be avoided. Any LRU failure during self-test is an OMRSD violation and requires a waiver to proceed.
- G. TACAN system health can be monitored prelaunch by viewing the actual range and bearing data. These values will show the range and bearing from the launch pad to the selected ground station; either KSC (primary) or Patrick Air Force Base (secondary). This data is listed in table 1.4-IV.

TABLE 1.4-IV. - TACAN PAD TO GROUND STATION DATA

From		To		
		KSC (59Y)	PAFB (97X)	OMN (73X)
Pad A	Range	4.96 nm	22.3 nm	49.6 nm
	Bearing	282.3°	181.8°	327.5°
Pad B	Range	3.96 nm	23.4 nm	48.2 NM
	Bearing	269.1°	179.6°	327.6°

- H. During an IMU Attitude Determination (ATT DET), the accelerometers are used to determine the estimated acceleration vector (THETA) and the estimated drift vector (ETD). These two vectors are normally non-zero, but under the following conditions will be equal to zero.
1. If the velocity input data is constant due to a commfault or some hardware failure, then ETD will be zero.
 2. If the Z axis of an IMU is perfectly aligned with the UP axis (of the north, west, up reference frame), then the resultant acceleration will equal zero since the software subtracts 1 g from the Z sensed acceleration. This will result in THETA being a zero vector.

When these zero vectors are unitized by the OPS 9 software, a GPC error (Group 4 Code 28) will be generated. If this error occurs, ATT DET can be repeated after confirming the above scenario was the cause and that it has been corrected. ATT DET must be redone before continuing any IMU calibration. Reference PASS User Note for DR 35322, September 1987.

- I. In OPS 1, the TACAN SOP is not active, but the PASS GPC's are transmitting the TACAN Control Word to the LRU's. This is necessary to protect for an RTLS abort in which TACAN's will be used for the entry phase. Because the SOP is not running, the control word will contain all zeros. This will cause certain TACAN parameters on telemetry to be misleading (e.g. it may be transmitting on channel 97 while the downlist shows it in receive only on channel 0; refer to Figure 1.3-14 of SCP 1.3 for the TACAN control word description). The TACAN's will reject the control word because the sync bit is incorrect and will thus remain in the same configuration in OPS 1 as they were in OPS 9. Reference PASS User Note for DR 25108, September 1987.
- J. The Sensor operator is responsible for performing numerous tasks during the prelaunch timeframe. The checklist in Table 1.4-V and IRAMS calibration terms listed on the two pages immediately preceding the table are provided to assist the SENSORS operator in performing these duties.
- K. Per LCC GNC-57, 5 of the 6 IMU RPC's must indicate ON for launch to ensure IMU two-fault tolerance to two main bus failures. However, for a confirmed instrumentation failure, an RPC can be considered good (i.e. not functionally failed but loss of insight only). Instrumentation failure verification may require a control bus drop and verification that the IMU did not bypass. If a bypass does occur, a recovery of the IMU from the loss of power will be required before launch, which would take approximately 1 hour and 35 minutes to

complete. As such, two “no-later-than” recovery options are available to recover a caged IMU resulting from a control bus drop:

1. Option 1 is to perform the control bus drop no later than T – 1 hour and 45 minutes. In this case, any caged IMU would be fully recovered prior to resuming the count at T - 20 minutes and preserving the subsequent OPS 1 transition. This would be the preferred option for dropping a control bus for any single IMU RPC loss indication as it will have minimal impact on the launch timeline.
2. Option 2 is to perform the control bus drop no later than T – 55 minutes. This is the absolute no-later-than time that any control bus drop can be performed such that a caged IMU can be successfully recovered in time for launch. Assuming a 40 minute hold at T – 9 minutes, this would result in no more than 15 minutes between IMU recovery and launch. It is recommended that this option be used only in cases where two IMU RPC’s indicated OFF on separate IMU’s. This condition would provide a No-Go constraint for launch per GNC-57 unless one of the two RPC indications could be verified to be an instrumentation failure only.

This assessment assumes an ISS launch timeline with a 40 minute hold at T – 9 minutes with the following assumptions for IMU recovery duration:

1. Maximum allowed power off period is 10 minutes.
2. Platform is ready (Temp Ready On) for Operate within 5 minutes of power restoration.
3. Operate Warm-up Time required is 30 minutes maximum (3 x 10 minutes).
4. Activities required:
 - a. Platform Positioning – 5 minutes;
 - b. Attitude Determination – 4 minutes;
 - c. Pre-Flight Alignment – 38 minutes.
5. Significant time in GA-1 mode is not required.
6. A total overhead of 6 minutes is required for the Console Operator to work through the activities.

The parameters used to build the **IMU GYRO DRIFT BIAS LOAD** (DSM 43101) are:

<u>IMU AXIS</u>	<u>MSID</u>	<u>IRAMS TERM</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
IMU 1X	V99R2560C	DFX	X-GYRO REST D/H	deg/hr
IMU 1Y	V99R2563C	DFY	Y-GYRO REST D/H	deg/hr
IMU 1Z	V99R2566C	DFZ	Z-GYRO REST D/H	deg/hr
IMU 2X	V99R2561C	DFX	X-GYRO REST D/H	deg/hr
IMU 2Y	V99R2564C	DFY	Y-GYRO REST D/H	deg/hr
IMU 2Z	V99R2567C	DFZ	Z-GYRO REST D/H	deg/hr
IMU 3X	V99R2562C	DFX	X-GYRO REST D/H	deg/hr
IMU 3Y	V99R2565C	DFY	Y-GYRO REST D/H	deg/hr
IMU 3Z	V99R2568C	DFZ	Z-GYRO REST D/H	deg/hr

The parameters used to build the **IMU ACCEL BIAS LOAD** (DSM 43201) are:

<u>IMU AXIS</u>	<u>MSID</u>	<u>IRAMS TERM</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
IMU 1X	V99G2530C	KOX	X-ACC BIAS LO UG	μg
IMU 1Y	V99G2533C	KOY	Y-ACC BIAS LO UG	μg
IMU 1Z	V99G2536C	KOZ	Z-ACC BIAS LO UG	μg
IMU 2X	V99G2531C	KOX	X-ACC BIAS LO UG	μg
IMU 2Y	V99G2534C	KOY	Y-ACC BIAS LO UG	μg
IMU 2Z	V99G2537C	KOZ	Z-ACC BIAS LO UG	μg
IMU 3X	V99G2532C	KOX	X-ACC BIAS LO UG	μg
IMU 3Y	V99G2535C	KOY	Y-ACC BIAS LO UG	μg
IMU 3Z	V99G2538C	KOZ	Z-ACC BIAS LO UG	μg

- After the loads are manually built, store them in the following directory:
/users/gnc/Data/SSPXXX/MEDS. NOTE: All sim data should be removed from this directory prior to launch.
- Monitor the onboard accel bias and gyro drift bias values on downlist on **IMU SUMMARY** Display at the bottom left for accel bias and bottom right for gyro drift bias, respectively. NOTE: The gyro biases are rounded on the display, and the accel biases are truncated. To see the full precision middle click on the MSK display.
- DSM 43101 and DSM 43201 are built so that the calibration data from launch can be uplinked to the vehicle to return the IMUs to their prelaunch compensation values. These commands are also used as the basis to build further commands. Because of this it is desirable to have enough precision in the command to accurately return the IMU compensation to the prelaunch value. The best way to do this would be to type in all of the digits from the prelaunch cal. However, typing in this many digits could cause a typographical error so it was decided that 4 decimal places would be adequate.

EXAMPLE OF IRAMS OUTPUT USING IMU 1 CALIBRATION TERMS

Date 01/22/98 PREFLIGHT CAL LONG TERM DATA PAGE 1 OF 3
VEH: 105 STS: 089 TEST: 0007FSW: 0901 SITE: 39A

FD	DESCRIPTION	DATA	ERROR	SIGMA
---	-----	-----	-----	-----
IMU 1	-- S/N = 212			
V99A2520C	KIX X-ACC SF LO UG/G	-59.706	1.852	0.03
V99A2523C	KIY Y-ACC SF LO UG/G	-38.297	-0.283	-0.00
V99A2526C	KIZ Z-ACC SF LO UG/G	-39.594	-0.450	-0.01
V99G2530C	KOXX-ACC BIAS LO UG/G	-961.507	0.395	0.01
V99G2533C	KOYY-ACC BIAS LO UG/G	-1071.330	0.913	0.02
V99G2536C	KOZZ-ACC BIAS LO UG/G	-836.264	-5.996	-0.12
V99A2681C	KIXH X-ACC SF HI UG/G	-63.305	-1.576	-0.03
V99A2684C	KIYH Y-ACC SF HI UG/G	-38.572	-4.827	-0.08
V99A2687C	KIZH Z-ACC SF HI UG/G	-37.583	-4.418	0.07
V99G2670C	KOXH X-ACC BIAS HI UG	-955.721	-3.531	-0.07
V99G2673C	KOYH Y-ACC BIAS HI UG	-1070.337	5.999	0.12
V99G2676C	KOZH Z-ACC BIAS HI UG	-831.474	-4.759	-0.10
V99R2560C	DFX X-GYRO REST D/H	-0.0683196	0.0025175	0.42
V99R2563C	DFY Y-GYRO REST D/H	0.0851265	0.0017531	0.29
V99R2566C	DFZ Z-GYRO REST D/H	-0.0043340	0.0007455	0.12
V99U2576C	DSX X-GY SA MUB D/H/G	0.0092186	0.0008341	0.06
V99U2579C	DSZ Z-GY SA MUB D/H/G	0.0000244	-0.0006156	-0.04
V99U2582C	DOZZ-GY OA MUB D/H/G	-0.0034232	0.0012429	0.08
V99U5952C	DFR RED GYRO BIAS D/H	0.0342159	-0.0127828	-0.26
V99U5955C	DIR R-GY IA MUB D/H/G	0.0068201	0.0251796	0.50
V99U5958C	DORR-GY OA MUB D/H/G	0.0032860	0.0121370	0.24
V99U5961C	DSRR-GY SA MUB D/H/G	0.0247693	0.0254208	0.51
V99U5870C	DDFR RGM DELTA RES D/H	-0.0875290	-0.0185290	-0.37
V99U5964C	KXR RED GY-X SF NULL	0.90115900	-0.00085970	NOT EVALUATED
V99U5967C	KYR RED GY-Y SF NULL	0.43418970	-0.00066750	NOT EVALUATED
V99U5970C	KZR RED GY-Z SF NULL	-0.00320110	-0.00048810	NOT EVALUATED
V99G2500C	KTX X-GY TOR SF NULL	0.99995560	0.00000000	0.00
V99G2503C	KTY Y-GY TOR SF NULL	0.99993990	0.00000000	0.00
V99G2506C	KTZ Z-GY TOR SF NULL	1.00006290	0.00000000	0.00
V99A2510C	KSX X-ACC SYM UG/G	30.891525	0.000000	0.00
V99A2513C	KSY Y-ACC SYM UG/G	-26.333084	0.000000	0.00
V99A2516C	KSZ Z-ACC SYM UG/G	14.636058	0.000000	0.00
V99U2570C	DIX X-GY IA MUB D/H/G	0.01065270	0.000000	0.00
V99U2573C	DIZ Z-GY IA MUB D/H/G	0.00492350	0.000000	0.00
V99H2540C	DELTYX Y-ACC MALN-X S	-2.75546	0.000000	0.00
V99H2543C	DELTZX Z-ACC MALN-X S	-4.98245	0.000000	0.00
V99H2546C	DELTZY Z-ACC MALN-Y S	2.56680	0.000000	0.00
V99H2590C	BXY X-GYRO MALN-Y S	0.00123	0.000000	0.00
V99H2593C	BXZ X-GYRO MALN-Z S	-2.47346	0.000000	0.00
V99H2596C	BYX Y-GYRO MALN-X S	2.18002	0.000000	0.00
V99H2599C	BYZ Y-GYRO MALN-Z S	-0.25712	0.000000	0.00
V99H2602C	BZX Z-GYRO MALN-X S	1.96830	0.000000	0.00
V99H2605C	BZY Z-GYRO MALN-Y S	-3.63263	0.000000	0.00

TABLE 4.1-V - SENSORS PRELAUNCH CHECKLIST

Flight_____ Vehicle_____ Operator_____

Date_____ GMT_____ Team_____

- _____ VERIFY ROLL-TO-ROLL MATRICES (prior to launch)
- _____ VERIFY ALL BOOKS ARE UPDATED
- _____ SEND ROLL-TO-ROLL MATRICES TO ISP, & ODRC (ISPVALUE, Paper copy)
- _____ HARDCOPY ROLL-TO-ROLLS (REFS/ROLLS/QUATS DISPLAY)
- _____ PRE-FLIGHT CAL COMPLETE
- _____ ATT DET (5 MIN)
- _____ PRE-FLIGHT ALIGN (38 MIN)
- _____ ALIGN MAINTENANCE
- _____ OBTAIN IMU PRE-FLIGHT CAL RESULTS (MOIR/IMU)
- _____ OBTAIN GPS PRE-FLIGHT Delta Time Uplink information from ONAV/GPO (Nav018B product)
- _____ CHECK GYRO AND ACCEL BIASES ON IMU SUMMARY
- _____ SEND THE NEW GYRO AND ACCEL BIASES FROM THE PRE-FLIGHT CAL TO THE GCS AND STORE ON WORKSTATION
- _____ VERIFY NEW GYRO AND ACCEL BIASES ARE CORRECT IN GCS
- _____ HARDCOPY IMU SUMMARY & IMU GYRO BIAS & ACCELEROMETER BIAS DISPLAYS (DSM 43101 & 43201)
- _____ NAVAIDS ACTIVATION
- _____ CHECK TACANS ARE ON AND VERIFY CORRECT BRG AND RNG WITH SCP
- _____ VERIFY NO LCC VIOLATIONS (USE SCP)
- _____ FINAL ATT DET
- _____ FINAL PRE-FLIGHT ALIGN (38 MIN)
- _____ CONTINUOUS ALIGN (UNTIL T-4 MIN)
- _____ RE-VERIFY NO LCC VIOLATIONS
- _____ OPS-1 TRANSITION (TAKE HARDCOPY OF ALL DATA)
- _____ REVIEW RUNWAYS AND WINDS AT KSC AND TAL SITES
- _____ GET MER/IMU IRAMS FINAL GO FOR LAUNCH
- _____ T-4 MIN (TAKE HARDCOPY OF ALL DATA) IMUs IN FREE INERTIAL
- _____ LOAD REFSMMATS TO THE GCS
- _____ VERIFY REFSMMATS IN GCS (COMPARE to the REFS/ROLLS/QUATS DISPLAY)
- _____ LIFT-OFF (RGA's are Go CALL)
- _____ HARD COPY the REFS/ROLLS/QUATS DISPLAY & DSM 43001
- _____ LOG GYRO & ACCEL BIAS IN IMU LOG
- _____ NORMALIZE REFSMMATS

CONTROL CONSOLE

- A. The following data should be available at the console for this flight
- Copy of GNC post flight reports.
 - HAL names and slot locations for the variable downlist requirements.
- B. The prelaunch OMS gimbal profile will be performed at approximately T-7:30 hours. The profile is completely different from the in-flight OMS gimbal. The prelaunch profile is an automated ground procedure under KSC control. It drives each actuator one at a time using a single enable discrete (ENABLE 2 first, followed by ENABLE 1) to ensure that full redundancy is available. The procedure will automatically stop after completing a RETRACT or EXTEND when a problem is detected, such as an actuator failure to drive. KSC personnel can then, through a manual action, make the profile continue its normal procedure. KSC can also perform manual command for troubleshooting. When the procedure is complete, the control operator should verify that all drive rates and positions were as expected. The following table shows the order in which the actuators will be driven and can be used for real-time monitoring and post-gimbal check annotation.

ENABLE DISCRETE	DRIVE RANGE (COMPENSATED) (DEGREES)	ACTUATOR DIRECTION
L SEC EN 2	-6.01	L SEC YAW RET
L SEC EN 1	+6.01	L SEC YAW EXT
L PRI EN 2	-6.01	L PRI YAW RET
L PRI EN 1	+6.01	L PRI YAW EXT
L SEC EN 2	-5.80	L SEC PIT RET
L SEC EN 1	+5.80	L SEC PIT EXT
L PRI EN 2	-5.80	L PRI PIT RET
L PRI EN 1	+5.80	L PRI PIT EXT
R SEC EN 2	+6.01	R SEC YAW RET
R SEC EN 1	-6.01	R SEC YAW EXT
R PRI EN 2	+6.01	R PRI YAW RET
R PRI EN 1	-6.01	R PRI YAW EXT
R SEC EN 2	-5.80	R SEC PIT RET
R SEC EN 1	+5.80	R SEC PIT EXT
R PRI EN 2	-5.80	R PRI PIT RET
R PRI EN 1	+5.80	R PRI PIT EXT

- The commands are ramped at about 5.6 deg/sec rate.
- The enable discrettes are on for 4 seconds, then off for 4 seconds.
The entire check should take about 124 seconds.
- Reference OMI No.-S0007, Vol. 4, Seq. 43.

KSC OPERATIONS

The Kennedy Space Center launch operations team is organized and operates in a very different manner than that of the Houston MCC. During launch operations, two firing rooms are used. The Prime Firing Room (PFR) is responsible for overseeing / executing launch preparation operations and addressing any launch constraint violations. The Backup Firing Room (BFR) acts in support of the Prime Firing Room. The BFR, typically consists of a “brain trust” of engineers which includes high level management. Besides providing technical knowledge, the BFR acts as funnel, collecting any “outside” inputs that need to be communicated to the Prime Firing Room; this includes inputs from Houston-GNC. Figure 4.1-1 provides a graphical reference of the following discussion and may be useful while reading.

The Prime Systems Engineer (PSE) or Keyboard Operators, which report to the NASA Test Director (NTD) are located in the Prime Firing Room. The systems monitored by the Houston-GNC team are distributed across four PSEs at KSC and include: Flight Control, GNC, Console NavAids Systems Engineer (CNSE) (or Nav Aids), and Hyd. The PSEs (or Keyboard Operators) in the Prime Firing Room are USA personnel which are flanked by a NASA counterpart. Also, accompanying the Keyboard Operators in the PFR are Senior System Engineers (SSEs). The SSEs provide technical support to the Keyboard Operators and also act as a go-between for the Keyboard Operators and inputs from the Backup Firing Room.

The Backup Firing Room consists of support engineers for each of the Prime Firing Room PSE position. These positions are distinguished from the prime operators by placing the acronym “ETL” (Engineering Team Leads) after the associated designation (i.e. Flight Control ETL or GNC ETL). **All communications from Houston-GNC to our KSC counterparts should be coordinated through the ETLs in the Backup Firing Room.** Addressing the Prime Firing Room - Prime Systems Engineer (PSE), can be a counterproductive distraction during times of critical operation. The ETLs also do not normally directly interface with the PSEs. Instead the ETLs discuss trouble shooting techniques, waivers and other required information with the SSEs in the Prime Firing Room (PFR), who then filter it to the PSE.

Besides providing technical support to the Prime Firing Room Operators, the ETLs also support and provide inputs to the Chief Engineers which are also assembled in the BFR. The Chief Engineers can then provide inputs to the Shuttle Program Engineer (SPE), NTD, or the Launch Director. The SPE acts as a coordinator, gathering the appropriate personnel to address any issue. This can include Keyboard Operators, Chief Engineer, ETLs, MER, Houston-GNC and others. Discussion by Houston-GNC on the SPE loops are typically initiated on request by SPE or at the direction of the Houston-Flight Director. Houston-GNC’s primary point of input to KSC pre-launch operations is the ETLs in the BFR.

In summary, the Houston GNC team has several avenues that can be used to support launch operations at KSC. Since Houston-Flight (Flight Director) has a direct input to the top level decision tree during launch operations, keeping Houston-Flight updated is of critical importance. **The best way for Houston-GNC to provide support in a coordinated effort with our KSC counterparts is by communicating through the ETLs in the Backup Firing Room (BFR). At times and when requested, Houston-GNC may be required to provide inputs to the Shuttle Program Engineer (SPE).**

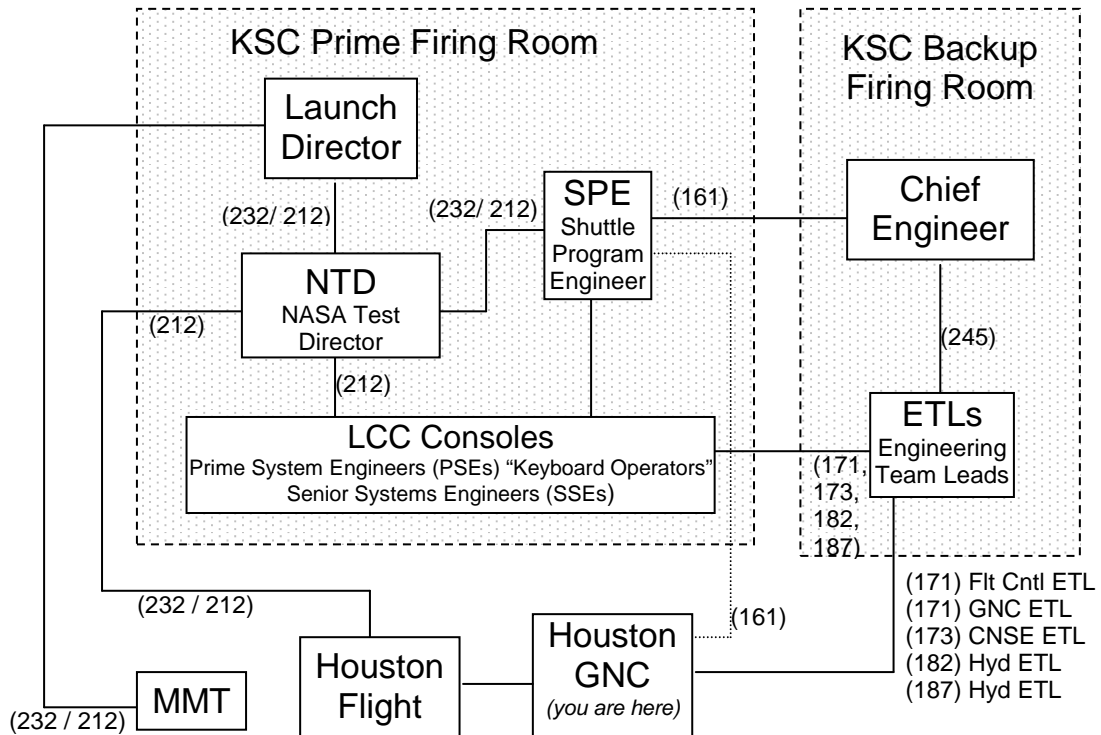


Figure 4.1-1. Figure 4.1-1 provides a simplified view of comm loop interface during launch operations. This table is intended to serve as a guideline specifically from the Houston-GNC point of view. It should be noted that several of the loops mentioned are shared with and used by other disciplines.

What follows is a breakdown of the GNC systems and the associated KSC counterpart for that system. It is important to realize that the KSC loops mentioned below are shared with other systems not related to GNC. Loop traffic can be very congested on launch day and should be limited to essential communications, particularly as the launch time approaches.

	Systems	KSC ETL counterpart	ETL Loop
C S O Y N S T T R E O M L S	ASA, ATVC (SSME &SRB), Elevons, Rud, SB, RHC,THC,RPTA,DDU OMS TVC, RJDs, FCS mode sw, DAP panel,Trim sw	Flt Cntl ETL	171
	Actuators (Elevon, SSME) SSME Switching Valves, APUs, Circ Pump, MPS TVC Iso Vlv, Nose Wheel Steering	Hyd ETL (Orb)	182
	HPU, SRB Switching Valves, SRB Actuators	Hyd ETL (SRB)	187
S S E Y N S S T O E R M S S	TACANS, GPS, MLS, RA	CNSE ETL (Nav Aids)	173
	IMU, ADTA, ST	GNC ETL	171
	RGA, AA	Flt Cntl ETL	171

TABLE 4.1-VI. TABLE 4.1-VI PRESENTS A BREAKDOWN OF THE GNC SYSTEMS AND THE ASSOCIATED KSC ETL COUNTERPART FOR THAT SYSTEM ALONG WITH THE COMM LOOP THAT SHOULD BE USED TO CONTACT KSC.

Besides the differences in operational organization, KSC facility capabilities differ considerably from that of the Houston MCC. The following information is presented to provide insight as to those differences. The KSC workstation comm system can only monitor 4 loops at any given time. Many of the loops are also shared with other disciplines. This at times leads to some conversation being held over phone lines. Each console has LCC monitoring software specific to that console. Backup consoles are available in the event of a console crash. Backup consoles may not always provide full capability, but combined with the monitoring tools in the BFR, most, if not all monitoring capability should be recovered. KSC consoles can plot a maximum of 6 parameters per console simultaneously. On-console training at KSC is quite a bit less frequent than in Houston. S0044 simulations are typically scheduled every 30 to 45 days, and one Terminal Countdown Test (TCDT) S0017, is scheduled per vehicle flow. Our KSC counterparts devote a large majority of their time to vehicle processing, rather than console training.

TITLE

FCS CHECKOUT MONITORING

PURPOSE

The purpose of this SCP is to allow the controllers to easily follow the FCS C/O procedures and have rationale available for every step to aid in the monitoring of systems and crew. For a more in-depth breakdown of the FCS C/O part 1, see SCP 1.6 CONTROL FCS CHECKOUT MONITORING.

Prior to the start of FCS Checkout, start the VCR function on one of the GNC workstations so that the data can be captured for quick playback if required. Otherwise, ODRC data can be gathered in a less timely fashion. Use CRANS and digital displays to verify that all entry LRUs are powered, since all of these units will be used in FCS Checkout.

PROCEDURE

FCS CHECKOUT

<p><u>DISPLAY/DPS CONFIG</u> RGA (four) - ON cb MNA, B, C ADTA (four) -cl cb MNA, B ACCEL 1,2 (two) -cl ✓DDU L (two) -cl MNB, C DDU R (two) -cl</p>	<p>✓all RGA SMRDs clear ✓all power feedbacks on CRANS and/or high density displays ✓no L or R DDU BITES ✓FLT CNTLR PWR - OFF</p>
<p>----- If APU will be used: ASA (four) - ON</p>	<p>----- ✓all power feedbacks on CRANS and/or high density displays ASAs must be on prior to the OPS 8 transition so that the proper position feedbacks are snap shot on the transition. The commands are then set equal to the selected feedback (uncalibrated voltage values, i.e. 0 volts = -7.5° for elevons, and 0 volts = 45 percent for speedbrake) multiplied by a command scale factor. For example: SB cmd = SB sel fbk * 0.966, RUD cmd = RUD sel pos fbk * 1.000, and ELEV cmd = ELEV sel pos fbk * 0.880. These offset commands allow the SB to be relaxed from the overclosed position, and allow the elevons to be commanded slightly off the hardstops in case a circ pump had driven them there. If for some reason an ASA does not come on, make sure that at least 2 of ASAs 1, 2, and 3 are powered so that the proper feedbacks will be read. The nominal selection filter will determine the selected feedbacks (i.e. MVS 1, 2, 3 - then use CH 4 for comm faults).</p>
<p>----- If circ pump will be used: ✓ASA (four) - OFF</p>	<p>----- ✓all power feedbacks on CRANS and/or high density displays Leaving the ASAs off for the circ pump checkout, configures the position feedbacks to the 0 volt values for the OPS 8 transition snapshot. This will set the commands to the 0 volt value, which will be required later in the procedure to prevent inadvertant AERO DRIVE messages. Therefore, these need to be off prior to the OPS 8 transition.</p>
<p>----- ACCEL 3,4 (two) - ON</p>	<p>----- ✓all power feedbacks on CRANS and/or high density displays</p>
<p>----- BRAKES (three) - OFF ANTISKID - ON</p>	<p>----- N/A for GNC</p>

<p>ATVC (four) - ON</p>	<p>✓all power feedbacks on CRANS and/or high density displays</p> <p>Since the 4 ATVCs are powered and an APU is about to be started, check to see that the MPS TVC isol valves are closed. If they are open, verify that there are no 2° command/position deltas on the main engines. If they are within 2°, the MPS TVC isol valves can remain open. However, if there is a step constraint violation, the MPS TVC isol valves must be closed when the APU is in low press, prior to taking it to norm press. APU 1 can supply pressure to the center and left engines. APU 2 can supply pressure to the left and right engines. APU 3 can supply pressure to the center and the right engine. If for any reason, an MPS TVC isol valve is stuck open AND there is a 2° step constraint violation on an main engine actuator, the APUs that supply hydraulic pressure to that actuator cannot be used for FCS C/O, unless it is performed in low press.</p>
<p>TACAN MODE (three) - GPC</p> <p>RADAR ALTM (two) - ON MLS (three) - ON</p>	<p>✓all power feedbacks on CRANS and/or high density displays</p> <p>The GPC position on the TACANs power the units. The TACANs are powered on here so that they will have 15 minutes to warm up before they are tested. The 15 minute warm up time is for the old Gould TACANs. The new Collins units will warm up with in minutes so they could be delay if it were required. For consistency and simplicity, all TACANs are powered up here.</p> <p>The ADTA and MLS units should be powered prior to going into OPS 8 so that unnecessary GPC I/O error messages are not annunciated. These are also called out in the G2 to G8 TRANSITION procedure. If any of these fail off, it is still OK to perform the OPS 8 transition. DPS should be told of the problem so that they can expect some I/O errors.</p>
<p>INST PWR - FLT INST PWR - ON TRIM PNL (two) - ON HUD PWR (two) - ON</p>	<p>✓all power feedbacks on CRANS and/or ELOG</p>
<p>HSIs: ✓Off flag - not visible ADI: ✓Error needles & Rate pointers - visible</p>	<p>The HSI and ADI flags are crew observation only.</p>
<p>✓FCS CH (four) - AUTO</p>	<p>✓all FCS CH feedbacks on CRANS and/or high density displays</p> <p>If any of the FCS channels are OFF, they need to be taken to AUTO prior to the OPS 8 transition. This is required to assure that the proper aerosurface positions are snapshot on the OPS 8 transition. If any of the FCS channels are in OVERRIDE, the proper position feedbacks will be snapshot. However, the remainder of the FCS checkout procedure is assuming that the FCS channel switches are in AUTO.</p>
<p>✓DAP: A1/AUTO/VERN</p>	<p>DAP A1 is the generic orbit DAP. A1 specifically is not required. Any DAP with a 1° attitude deadband on verniers is OK. Vernier jets can control the vehicle with an APU running. However, do not use tight attitude or rate deadbands because the APU venting will cause an increase in jet firings. Any of the ALT DAPs and PRI DAPs are acceptable. Caution should be taken and engineering judgment should be used if an ALT DAP with a long delay time is used. This would be a very off nominal case.</p>
<p>Perform G2 to G8 TRANSITION (DPS), then:</p>	<p>The G2 to G8 TRANSITION procedure is in the DPS section of the ORB OPS CL. One thing to note about this transition is that all of the aerosurface positions are snapshot and the commands are set close to those values to prevent a 2° step difference from occurring which could damage the actuators when an APU is started.</p> <p>This procedure will have the proper TFLs loaded to provide GNC high data rate. If this is not the case, INCO can have the proper TFLs loaded.</p>
<p>If using a circ pump for Part 1: FCS CH 2,3 - OFF ASA (four) - ON Goto step 7.b.</p>	<p>✓all FCS CH feedbacks on CRANS and/or high density displays</p> <p>If a circ pump is used for FCS C/O, the aerosurface commands need to be properly configured for the checkout. This is done by turning off 2 of the first 3 FCS channels. The aerosurface position feedback selection filter MVS's channels 1, 2, and 3.</p>

ON-ORBIT FCS CHECKOUT, PART 1

NOTE

Only one APU will be used for FCS C/O. If APU does not start or MCC advises abbreviated actuator check, circ pump will be used. Selection of APU or circ pump will be made real time by MCC.

NOTE

Any previously failed actuator channel should be bypassed via ITEM 21 on FCS/DED DIS C/O display prior to APU start.

Flight rules allow one start on one of the APUs. If no joy, a circ pump will be used for the secondary actuator check. The procedure will have the crew perform a G8 to G2 transition, power off the ASAs, and then transition back to G8. The loss of an APU is MDF. If for some reason a circ pump is not available, the secondary actuator check can be performed after the D/O burn using the remaining APUs. However, it is prudent to do it in OPS 8 with a circ pump since there is plenty of time to perform the tasks.

Previously failed aerosurface actuators need to be manually bypassed since the bypassed actuators are reset with the power cycle of the ASAs. There is no manual bypass capability for the main engine actuators. Previously failed main engine actuators are not of concern, especially since the MPS TVC isol valves are closed. The aerosurface manual bypasses can be confirmed on the Control Entry display.

1. FCS C/O PREP

2. APU PRESTART

Inform MCC: READY FOR APU START
Wait for MCC GO

✓all power feedbacks on CRANS and/or ELOG, and verify commands and positions on the high density displays.

The following constraints must be met prior to APU start:

- RIB, ROB, LIB, LOB, SB, RUD positions must be within 2° of the commanded position (Note - there is the potential to violate the 2° constraint on the elevons, when they are at or near their hardstops. This will not be a problem, since the APUs are brought up in low press. However, the 2° constraint must be strictly adhered to with the speedbrake and rudder, since these surfaces will not move under low pressure.)
- ASA (four) - ON
- ATVC (four) - ON
- FCS CH (four) - AUTO (if any are OFF, verify bypass indications and good command/position deltas on the other channels)

GNC → FLT: GO (NO GO) for APU start

3. APU START

✓APU hydraulic pressures (control entry display):
~900 psi = low press
~3000 psi = norm press

✓all switching valves move to the proper positions (CRANS)

4. AEROSURFACE DRIVE

SURF DR START - ITEM 10 EXEC (*)
Verify all surfaces cycling for 30 sec

POS ↓ may be indicated until HYD SYS is warm

- * If FCS CH failure (↓ port status), *
- * reset affected FCS CH: *
- * FCS CH - ORIDE, then *
- * - AUTO *

After 30 sec of aerosurface drive,
SURF DR STOP - ITEM 11 EXEC (*)
✓Surfaces not moving

The following will drive the aerosurfaces in order to warm up the hydraulic fluids.

✓all aerosurfaces driving in both directions (control entry display)
✓secondary delta P's on digitals and RTPLOT for potential bypasses

There is a potential for a port to bypass with the cold hydraulic fluid. If this occurs, attempt to reset the port by taking the affected FCS CH switch to ORIDE, then back to AUTO. If it continues to bypass, check the driver and position feedback ducer for other potential explanations for the problem.

When the SURF DRIVE test begins, the aerosurfaces will drive with the following characteristics:

SURFACE	POS #1	POS #2	FINAL POS	RATE
ELEVONS	18°	-33°	0°	5.8°/sec
RUDDER	5°	-5°	5°	5.0°/sec
SB	10°	2°	10°	2.7°/sec
BF	93.6%	3.5%	34.2%	N/A

<p><u>5. SECONDARY ACTUATOR CHECK (APU)</u></p> <p style="text-align: center;"><u>NOTE</u></p> <p>If a port does not bypass during check, bypass affected port after APU shutdown: SEC ACT BYPASS - ITEM 21 + <u>XX</u> EXEC If affected port still does not bypass: SEC ACT RESET - ITEM 22 + <u>XX</u> EXEC</p> <ol style="list-style-type: none"> ✓ POS STIM ENA, ITEM 20 - (*) ✓ FCS CH 1,2,3,4 - AUTO SEC ACT CK, CH 1 - ITEM 15 EXEC (*) ✓ All CH 1 ports bypass ('↓') STOP - ITEM 19 EXEC (*) FCS CH 1 - ORIDE ✓ All CH 1 ports reset (no '↓') FCS CH 1 - AUTO Repeat steps c thru e for CH 2, 3, 4 NEG STIM - ITEM 20 EXEC (no *) Repeat steps b thru f 	<p>✓all secondary delta P sensors on RTPLOT to verify the bypass spike.</p> <p>During the secondary actuator check, each individual port will be biased to induce a bypass. If the port fails to bypass, one of two possible problems exist. Either the driver has failed such that its output was not large enough to cause a significant force fight, or the driver did work properly and the bypass function failed. The note takes care of both of these scenarios. If the driver has failed, the port will be manually bypassed. If the manual bypass did not work, the most likely problem is the loss of isolation capability. Therefore, the note has the port reset, so that the system will work nominally given no other failures. The crew will have to rely on the MCC to confirm which problem has occurred. The MCC has insight to the drivers performance. If the force fight occurs with no isolation, the affected channel will work fine as long as there is no subsequent failure that requires a bypass of the affected port. If no force fight occurs, the driver is failed and a manual bypass is required.</p>
<p><u>6. APU SHUTDOWN</u></p> <p>Proceed to part 2</p>	<p>Step 7 will not be used as long as an APU is used for part 1. Therefore, part 1 is complete after APU shutdown.</p>
<p><u>7. CIRC PUMP ACTIVATION</u></p> <p style="text-align: center;"><u>NOTE</u></p> <p>OPS 2/8 trans must be performed with ASAs off to avoid AERO DRIVE fault msgs during actuator checks.</p> <ol style="list-style-type: none"> Perform G8 to G2 TRANSITION, then: ASA (four) - OFF Perform G2 to G8 TRANSITION, then: ✓FCS CH 1,4 - AUTO 2,3 - OFF ASA (four) - ON ✓HYD BRAKE ISOL VLV X tb - CL ✓HYD CIRC PUMP (three) - OFF HYD CIRC PUMP X - ON 	<p>✓all power feedbacks on CRANS and/or ELOG</p> <p>Step 7a will only be used if an APU fails during the checkout and the decision is made to continue using a circ pump. Since the original configuration is for using an APU, the aerosurface command initialization must be redone in order to achieve the proper commands. To do this, an OPS 2 to 8 transition must be done with the ASAs turned off. Therefore, the first thing to do is to transition back to OPS 2, turn the ASAs off, then transition back to OPS 8. This transition will set the aerosurface commands to the 0 volt values of -7.5° for elevons, 0° for rudder, and 45% for speedbrake with the appropriate scale factors applied (as explained in the <u>DISPLAY/DPS CONFIG</u> section).</p> <p>After the OPS 8 transition is complete, the FCS channel switches are then configured properly to perform the checkout with the circ pump. Throughout the checkout, 2 of the first 3 FCS channels will remain off. This is done to prevent the AERO DRIVE messages from occurring. The message is being prevented by ensuring the selected aerosurface position feedbacks never differ from the commands. The position feedback selection filter will MVS channels 1, 2, and 3 to determine the selected feedback. Therefore, leaving 2 of the first 3 channels off will make the selected position feedback equal the commands, regardless of the actual position.</p>
<p><u>8. ABBREVIATED SECONDARY ACTUATOR CHECK (circ pump)</u></p> <p style="text-align: center;"><u>NOTE</u></p> <p>If an elevon does not move to commanded position, bypass affected port after check of all channels: SEC ACT BYPASS - ITEM 21 + <u>XX</u> EXEC</p> <ol style="list-style-type: none"> ✓POS STIM ENA, ITEM 20 - (*) ✓FCS CH 1,4 - AUTO ✓ 2,3 - OFF ✓All elevons move to U7.5°±0.8° SEC ACT CK, CH1 - ITEM 15 EXEC(*) Wait 5 sec Turn off FCS CH not being checked: FCS CH (three) - OFF ✓All elevons move to U1.5°±0.8° <p>* If any elevon drives past 0°, turn on all * FCS CHs to stop movement: *</p>	<p>Use the Control Entry display for this part of the checkout.</p> <p>Performing the positive stimulus enable tells the software to put a positive 6° bias on the elevons when the secondary actuator check is enabled. Only the positive stimulus will be used for the check out with the circ pump. This will be enough to determine if any drivers are failed to null.</p> <p>The secondary actuator check is then enabled causing a one-on-one force fight between the two active channels. Even though the brakes won't release on the rudder and speedbrake under circ pump pressures, a force fight can still be observed in the secondary delta pressures.</p> <p>After 5 seconds, the channel not being checked will be turned off. This will cause the elevons to move to the biased commands of -1.5°. This motion will indicate that the elevon drivers are working properly. The stimulus is then removed which will drive the elevons back to -7.5°.</p> <p>If for some reason the elevons continue to drive past zero, there is a problem in the actuator or driver. Control of that surface can be regained by turning on all four channels. Once this is done, the stimulus can be removed and two of the first three channels can be turned off to stop the associated AERO DRIVE messages.</p>

<p>* FCS CH (four) - AUTO * Expect AERO DRIVE msg. Continue * * procedure and report to MCC. *</p> <p>f. STOP - ITEM 19 EXEC(*) ✓All elevons move to $U7.5^{\circ} \pm 0.8^{\circ}$</p>	<p>The test will be repeated for all channels using the FCS channel switch configuration table shown below.</p>																									
<p>g. Config FCS Chs for check of next CH:</p> <table border="1"> <thead> <tr> <th>NEXT CH</th> <th colspan="4">FCS CH SWITCHES</th> </tr> </thead> <tbody> <tr> <td>2</td> <td>4</td> <td>1</td> <td>2</td> <td>3</td> </tr> <tr> <td></td> <td>AUTO</td> <td>OFF</td> <td>AUTO</td> <td>OFF</td> </tr> <tr> <td>3</td> <td>AUTO</td> <td>OFF</td> <td>OFF</td> <td>AUTO</td> </tr> <tr> <td>4</td> <td>AUTO</td> <td>OFF</td> <td>OFF</td> <td>AUTO</td> </tr> </tbody> </table> <p>h. Repeat steps d thru g for Chs 2, 3, 4</p>	NEXT CH	FCS CH SWITCHES				2	4	1	2	3		AUTO	OFF	AUTO	OFF	3	AUTO	OFF	OFF	AUTO	4	AUTO	OFF	OFF	AUTO	<p>The FCS channel switch table is designed to always keep 2 of the first 3 channels off to prevent the AERO DRIVE message from occurring. The table is also set up in the specific order of 4, 1, 2, 3 for switch throws. As long as the FCS channel switches are thrown in this order, the AERO DRIVE message will be avoided.</p>
NEXT CH	FCS CH SWITCHES																									
2	4	1	2	3																						
	AUTO	OFF	AUTO	OFF																						
3	AUTO	OFF	OFF	AUTO																						
4	AUTO	OFF	OFF	AUTO																						
<p>9. <u>HYDRAULIC SYSTEM RECONFIG</u></p> <p>HYD CIRC PUMP (three) - GPC</p>	<p>✓ ELOG for circ pump feedback.</p> <p>Once the test is complete, the circ pump will be returned to automatic control by the GPCs.</p>																									
<p>10. <u>FCS CH RECONFIGURATION</u></p> <p>a. Perform G8 to G2 TRANSITION, then: FCS CH 1, 2, 3 - AUTO ✓4 - AUTO</p> <p>b. Perform G2 to G8 TRANSITION, then: Continue with Part 2</p>	<p>The G8 to G2 transition is done in preparation to perform another G8 to G2 transition. Earlier in the procedure a G2 to G8 transition was performed with the ASAs off. This was done to set the elevon commands to the 0 volt value (-7.5°) upon the transition. Now that the secondary actuator check is complete, the channels and feedbacks need to be configured to support the surface feedback test in part 2. This requires all four ASAs and channels to be on. However, to prevent AERO DRIVE messages a G2 to G8 transition must be performed with the ASAs on. This will ensure that the speedbrake positions will indicate the true position (0%) instead of the zero volt value (45%), and set the commands accordingly.</p>																									
<p><u>ON-ORBIT FCS CHECKOUT, PART 2</u></p> <p>1. <u>SENSOR TEST - MLS, TAC, RA, AA</u></p> <p><u>NOTE</u> During MLS/TAC/RA/AA test, deselect LRU for failure indicated: MLS, TAC, RA, AA - '↑' or '↓' or AA - BAIS/NULL limits exceeded Record values of failures defined</p> <p>GNC 40 SENSOR TEST</p> <p>✓DES: (no*) ✓STAT: blank ✓RNG, AZ, EL: no M</p>	<p>Any LRUs that fail self-test will be deselected and considered failed per Flight Rules. Deselecting LRUs during FCS C/O will carry over into OPS 3 in the PASS. However, these units must be deselected in the BFS after it is brought up during deorbit prep.</p>																									
<p><u>CONFIG FOR FREE DRIFT</u></p> <p>ADI RATE - LO DAP: A1/INRTL/VERN ✓R, P, Y rates $0 \pm 0.1^{\circ}/\text{sec}$, then: DAP: FREE</p>	<p>The orbiter is placed in free drift to null the accelerations due to jet firings. This is done in order to verify that the AAs are showing a good null value as well as to prevent corrupting the self-test. If for some reason that free drift cannot be selected, A/AUTO/VERN(PRI or ALT) are acceptable. The verniers have little to no affect on the AAs. The primary jets' effect is more substantial, but the data between firings can be analyzed. The rate check is to prevent placing the orbiter in free drift with abnormally high rates, since free drift will be selected for a while.</p>																									
<p><u>AA BIAS/NULL SHIFT TEST</u></p> <p>✓Y,Z within limits: Y -0.5 to +0.5 Z -1.3 to +1.3</p>	<p>The AA data can be monitored on the Entry Sensors display. With no accelerations on the vehicle, the AAs should be displaying values within these limits. If any are outside of these limits, press on with the self-test to gather more data.</p>																									

<p><u>MLS, TAC, RA, AA TEST</u></p> <p>START - ITEM 13 EXEC (*)</p> <p style="text-align: center;"><u>NOTE</u></p> <p>*** blanks when test complete; ✓ no '↑' or '↓'</p> <table border="0"> <tr> <td></td> <td style="text-align: center;">RNG</td> <td style="text-align: center;">AZ</td> <td style="text-align: center;">EL</td> </tr> <tr> <td>MLS</td> <td>15.0 to 15.4</td> <td>±2.9 to ±3.1</td> <td>5.9 to 6.1</td> </tr> <tr> <td>TAC</td> <td>0 to .5</td> <td>177.5 to 182.5</td> <td></td> </tr> </table> <p style="text-align: center;"><u>ALT</u></p> <p>RA 900 to 1100</p> <table border="0"> <tr> <td></td> <td style="text-align: center;">Y</td> <td style="text-align: center;">Z</td> </tr> <tr> <td>AA</td> <td>14.40 to 17.80</td> <td>57.70 to 71.10</td> </tr> </table> <p>STOP - ITEM 14 EXEC (*) TACAN MODE (three) - OFF</p>		RNG	AZ	EL	MLS	15.0 to 15.4	±2.9 to ±3.1	5.9 to 6.1	TAC	0 to .5	177.5 to 182.5			Y	Z	AA	14.40 to 17.80	57.70 to 71.10	<p>The MLS, TAC, RA, and AA. are tested during the sensor test. The LRU data can be viewed on the Entry Sensors display. When the self-test is first initiated, the MLS azimuth data should be the first data reviewed, since the polarity of the azimuth data will change 3 seconds after the self-test is initiated. It is easiest to get 2 hard copies during the test; one within 3 seconds of test initiation and one after the MLS azimuth data changes polarity.</p> <p>It is also important to note that this data is only active when the GNC SPEC 40 is called up. If for some reason the SPEC is dropped, this data becomes static.</p> <p>The TACANS are powered off as soon as the test is complete because the old Gould TACANS are a significantly large heat source. Therefore, turning them off after the self-test is complete is prudent.</p>
	RNG	AZ	EL																
MLS	15.0 to 15.4	±2.9 to ±3.1	5.9 to 6.1																
TAC	0 to .5	177.5 to 182.5																	
	Y	Z																	
AA	14.40 to 17.80	57.70 to 71.10																	
<p><u>2. SENSOR TEST - RGA, ADTA</u></p> <p style="text-align: center;"><u>NOTE</u></p> <p>During RGA, ADTA test, deselect LRU for failure indicated:</p> <p>RGA - bias null limits exceeded, '↑' or '↓', or SMRD ADTA - any '↑' or '↓', except temp (T)</p> <p>If RGA does not respond to HIGH or LOW TEST, or displays 'SMRD' indication in STAT column:</p> <ul style="list-style-type: none"> ✓MCC, confirm that payload config can support PRCS firings Null vehicle rates Maneuver at 0.5°/sec about the appropriate axis; monitor RGA data <p>If RGA responds, self-test circuitry or SMRD circuitry is failed</p> <p>If no RGA response, deselect sensor</p> <ul style="list-style-type: none"> ✓DES: (no*) ✓STAT: blank ✓PS, PαC, PαU, PαL, T - no M 	<p>The RGAs and ADTAs will be tested during the second sensor test. Verify that the RGA and ADTA data falls within limits during the test. This data can be viewed on the Entry Sensors display.</p> <p>If an RGA fails the sensor test, the vehicle can be maneuvered at .5°/sec to determine the health of the gyro. For example, if the RGA does not respond to the high or low test, but works properly during a maneuver, it can be concluded that failure is in the self-test circuitry itself. Therefore, it is prudent to do the additional test of a maneuver to assess the health of an RGA that has indicated a problem. For the maneuver test, the RGA output can be compared with the other three units to determine the correct value that it should be reading.</p>																		
<p><u>CONFIG FOR FREE DRIFT</u></p> <ul style="list-style-type: none"> ✓DAP: A1/INRTL/VERN ✓R, P, Y rates 0±0.1°/sec, then: DAP: FREE 	<p>The orbiter is placed in free drift to null the rates due to jet firings. This is done in order to verify that the RGAs are showing a good null value as well as to prevent corrupting the selftest. If for some reason that free drift cannot be selected, A/AUTO/VERN(PRI or ALT) are acceptable. The verniers in DAP A1 have little to no affect on the RGAs with INRTL. The primary jets' effect is more substantial, but the data between firings can be analyzed. The rate check is to prevent placing the orbiter in free drift with abnormally high rates, since free drift will be selected for a while.</p>																		
<p><u>RGA BIAS/NULL SHIFT TEST</u></p> <p>✓R, P, Y within limits: R -0.4 to +0.4 P/Y -0.2 to +0.2</p> <p><u>HIGH TEST</u></p> <p>TEST HI - ITEM 9 EXEC (*) after 10 sec (no *)</p> <p>✓No '↑' or '↓' If ADTA BITE, ✓MCC</p> <p>TEST STOP - ITEM 11 EXEC (*)</p>	<p>With the orbiter rates nulled, the RGAs should be reading within the following limits. It is important to note that 1 PCM count for P and Y is .08°/sec, while one PCM count for the R axis is .16°/sec. Therefore, the granularity on the data is not that good for very low rates. That is why the rate limits seem to be rather large, for the null test.</p> <p>During the high test, verify the RGA and ADTA data on the Sensors Entry and the FCS C/O UDD display to determine if they are in limits. It is typical to see 1, 2, or 3 PCM count differences between the RGAs during this test. However, the ADTAs should agree nicely with each other.</p> <p>ADTA BITE can be monitored on CRANS. If a BITE occurs, evaluate the digital data to determine if there is any visible degradation of the ADTA electronics. Even if the digital data looks good, the ADTA should be considered failed for planning purposes, until it can be resolved whether or not the ADTA performance</p>																		

LOW TEST

TEST LOW - ITEM 10 EXEC (*)
after 10 sec (no *)
✓No '↑' or '↓'
If ADTA BITE, ✓MCC

TEST STOP - ITEM 11 EXEC (*)
DAP: A1/AUTO/VERN

HIGH TEST LIMITS

	R	P & Y
RGA	18.8 to 21.2	9.4 to 10.6
	PS	PαC
ADTA	0.813 to 0.817	5.473 to 5.477
	PαU	PαL
1.712	2.740 to 2.744	1.708 to
	T	
	173.56 to 173.60	

LOW TEST LIMITS

	R	P & Y
RGA	-18.8 to -21.2	-9.4 to -10.6
	PS	PαC
ADTA	24.887 to 24.889	29.527 to
29.531		
	PαU	PαL
14.717	21.708 to 21.712	14.713 to
	T	
	18.50 to 18.54	

is affected.

The DAP is taken back to AUTO when the test is complete, since there is no more requirement for free drift.

3. SENSOR TEST - GPS

NOTE
After GPS S/TEST, deselect LRU for failure indicated by '↓'. GPS self-test takes about 2 min to complete. 'BIT' in STAT field on SPEC 55 indicates hardware feedback, and clears when test is complete

GNC 55 GPS STATUS

✓NAV – ITEM 18 (*)
If 'RPF' in STAT field, ✓MCC (If LOS, proceed with test)
S/TEST – ITEM 12 EXEC (*)
✓'BIT' in STAT field after ~6 sec, Wait for 'BIT' to clear after ~2 min
✓S/TEST '↑'; if '↓' deselect GPS
NAV – ITEM 18 EXEC (*)
✓MODE – INS

GPS is tested via GPC initiated self-test command. The affected GPS unit should be deselected for entry if a failure is detected during the self-test, as indicated by a down-arrow at completion of the self-test. The self-test takes 2 minutes to complete after it is initiated via crew commanded item entry. A 'BIT' indication on SPEC 55 indicates that Built-In-Test is in progress via output from the GPS hardware, and clears from the display status field on SPEC 55 when the self-test sequence is complete.

GPS should be commanded to SELF-TEST mode from NAV MODE only. Only transitions to and from NAV MODE are valid GPS mode transitions. If an 'RPF' message is displayed in the status field on SPEC 55, it indicates that the GPS unit detected an internal hardware fault, and the crew should check the MCC prior to proceeding with a self-test (if the crew is able to talk with the MCC).

GPS2 Self-Test is initiated via the ITEM 12 on SPEC 55. A hardware feedback of 'BIT' should be received from the GPS hardware within 6 seconds of the self-test commanded item entry and displayed on SPEC 55 in the status field. It will take 2 minutes for the self-test to complete. Once the self-test is complete, an up arrow will indicate a "pass" of the test, and a down-arrow will indicate a "fail" of the self-test. The GPS unit should be deselected to preclude its use during entry if it failed self-test.

For a nominal self-test, all 18 self-test fault log words on downlist will be 0000 in hexadecimal format. To analyze the self-test data, the SENSORS operator should pull all 18 GPS fault log words on downlist from MEWS/ODRC in hexadecimal format (or use a Universal Digital (UDD) format). For any non-zero fault log words, refer to the tables in SCP 4.13 GPS SELF-TEST to determine the exact nature of the self-test failure.

Once self-test is complete, the GPS unit should be commanded back into NAV mode to allow the GPS receiver to resume satellite tracking to compute a valid navigation state. While in self-test the GPS unit is not tracking satellites. After NAV mode is commanded via item entry, the GPS unit should mode into INS mode indicating that it is receiving IMU data from the GPC's.

4. FCS MODE/CH SWITCH TEST

NOTE

During tests, FCS CH:

Fail open or fail closed - deselect failed contacts. FCS CH OVERRIDE function of a CH with failed contacts may be made

operable if at least one good contact is available.

FCS MODE:

Fail op - 2 op or 1 op/1 cl contacts preclude

use of sw

Fail cl - 1st failure, des failed contact
2nd failure L(R), des all L(R) contacts

ENTRY MODE:

Fail op or cl - 1st, 2nd failure, des contact
3rd failure, when in OPS 3
GNC 51 OVERRIDE
AUTO SEL - ITEM 42 EXEC

(*)

FCS CH:

The FCS CH auto/override switch is a three contact switch, any of which are deselectable on SPEC 42. As long as there is one operational contact, the override function can be used. Failed contacts can be deselected, leaving either one or two available contacts. If only one good contact remains, the FCS channel is one failure away from losing the auto isolation capability or the override capability.

Should that contact fail high, the channel will transition from auto to override. The channel will still work, and can be isolated by either turning the FCS CH swith to off, or manually bypassing an individual or multiple ports.

Should the last contact fail off, the FCS channel will function without the software override capability (i.e. the channel will functionally act as if it were in the auto mode).

FCS MODE:

The FCS MODE switches, shown on SPEC 42, are three contact switches. If a single contact fails either high or low, deselect it and use the switches as normal. If two or more fails "on", are failed, all contacts should be deselected and the switches on the other panel should be used. Deselecting all contacts when only one remains prevents the possibility of that last contact failing high and permanently selecting the "on" state of the switch. For example, if the Pitch AUTO button fails "on", the pitch axis would be stuck in AUTO. To fly CSS in the pitch axis, the Pitch CSS pbi would have to be held in as long as the crew needed CSS.

It is important to note that deselecting contact 1 of any of the FCS mode switches, deselects the contact 1 of all of the FCS mode switches on that side of the cockpit. For example, if L PITCH CSS contact 1 is failed and deselected with an item 13 on SPEC 42, then the L PITCH AUTO, L PITCH CSS, L R/Y AUTO, L R/Y CSS, L SPDBK/THROT AUTO/MAN, and L BDY FLAP AUTO/MAN pbi contact 1 is deselected. The switches on the other side of the cockpit are unaffected.

ENTRY MODE:

The ENTRY MODE switch is a four contact switch. For the first and/or second failure, deselect the bad contacts. With two contacts failed/deselected the ENTRY MODE switch is single fault tolerant from an uncommanded mode being selected. However, it is only zero fault tolerant for being able to select an a mode since it takes 2 contacts in a postion for the switch to work.

The AUTO can be selected in OPS 304 and 305 via an item 42 on SPEC 51 should the switch totally fail while in either low gain or no yaw jet mode.

The forward THC contacts are being deselected prior to turning flight controller power to avoid any unnecessary jet firings due to possible THC/DDU power transients.

Deselect L THC:

THC L DES - ITEM 1,2,3 EXEC (*)

NOTE

During following tests verify '*' appears except as noted. If '*' remains after releasing pb, contact failed closed.

FLT CNTLR PWR (two) - ON
FCS CH (four) - ORIDE (wait 5 sec)
- AUTO (no*)

PITCH pb - AUTO
- CSS

ROLL/YAW pb - AUTO
- CSS

SPDBK/THROT pb - AUTO

BODY FLAP pb - AUTO

SBTC TAKEOVER pb - push

✓THC&SWITCHES display to monitor the switch test.

During the FCS CH switch test, monitor the ASA and ATVC performance to verify that they were not adversely affected by the transient power cycles that result from the switch throws.

See above for actions required for any switch anomalies.

5. SURF TEST

Notify MCC if any single surf feedback exceeds average of other three feedbacks by greater than:

Elevons (1.3°)
Rudder (1.2°)
SPD BK (2.2%)
BDY FLP (3%)

The surface feedback test is simply a comparison between each aerosurface's position feedbacks. No action is required if these limits are exceeded. RM will fail out any bad position feedbacks as long as RM is running. If RM has terminated for any reason, the bad position feedbacks can be isolated by deselecting all of the feedbacks on the affected channel.

See above for actions required for an ENTRY MODE switch anomaly.

<p>During following switch test, verify '*' appears</p> <p>ENTRY MODE - LO GAIN - NO Y JET - AUTO (no *)</p>	
<p>6. <u>NWS CHECK</u></p>	<p>N/A for GNC</p>
<p>7. <u>CONTROL & SWITCH TEST</u></p> <p><u>NOTE</u> During controller/switch test, THC: <u>One</u> TX(TY,TZ) failed CLOSED - reselect <u>all</u> contacts (failed contact last) <u>One</u> TX(TY,TZ) failed OPEN - reselect <u>good</u> contacts only TZ <u>Multi</u> +TX, -TX, +TY, -TY, +TZ, - failure - reselect <u>good</u> contacts only</p> <p>SPDBK L(R): Des failed xdcrs After 2nd L(R) failure, use other side RUD PED L(R): <u>One</u> failure - des failed xdcr <u>Multi</u> L(R) failures - des all L(R) xdcrs RHC L(R): <u>One</u> xdcr failure - reselect good xdcrs only <u>Multi</u> L(R) failures - reselect good xdcrs L(R) & F7(F8) BDY FLP L(R): Fail close, des all L(R) contacts RHC or PNL TRIM L(R): If contact failed, des failed contact row.</p>	<p>THC: The forward THC will be checked out by deselecting the contacts and deflecting the THC. If any contact fails closed, reselect all contacts, but reselect the bad one last so that it can fail RM again. If any contact fails open, reselect the good contacts only. GNC SSR-9 can be run as part of the RCS Hot Fire to allow RM to isolate the bad contact, and regain the use of the other good contacts. If multiple problems exist, reselect the good contacts and perform GNC SSR-9 if required. If multiple problems exist, an option of an IFM is available to swap the forward and aft THCs.</p> <p>SPDBK: The left and right SBTC are three channel controllers. Deselect any failed transducers. If multiple failures exist on a controller, the other SBTC should be used.</p> <p>RUD PED: The left and right RPTA are three channel controllers that are mechanically linked together. If a single transducer is failed, it should be deselected. If multiple transducers fail on one controller, all transducers on the bad actuator should be deselected. Since the two RPTAs are mechanically linked, the CDR can still use his rudder pedals even though all transducers are deselected.</p> <p>RHC: The RHCs are three channel controllers. If any transducers fail, they should be deselected. If multiple failures occur on an RHC, an option exists to perform an IFM to swap the bad RHC with the aft RHC.</p> <p>BDY FLP: The body flap up/down switch is a two contact switch. Therefore, if one of the contacts fails closed, the body flap is one failure away from driving up or down if manual body flap is selected.</p> <p>RHC TRIM: The RHC TRIM is a two contact switch. If a contact fails open or closed, deselect the bad contact. This will make the trim switch available for use, should it be required. If the contact is failed closed, the trim switch will still work without being deselected. However, if the good contact becomes comm faulted, uncommanded motion will result.</p> <p>For nominal operations, the bad trim switch should not be used. However, the RHC TRIM can be used for landing derotation, once the airspeed drops below 195 knots. Above 195 knots, two contacts are required to initiate derotation. Reference GNC Systems Briefs 13.2.2.4.3, Beep Trim Derotation Logic.</p> <p>PNL TRIM: The PNL TRIM is a two contact switch. If a contact fails open or closed, deselect the bad contact. This will make the trim switch available for use, should it be required. If the contact is failed closed, the trim switch will still work without being deselected. However, if the good contact becomes comm faulted and the trim is enabled, uncommanded motion will result. A failure of this switch will not be a factor in the decision to use the RHC trim for derotation.</p>
<p>a. <u>THC</u> L THC - deflect in each axis ✓THC: '+' & '-' Reselect THC contacts: THC L - ITEM 1,2,3 EXEC (no *)</p>	<p>✓THC&SWITCHES display to monitor the switch test.</p> <p>See above for actions required for a THC anomaly.</p>
<p>b. <u>L SBTC</u> L SBTC - full aft; ✓>95% - full fwd; ✓<15%</p>	<p>✓THC&SWITCHES display to monitor the switch test.</p> <p>See above for actions required for a SBTC anomaly.</p>
<p>c. <u>RUDDER/BRAKE</u></p>	<p>✓THC&SWITCHES display to monitor the switch test.</p>

<p>RUD PED - full L; >87% and ch Δ <9% - full R; >80% and ch Δ <9% - null; between L 14% and R 4%</p> <p>BK PED - depress to verify unrestricted movement</p>	<p>See above for actions required for a RPTA anomaly.</p>
<p>d. <u>BODY FLAP SWITCH</u> BDY FLP - UP, DN ✓BDY FLP UP, DN - **</p>	<p>✓THC&SWITCHES display to monitor the switch test.</p> <p>See above for actions required for a BODY FLAP switch anomaly.</p>
<p>e. <u>L RHC</u> Des L RHC: RHC L DES - ITEM 23,24,25 EXEC(*) L RHC - deflect to hardstop in each axis ✓RHC L: R,P - >92% Y - >88%</p> <p>Res RHC CHs: RHC L DES - ITEM 23,24,25 EXEC(no *)</p>	<p>✓CONTROL ENTRY display to monitor the RHC test.</p> <p>See above for actions required for a RHC anomaly.</p>
<p>f. <u>L RHC TRIM SWITCH</u> L RHC Trim - deflect switch in each axis ✓RHC TRIM L: R - R/L P - U/D</p>	<p>✓THC&SWITCHES display to monitor the switch test.</p> <p>See above for actions required for a RHC TRIM switch anomaly.</p>
<p>g. <u>L PANEL TRIM SWITCHES</u> ROLL TRIM - R, then L PITCH TRIM - UP, then DN YAW TRIM - R, then L ✓PNL TRIM L: R,Y - R/L P - U/D</p> <p>TRIM RHC/PNL - ENA (wait 5 sec; no crew insight) TRIM RHC/PNL - INH</p>	<p>✓THC&SWITCHES display to monitor the switch test.</p> <p>See above for actions required for a PNL TRIM switch anomaly.</p>
<p>h. Repeat steps b&d thru g for R cntlrs/sw: RHC R DES - ITEM 26,27,28</p>	
<p>i. <u>DDUs</u> O14:E cb MNA DDU LEFT – op O16:E cb MNC DDU RIGHT – op (wait 5 sec) O14:E cb MNA DDU LEFT – cl O16:E cb MNC DDU RIGHT – cl O15:E cb MNB DDU L,R (two) – op (wait 5 sec) O15:E cb MNB DDU L,R (two) – cl</p>	<p>Step i. should be performed with flight control power ON. Temporarily loosing flight control power during this step indicates that one of the two redundant power sources for the effected DDU (Left or Right) is not functioning. This suggests that the effected station may be critical to one power path.</p> <p>To identify which power path is not available have the crew,</p> <ol style="list-style-type: none"> 1) Verify flight control power is ON 2) Verify both cb on the effected side have been closed per step i. 3) Repeat step i. for the effected side (Left or Right) only, with a mark for each time a circuit breaker is moved.
<p>8. <u>MEDS CHECKOUT</u></p>	<p>N/A for GNC.</p>
<p>9. <u>HUD CHECK</u></p> <p>✓HUD BRT (two) - as reqd MODE (two) - TEST ✓Brightness ✓Format 'COMPLETE' msg HUD MODE (two) – NORM</p> <p>DED DIS FWD - ITEM 1 EXEC (*) LOW - ITEM 4 EXEC (*)</p> <p>✓HUD using HUD low value test diagram</p> <p>✓Readouts for L (R) DATA BUS 1,2(3,4)</p> <p>DED DIS OFF - ITEM 6 EXEC (*)</p>	<p>MCC has no insight to this test.</p> <p>It is prudent to alert any disciplines using ADI attitude, rate, and error measurements that they will be incorrect during the test, since the downlisted data will be the selftest values.</p>
<p>10. <u>MODE LAMP TEST</u> <u>TEST START</u></p>	<p>The MCC can monitor the mode lamp test. However, the data being downlisted is the software commanded lights for the PBIs. Therefore, checking these values merely verifies that the OPS 8 software is working correctly. The crew will have</p>

<p>MODE LT ON - ITEM 7 EXEC (*)</p> <p>✓PITCH AUTO, CSS lt (two) - on</p> <p>✓ROLL/YAW AUTO, CSS lt (two) - on</p> <p>✓SPDBK/THROT AUTO, MAN lt (two) - on</p> <p>✓BDY FLP AUTO, MAN lt (two) - on</p> <p><u>TEST TERMINATE</u></p> <p>MODE LT OFF - ITEM 8 EXEC (*) FLT CNTLR PWR (two) - OFF</p>	<p>to report any burned out lamps.</p> <p>All of the hardware testing is complete at this point. Flight controller power is removed since it is no longer required.</p>
<p><u>DISPLAY/DPS RECONFIG</u></p> <p>Perform G8 to G2 TRANSITION (<u>DPS</u>),</p> <p>TRIM PNL (two) - OFF HUD PWR (two) - OFF INST PWR (two) - OFF FCS CH (four) - AUTO MLS (three) - OFF RADAR ALTM (two) - OFF RGA (four) - OFF cb MNA,B,C ADTA (four) - op MNA,B ACCEL 1,2 (two) - op DDU L (two) - as reqd MNB,C DDU R (two) - op ASA (four) - OFF ACCEL 3,4 (two) - OFF BRAKES (three) - OFF ANTISKID - OFF ATVC (four) - OFF</p>	<p>The G8 to G2 transition is performed since OPS 8 is no longer required. The nominal TFL will be reloaded, which may or may not contain high rate GNC data. Therefore, if any other testing is required, it must be done prior to this OPS transition.</p>

DOCKED FCS CHECKOUT

During STS-116, an undocked day was deleted from the timeline to add a docked day for array retract troubleshooting. Due to the limited time available post un-docking, GNC was asked if FCS Checkout could be performed while docked. Part one cannot be completed while docked due to APU contamination and load concerns. Part two, however, could be completed in a docked configuration. Despite this possibility, during STS-116 the complete nominal FCS Checkout was performed post undocking.

To aid with future requests, a “hip-pocket” version of a Docked FCS Checkout Part 2 procedure has been created and is located on the GNC S:\ drive. The following documents rational and group concerns raised during the development of this procedure.

Summary of Differences between Docked and Nominal FCS Checkout Part 2

1. There is no MLS or TACAN commanded sensor test.
2. There is no immediate maneuver backup test for RGAs since the entire stack would have to be maneuvered.
3. The DDU cb closures were moved to immediately precede the FCS MODE/CH Switch Test and after all FWD controller contacts are deselected to ensure the controllers are not powered when contacts are available.

4. Regardless of contact failure modes, only good channels are reselected at the end of the controller checkout. GNC can optimize contact configuration post undock if required.
5. No SURF TEST. This data can be obtained during Part One after undocking.

Note: A FES Dump should not be scheduled during this procedure to aid with data gathering during the sensor test.

TACANs and MLS

As of February 2007, The Communications and Tracking Technical Panel has stated the TACAN and MSL keep out zones (KOZ) must be maintained. Thus, the docked version of FCS C/O performs modified powering of MLS and TACANs to enable the systems to perform their power-up self tests and provide a limited time for GNC to observe data from the boxes without the concern of radiation.

MLS will transmit during the commanded sensor test. Thus to prohibit transmission, MLS is powered on before the G2 to G8 transition and powered off before the sensor test is commanded. MLS is left unpowered for the remainder of the procedure and DPS has stated it is safe to leave MLS unpowered during the G8 to G2 OPS transition, especially since FCS C/O is usually performed with a single GPC.

TACANs will transmit whenever they are powered on in a mode other than receive (RCV), however, the TACANs must be in GPC mode in order to receive the sensor test command. To prohibit transmission, the TACANs are powered on in RCV mode and no sensor test is performed. While in RCV mode, the receiver-transmitter will only output bearing data. The unit will still perform a power-up test.

Further knowledge of MLS and TACAN docked operations as of February 2007 is summarized below:

When MLS is powered on, a power-up self test bit is present for six seconds from the initial power up. However, internal logic in the RF Assembly inhibits MLS from radiating for ~60 seconds after power-up. During this time, the DME data from the self test is invalid. After this clock times out, there will still be no RF transmission until the Navset detects valid Solicit pulses from a ground station or BIT circuits (this is highly unlikely), or the crew initiates the sensor test.

During the sensor test, MLS will radiate for 28.8 microseconds. The BIT cycle time during the sensor test lasts for 6.4 seconds. During this duration, the BIT generator produces 32 beams of AZ, EL and DME every 200 milliseconds ($32 \times 0.2 = 6.4$ seconds). The RF Assembly does not radiate during AZ or EL beams. The DME cycle is allocated 39 milliseconds per 200 millisecond beam during which it transmits 15 pulse pairs each lasting 0.3 microseconds. Thus of the test's 6.4 seconds, the RF assembly radiates for 30 pulses (15 pairs) \times 0.3 microseconds \times 32 beams = 28.8 microseconds.

TACANs will periodically transmit when powered (if not in RCV). In order to command the sensor test, the TACANs must be in GPC mode. When the sensor test is commanded with the TACANs in RCV mode, the crew will not see any change in the TACAN data from that before the test. Commanding the test with the TACANs in GPC mode (to send the self test command) and then immediately moding the TACANs to RCV will cause the sensor test to terminate early.

If in the future it is determined the TACANs can be tested while docked to station, transmissions could be minimized by powering the TACANs on in RCV and then taking the TACANs to GPC right before the sensor test is initiated. After the test, the TACANs could be taken back to RCV.

TACANs nominally transmit pulses at 1.2KW for a 3.5 ± 0.5 microsecond duration at a rate of 2700 ± 90 pairs per second. MLS nominally transmits at 2.5KW with a 15.4 Ghz frequency. Analysis presented to the Communications & Tracking Panel in February of 2005 reported that MLS and TACAN Keep Out Zones (KOZ) are defined by a spherical radius about the antenna. For MLS, the KOZ is 3.9 m and the TACAN is 5.8 m. There are no stationary ISS ORUs within the MLS KOZ. However, the US Lab is partially within the TACAN KOZ and in future configurations Node 2, and the ESA and JAXA modules may be within this KOZ as well. The SSRMS should not be allowed inside the MLS KOZ when it is transmitting and the SRMS should be placed in the stowed position to minimize exposure.

The RF clear zones specified by KSC for the MLS is 0.8 inches and 8 inches for the TACAN. Allowing the MLS and TACANs to radiate presents no human hazards while docked.

Reference

ISS ORU RF Keep Out Zone from SSO High Power MSBLS and TACAN Antennas, EV7-05-3113. Lockheed Martin Space Operations Avionic Systems Analysis Section. Jan. 25, 2005.

FREE Drift for the Sensor Test

The nominal FCS Checkout procedure calls for FREE drift during the sensor test to help evaluate AA and RGA performance. The group has decided ISS and Orbiter FREE drift would not be required for the sensor test if docked due to the small rotation rates observed by the mated stack. If an AA or RGA violated one of the limits set by FCS Checkout, post analysis of the data could be performed to determine if the rates were the result of a jet firing. If required, further analysis could be performed post undocking.

The group did consider commanding the Orbiter to FREE if it is in control of the mated stack or giving the crew a "GO" for the sensor test based on the attitude/rate error locations in the phase plane to decrease the probability of firing an Orbiter jet. The group decided this would only complicate the procedure when rates are already expected to be very small.

Controller Checkout

DDU cb closure and forward controller contact deselection have been reordered to minimize the time the DDU's are powered and ensure flight control power is not turned on before the contacts are deselected. For this reason, the crew notes were changed to reselect only good channels after flight control power has been turned off. For THC contacts failed closed, the nominal FCS Checkout has the crew reselect the channel. For the docked version, GNC decided we will optimize the controller configuration post undocking to prevent selecting contacts while the controllers are powered.

If all controller contacts are deselected, the controllers will not cause a jet firing regardless of the DAP configuration. While docked, the shuttle is likely to be in VERN. In this configuration the primary logics and drivers are usually unpowered preventing a primary jet from firing. Thus, there are nominally two levels of protection (contact deselection, and primary logics and drivers powered off) for firing jets during deflection of the THC.

If the shuttle is in attitude control in ALT then there is only one level of protection against firing a primary jet during THC deflection (contact deselection). In this scenario to gain a second level, the primary logics and drivers could be powered off before the procedure assuming Station can be in attitude control.

Similarly, there is one level of protection (contact deselection) for firings due to RHC deflection since the RHC will fire vernier jets. However, the consequences of firing a vernier jet while docked are not as serious as firing jets in PRI mode.

Due to detent limits in the Orbit DAP, power switch transients in the DDU could only cause a jet firing for the THC. This scenario would require the crew to not properly deselect the contacts when the primary logics and drivers are powered and either 1) only one contact for the THC is good, or 2) the crew removes power from the DDU before flight control power is turned off. Thus, the group felt having the crew deselect controller contacts was sufficient protection against firing jets.

Note that SPEC 25 is not available in OPS 8 and a commanded sw RM Inhibit in OPS 2 will not be honored in OPS 8.

The left flight control power and DDU could be turned off during the NWS Check since only the Right AC and DC power is required. However, it was decided the 2-5 minute reduction in time that left flight control power is on was not worth the additional steps since there nominally will be two levels of inhibits to firing a primary jet.

TITLE

CONTROL FCS CHECKOUT MONITORING

PURPOSE

To define the procedures for monitoring the on-orbit flight control system (FCS) checkout. The checkout is performed to determine the health of the entry critical line replaceable units (LRU's) in order to establish the best systems configuration for entry. Ground coverage is highly desired while the crew is performing the checkout.

BACKGROUND

The FCS checkout is composed of two parts. Part 1 consists of the secondary actuator check; part 2 consists of sensor, switch, controller, and light checks. Part 1 is required to ensure that no null failures exist in aerosurface servoamplifier (ASA) driver outputs. Part 2 will be done when practical. It is preferred that the checkout be performed in OPS 8. This is the nominal environment; it provides the time and capability to work problems. Part 2 can only be done in this memory configuration. Also, OPS 8 provides MMACS with insight to the three individual nose wheel steering position transducers, insight only available in OPS 8. If necessary because of off nominal situations, the secondary actuator check may be performed in OPS 3 using GNC SPEC 53 ENTRY CONTROLS.

PROCEDURES

A. CONSOLE CONFIGURATION

Configure the workstation with the Entry Control Display and the THC & Switches Display. Configure the RTPLOT to monitor FCS channel positions and secondary delta pressures. Also configure CRANS to monitor FCS channel secondary pressures and bypass status as well as APU status.

B. AEROSURFACE DRIVE TEST (ADT)

The first test to be performed is the ADT. This test issues a triangular waveform command to all of the aerosurfaces in order to thermally condition the hydraulic fluid. Furthermore, it verifies that the FCS is responding properly to position commands. The ADT is initiated by the crew by item 10 on the FCS/DED DIS C/O display. The surfaces will then continue to cycle until the drive test is terminated via item 11. After the ADT has been initiated, the control operator should monitor RTPLOT for proper cycling of the aerosurfaces and for proper surface rates as follows:

<u>Surface</u>	<u>Position</u>	<u>Rate (deg/sec)</u>
ELEVONS	-33° to +18°	5.8
RUDDER	-5° to +5°	5.0
SPD BRK	2 to 10 percent	2.7
BDY FLP	3.5 to 93.6 percent	3.0

The control operator will also monitor the RTPLOT's to verify that secondary delta pressures (ΔP 's) are nominal (within several hundred psi of zero.) CRANS and the Entry Control Display should be monitored for channel failures. Any channel failure indication or abnormal secondary ΔP 's will be reported to GNC.

Item 11 is executed to terminate the drive test. When this item is executed, the software will command final aerosurface positions that are specific to the secondary actuator check. The control operator will verify that all aerosurfaces have driven to the positions listed below:

<u>Surface</u>	<u>Position</u>
ELEVON	0.0°
RUDDER	5.0°
SPD BRK	10.0°/10.2%
BDY FLP	0°/34.2%

Item 11 (stop) is mandatory regardless of whether item 10 (start) is executed. The stop sequence ensures that the surfaces are commanded to the proper position for the secondary actuator check.

An AERO DRIVE fault message can be generated in OPS 8 only. The message will be annunciated if the following condition is satisfied: the command channel differs from the selected position feedback value by more than an I-loaded limit for any aerosurface except the body flap. The I-loads are 5.8°, 5.5°, and 10.5° for elevons, rudder, and speedbrake, respectively. The software inhibits the message from occurring when the secondary actuator check is active on channel 1 only. (It used to occur when channel 1 was stimulated because the command/position deltas for the six surfaces violated the I-loaded limits.) The fault message will not be generated during a checkout if nominal procedures are followed. At the OPS 2 to 8 transition, each aerosurface position command (on all four FCS channels) is set equal to the selected position feedback (MVS of 1, 2, 3; 4 is substituted for commfaults). While in OPS 8, the position commands can only be changed one channel at a time by issuing the secondary actuator check. When the FCS channel switches are off, the position transducers are unpowered. The zero volts values are -7.5°, 0°, 44.3%, and 50.3% for the elevons, rudder, speedbrake, and body flap, respectively. The AERO DRIVE message can occur if the FCS channel switches are configured so that the command/position delta for any of the six surfaces exceeds the aforementioned limits. The message will be annunciated every 4.8 seconds as long as the out-of-tolerance condition exists.

C. SECONDARY ACTUATOR CHECK - APU OPTION

The primary purpose of the secondary actuator check is to detect fail-to-null ASA driver outputs. A secondary purpose is to verify that the secondary ΔP fault detection (bypass monitor) circuitry is functioning properly. The test is performed on one channel at a time, first with positive stimulus and then with negative stimulus. The bipolar stimulus is required to fully check the bypass monitor circuitry; either positive or negative stimulus is sufficient to test for a null driver failure.

The crew executes items 15-18 on the FCS/DED DIS C/O display to exercise the secondary actuator check on channels 1-4, respectively. For the actuator check, the vehicle utility (VU) software will send delta position commands to the six surfaces on the channel being tested. The delta position command is computed by biasing the current position by 6°, 12°, and 16°, for the elevons, rudder, and speedbrake, respectively. The position biases are positive for the

positive stimulus and vice versa. The commands for the three channels not being tested remain unchanged. If a null failure does not exist, the resulting command/position delta on the channel being tested will result in a force fight causing the channel to bypass all surfaces. After the crew has verified that the proper ports have bypassed, the stimulus is removed and the channel is reset. The process is repeated until all channels have been tested with positive and negative stimuli.

The fact that a port did not automatically bypass may be caused by a failure of the bypass monitor circuitry as opposed to a null driver output. The crew action (manual bypass) will protect for any one future channel failure on that surface. However, it may cause a good channel to be not used if the failure is only in the bypass monitor circuit. The MCC has sufficient insight to distinguish between either of these two problems. For a bypass monitor failure, the MCC should instruct the crew to remove the manual bypass. In this case, the MCC accepts the responsibility of providing the fault detection function for the failed port.

The note that instructs the crew to manually bypass ports that fail to bypass automatically also instructs the crew to undo a manual bypass (item 22, RESET) if the manual bypass action is not successful. If a port does not bypass automatically and cannot be bypassed manually, the most likely problem (and only single point failure) is a failure in the isolation circuit. If two faults do not exist, then the driver and fault detection circuits are healthy. Assuming one fault exists, the manual bypass is reset so that subsequently the port will not be bypassed should the problem in the isolation circuit clear.

DR 35572 (OI7 User's Guide, page 3.8011-6) warns of the unpredictable consequences of executing a secondary actuator check if any surface is not at the correct position. This situation occurs because the position delta command is added to the left justified position feedback value. An overflow condition may result if the position value is near an extreme causing the sign of the test stimulus to change. In this event, the test results cannot be predicted. During the secondary actuator test, the control operator will monitor the Entry Control display for the status of the FCS channel switch. The RTPLOT's will be monitored for aerosurface positions and secondary delta pressures. From the RTPLOT's the Control operator will verify that the secondary pressures for the "good " channels properly oppose the bad one. From the RTPLOT's and displays, the operator should check that the secondary ΔP 's return to near zero after the bad ports are bypassed. Control will also monitor CRANS for bypass indications on elevons, rudder, and speedbrake. Results are to be reported to GNC.

D. SECONDARY ACTUATOR CHECK - CIRCULATION PUMP OPTION

In the event that an APU is not available for the actuator check, the elevons can be checked for null driver using a circ pump (refer to flight rules A8-104 and A10-29). This procedure has been flight tested as a DTO on all three Orbiters (refer to the post flight reports for STS-28, STS-33 and STS-36). It was also used to perform the checkout on STS-76 (OV-102) when an APU leak precluded the use of an APU for FCS C/O. The data shows that the circ pump option provides a valid test for elevon null driver failures.

This option relies on the circ pump to actually drive the elevons to a commanded position (remember the rudder and speedbrake will not drive with less than full hydraulic pressure). The commanded position is the result of the positive stimulus when the secondary actuator check is active (the positive stimulus was chosen because it is the default selection in OPS 8). Single FCS channel control is required to enable the elevons to drive. The three channels not being tested are turned off so that there will be no force fights to hinder surface movement. Since

single channel control is used, the FCS channel switches must be manipulated in the proper sequence to avoid generating AERO DRIVE fault messages.

To configure the FCS channels properly for the circ pump option, the OPS 2 to 8 transition must be made with the ASA's (or FCS channels) powered off. This results in the six aerosurface position commands being set to the zero volts values. While in OPS 8, the ASAs and FCS channels are managed so that at least two of channels 1, 2, and 3 remain off. This ensures that the selected surface positions are always equal to the commands so that no AERO DRIVE messages will be annunciated. The speedbrake is the surface most likely to cause an AERO DRIVE message if the procedure is not followed correctly. The command after transition is 44.3 percent, however the actual position is really 0 percent (stowed). If two of the first three channels are turned on, the selected position will be 0 percent versus the 44.3 percent command which causes the AERO DRIVE message. Normally, channel 4 and one other channel will be on when the actuator check is not active.

When the circ pump is activated, the elevons should drive to the commanded -7.5° , zero volts position. The rudder will be at its commanded (and zero volts) position of 0° . The speedbrake command will be 44.3 percent, but it will not drive under circ pump pressure. Flight data show that the elevons will drive between 1-2.5°/sec and may drive sequentially because of the low hydraulic pressure/flow. The crew checks that the elevons get to -7.5° within 0.8° . This tolerance is taken from the elevon position LCC redlines and applies to four channel control; the proper position tolerance for single channel control has been requested from Rockwell, but not yet provided (it should be larger in magnitude).

When the actuator check is commanded on a channel, this channel will fight against the other channel that is on (the reason for having two channels on initially). The force fight is allowed to persist for a few seconds and then the channel not being checked is turned off. At this point, the elevons should move to the biased command value of -1.5° , indicating that the elevon drivers are working properly.

The actuator check is stopped and the elevons drive back to $-7.5^\circ \pm 0.8^\circ$. The FCS channels are reconfigured. Channel 4 is turned on to provide two channel control. The channel just checked is turned off and the next channel to be checked is turned on. If the channel switches are manipulated in the left-to-right sequence shown in the table, the AERO DRIVE message will be avoided and at least one FCS channel will be on at all times.

All four channels are checked with only the positive stimulus. One stimulus is sufficient to check for null failures (bi-polar stimuli are used in the APU option to fully check out the bypass monitor circuits in the ASAs).

After all four channels have been checked, the circ pump is turned off. Hydraulic thermal conditioning is reestablished. Before proceeding to Part 2, the FCS channels are reconfigured so that the speedbrake command will be set to its actual position of 0 percent. The GNC computers are transitioned back to OPS 2, all four FCS channels are taken to AUTO (the ASA's are already ON), and then OPS 8 is reentered. This causes all aerosurface commands to be set to their current positions. This re-establishment of aerosurface commands is performed for two reasons regarding Part 2 of the checkout: 1) so that no AERO DRIVE messages will occur when the FCS channel switches are taken to override, and 2) so the crew can look for out-of-tolerance conditions among the surface position feedbacks.

E. FCS MODE/CHANNEL SWITCH TEST

After the hydraulics have been deactivated, the crew will perform the controller and switch test. During this test, the crew will exercise the controllers full scale in each axis/direction and cycle all of the flight control switches in order to verify that all of the transducers or switch contacts are in agreement.

The first test in this sequence is for the FCS mode switches. The control operator can monitor these switches from the Entry Control Display and the THC & Switches Display. A note at the beginning of the switch test provides the crew with information and instructions concerning contact failures. Contact failures are handled differently depending on the function of the switch. For FCS channel switches, a single contact will be prime selected. The software only monitors the override position of the switch. A fail-on of the prime selected contact would place that channel in the override state which results in loss of automatic fault detection and isolation. This configuration is acceptable, just not optimum for the next failure. (Manual bypass can be commanded through SPEC 53 ENTRY CONTROLS with an FCS channel in software override.) The consequence of not prime selecting the last contact, by leaving a dilemma condition or by deselecting all contacts, is that automatic fault detection in the ASA cannot be inhibited. This prevents one from optimizing for next worst failures when certain systems failures exist (unisolated hardovers, two channel control, off nominal stringing, etc.)

The functions of the FCS mode switches are different from that of the FCS CH switches. Consequently, failed contacts are managed differently. Furthermore, these mode switches are redundant in that they are duplicated on the left and right side of the cockpit. A single good contact will not be prime selected to prevent the next failure from changing the mode of the flight control system. (Unfortunately, the deselection action affects all switches on that side.) If two contacts on a switch are failed, all contacts will be deselected which no-ops all switches on that side. The redundant switches are relied on to provide the moding functions.

The ENTRY MODE switch is a three-position, four contact. One or two failed contacts will be deselected to preserve the function of the switch. Three failed contacts could cause the flight control system to mode from AUTO to NO YAW JET or LO GAIN. These modes are undesirable if not required (however, the no yaw jet mode is certified from qbar of 20 psf to the ground and the lo gain mode should provide acceptable control in most situations). Instead of deselecting all contacts if three or more have failed, a software override is enabled in OPS 3 by selecting the AUTO mode (item 42) from the GNC 51 OVERRIDE display. During entry, the failed mode of the switch can be enabled by toggling off the selection of the AUTO override.

During the check of the FCS channel switches, each switch is left in the override position for 5 seconds to ensure that the ATVC and ASA electronics have time to power up. This check verifies that no hidden problems exist in the electronics that would only be observable in override. Reference ATVC Systems Brief 11.0 for DF NOI 171.

The crew also checks aerosurface position feedbacks. For each surface, the check is to ensure that no single feedback exceeds the average of the other three feedbacks by greater than the amount listed.

The values represent three sigma limits and are taken from SODB table 3.4.5.1-2, GNC Component Self-Test Limits. They are summarized in the following table. RM limits are included for comparison and three sigma number equated to percent of full-scale deflection.

SURFACE	Delta value for crew check	RM LIMIT	XDUCER ACCURACY % FULL SCALE
Elevon	1.3°	2.38°	2.25
Rudder	1.2°	2.22°	4.3
Spd Bk	2.2%	4.04°(4.1%)	2.2
Bdy Flp	3.0%	1.8°(4.9%)	6.3

One can see that the RM limits are significantly larger than the delta values. The intent of having the crew check the feedback transducers is to detect a potential problem. The crew is to notify the MCC if an out-of-tolerance condition is detected. The bad transducer(s) is not deselected because manual deselection downmodes all transducers on the affected FCS channel. Instead, RM will be allowed to deselect the individual transducer if the limit is violated. The MCC should monitor the bad transducer (and the resulting force fight) closely.

F. CONTROLLER AND SWITCH TEST

The controllers are tested in the order of translational hand controller (THC), speedbrake/thrust controller (SBTC), rudder pedal transducer assembly (RPTA), body flap switches, rotational hand controllers (RHC), and RHC and panel trim switches. The left side controllers are checked first followed then by the right side controllers. All of the controllers and switches can be monitored via the THC & Switches Display.

For the THC test, the Control operator will verify all outputs are in agreement.

The SBTC transducer outputs should track within the RM limit of 5.3°. Full forward deflection should produce > 95 percent output and full aft deflection < 5 percent.

The RPTA transducer outputs should all track within the RM limit of 3.6° (9 percent). The pedals should be deflected to the left > 87 percent and to the right > 80 percent. Brake pedal movement should be unrestricted for 20° to 25°.

The body flap switch is checked by verifying that actuating the switch produces the correct software output. Control should verify that all contacts are in agreement.

The RHC is checked by deflecting it to the hardstop in both directions of all axes and verifying that transducer outputs track within the RM limits (roll - 6.8°, pitch - 5.1°, yaw - 2.8°). Also, maximum deflection should exceed 92 percent for roll and pitch and 88 percent for yaw. These limits ensure that the software softstop limit can be achieved in each axis.

The RHC trim switches and the panel trim switches are checked by verifying that actuating the switch produces the correct software output.

G. FCS CHECKOUT FOR LOSS OF TWO FUEL CELLS

The contingency deorbit prep procedures for loss of two fuel cells used to contain a modified version of the FCS checkout. The checkout was removed during the latter part of 1987 after review of FCS checkout requirements at Entry Flight Techniques and after review of the loss of two fuel cell powerdown procedures. The unique aspects of this checkout are described here in

the event that a flight situation may arise in which a checkout is required during a severe powerdown.

In preparation for Part 1, all four ASA's were powered. Part 1 was changed from the nominal procedure only in that a SSME HYD REPRESS was added. After the aerosurface drive test, four ATVC's were powered, the appropriate HYD MPS/TVC ISOL VLV SYS X valve was opened for 10 seconds then closed, and then the ATVC's were unpowered. At the end of Part 1, all ASA's were powered off. Hydraulic thermal conditioning was enabled per the nominal procedure, however this action was being considered for removal because of power concerns and the impending deorbit.

Part 2 was modified to include power cycling of groups of LRU's to reduce the loading on the one remaining fuel cell. Flight controller, instrument, trim panel, and HUD power were cycled on only when required. An RCS DRIVER TEST was added to Part 2 between the sensors and the FCS mode/channel switch tests. This was in compensation for not performing the RCS hot fire test.

Prior to the sensors test, TACANS, MLS's, RA's and AA's were powered on. Additionally, AV BAY 2 FAN A is powered and remains on until completion of the sensors test for RGA's and ADTA's. After the test, these units are powered off. RGA's and ADTA's are powered for the second part of the sensors test. Again, these units are unpowered immediately after the test.

For the RCS driver test, the DAP was checked to free drift. SPEC 41 was used to first select RJDF and then execute the test. Procedures had the crew record any failed jet, advise the MCC, and CONTINUE. The test was repeated for RJD-A and RJD-B. The final step instructed the crew to reset jet counters via SPEC 23, item 47.

The remainder of Part 2 followed the nominal checkout aside from minimizing instrument, flight controller, and HUD power on time.

REFERENCES

1. GNC Systems Console Handbook, JSC-12843, apps. C and G, latest version.
2. Computer Program Development Specifications (CPDS), SS-P-0002-550L, vol. 5, book 5, p. 4-317, August 1, 1983.
3. Shuttle Calibration Data Book, vol. VIII, July 1988.
4. Level C Functional Subsystem Software Requirements, STS 83-0010B, GNC, Part D: Redundancy Management, section 4.7, June 30, 1987.
5. Shuttle Operational Data Book (SODB), JSC-08934, vol. I, rev E, sec. 3.4.5.1, Jan. 1988.

TITLE

GNC Pre-sleep Checklist

PURPOSE

To aid flight controllers in pre-sleep activities.

BACKGROUND

Standard presleep activities are documented in the FDF Orbit Ops Checklist. There are no GNC related items in that document, however there are standard checks made by the GNC flight control team, prior to the good-night call, which should be performed. This SCP was developed to document those checks, and serve as a training tool for new flight controllers, and a reminder to experienced personnel.

PROCEDURE

- STKR's in Track (VP 4000 HEX)
- All Flight Controller power off, DDU cb's out
- Confirm future maneuvers during sleep (if any)
- Check DAP config
 - Vern/Tail only
 - Set up for DEU Equivalent maneuvers (if any)
 - Confirm IMU switching not a problem
- Confirm IMU's will not exceed RM prior to wake-up

TITLE

MISSION CONTROL CENTER (MCC) TELEMETRY DATA PROCESSING

PURPOSE

In order to verify (in real time) the MCC displayed engineering units of a parameter. Also, in the investigation of anomalies which are observed on console displays, it may be necessary to know how a parameter is processed in the MCC before reaching the console display.

BACKGROUND

Telemetry data arrives at the Front End Processor (FEP) in several different formats (all of which are in units of Pulse Code Modulation (PCM) counts) from the Orbiter Pulse Code Modulation Master Unit (PCMMU). The FEP is responsible for recognizing the different formats and converting the PCM counts to meaningful engineering units for display on consoles. It has been seen that seemingly anomalous values or discrepancies between two parameters can be traced to the way the parameter(s) are processed in the FEP.

Several of the downlist data types make use of two's complement form. The following is a brief review: Two's complement form is a method used to express a negative number in binary, octal, and hexadecimal which do not have signs like decimal. A number which is known to be negative is converted (in binary form) to two's complement by reversing each bit (one's complement) and adding 1. The following example should jog the memory:

absolute value of number	00101100
one's complement	11010011
	<u>+ 1</u>
two's complement	11010100

Most binary numbers have an extra bit which gives the sign of the number. This bit, the sign bit, is typically the left most bit in the data word. If the sign bit is 1, the number is negative and expressed in two's complement. Otherwise, the number is positive and expressed in straight binary.

PROCEDURES

A. OBTAIN THE MSID OF THE PARAMETER OF INTEREST

There are several sources from which an MSID can be obtained for a given parameter. Probably the fastest is to click on the parameter on a MSKview display, if one is available. In addition MSID's can be found in the G&C Console Handbook Appendices or on a Space Shuttle Systems Handbook drawing.

B. DETERMINE THE DOWNLIST DATA TYPE

Data in the downlist is formatted in several different ways depending on the parameter and its uses. The Mission Information System (MIS) is a quick and easy method to get the data type and calibration curve. It contains only calibrations and MSID's listed on the Shuttle Data Tape, and so should not be considered a final authority. To obtain the desired information, access MIS from the Global Apps menu on the Master DNAV and select Query. Build a query or use an existing query such as 'msidtlm' to find the Data Type.

The data types are described in the MML Vol. 1, table 3-IV. Additional information can be found in the MCC Level B&C Requirements document, section 5.2.4. The most common type for GNC parameters is Analog MDM Bipolar (AMB) which is a 10 bit data word whose value ranges from -512 to +511 PCM counts that goes through an MDM and GPC to the PCMMU. AMB data is sent down in a 16 bit word. The right-most 6 bits are always zero and are thrown out. It looks like this in binary:

BIT	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Value	512	256	128	64	32	16	8	4	2	1	--	--	--	--	--	--
\\\\\\	S	MSB	X	X	X	X	X	X	X	LSB	0	0	0	0	0	0

where: S is the sign bit, 0 → positive, 1 → negative*
 MSB is the Most Significant Bit
 LSB is the Least Significant Bit
 X is a 1 or a 0
 *negative numbers are expressed in two's complement form

Other types that are likely for GNC parameters are AMU, BCD, BD, BMD, BSS, and BMS, all of which are explained in the above documents.

C. OBTAIN CALIBRATION CURVE

The FEP applies a calibration (cal) curve to the incoming (PCM count) value of a parameter to convert it to Engineering Units. The calibration curve is a fifth order polynomial of the form:

$$Y_{EU} = A_0 + A_1X + A_2X^2 + A_3X^3 + A_4X^4 + A_5X^5$$

where: Y_{EU} is the value in engineering units
 X is the value in PCM counts
 A_i are the cal curve coefficients (i=0,1,2,3,4,5)

For most applications, only the first two terms (A_0 and A_1X) are used and the remaining coefficients are set to zero. The cal curve is usually where the answer to problems are found, either in unexpected values or signs of the coefficients, so look at the data carefully.

To obtain the cal curve for the parameter of interest, access the Telemetry Services from the Global Apps menu on the Master DNAV. The users manual can be found on the CSOC Document & Data Control System (DDCS) web site at <https://csoc-ddcs.csoonline.com>. From

the web site, select Online Library and perform a search for Document Number LOR-TR1742. The document name is Consolidated Communications Facility (CCF) Software User's Handbook Volume III - TELECOM Position, and section of interest is 3.6 TELEMETRY SERVICES.

D. OBTAIN DETAILED VALUES OF PARAMETER OF INTEREST

A Parameter readout from the FEP can be obtained using the Telemetry Services Function found on the Global Apps menu on the Master DNAV. The users manual to help with this function can be found on EDP as described in previous paragraph.

E. OFF SCALE DETERMINATION

In order to prevent unreasonable values of a parameter from being displayed on a console, the FEP substitutes off-scale high and low indications ("H" and "L") for a parameter whose PCM counts have exceeded limits. These limits vary with the format of the data word. They are listed in section 5.2.4.1 - Off-Scale Determination, of the MCC Level B & C requirements. The following is included for reference only:

Data Format	Off-scale limit LOW	Off-scale limit HIGH
OI 8 bit unipolar	0	250
OI 8 bit bipolar	-125	125
GPC 10 bit unipolar	0	500
GPC 10 bit bipolar	-500	500

unipolar = unsigned

bipolar = signed

F. EXAMPLE

In a generic simulation, during the aft RHC portion of the aft Controller Checkout, two strange things were seen. On the GNC ORBIT display, at one time the roll axis showed two transducers off scale high and one at -89.5 percent. Later on, in the pitch axis, two transducers were off scale low and the third was at 78.0 percent. This at first seems to indicate bad transducers.

First, the MSIDs are easily determined to be V72K1245C, 55C, 65C, 46C, 56C, and 66C. Using MIS Query, V72K1245C was determined to be a data type AMB. The others are also type AMB. This tells us that the full range of the word in PCM counts is -512 to +511. In addition, the FEP shows off-scale low if the PCM count value is less than -500 and shows off-scale high if the PCM count is greater than +500.

Next, the cal curve is obtained giving coefficients of:

$$A_0 = 0 \quad A_1 = -0.19838552$$

Note that the second coefficient is negative.

Using these coefficients in the equation $Y_{EU} = A_0 + A_1X$ for a roll axis value of -89.5% and solving for X (PCM counts) yielded a value of +451 PCM counts for the one transducer while the other two transducers were off-scale high indicating values greater than or equal to 500 PCM

counts. This means that the three transducers were all within about 60 PCM counts, much closer than might be thought at first glance. The same thing holds for the roll axis.

In this case it turns out that the aft RHC cal curve is different than the FWD RHC's by a sign in the roll & pitch axes. This was done so that the output of the aft RHC would appear on the ground telemetry in Orbiter coordinates rather than RHC coordinates.

TITLE

TRAJECTORY CONTROL SENSOR (TCS) PERFORMANCE MONITORING

PURPOSE

This SCP serves as a guide to monitoring the performance of the TCS during nominal operations. Possible responses to certain failure scenarios are also discussed.

PROCEDURE

BACKGROUND

The TCS is a payload bay mounted laser range finder used primarily for providing range and range rate information to the Shuttle commander during rendezvous, prox ops, and docking operations with the ISS. Commands are sent and data received via an RS422 cable and a Windows-based Command and Display Software (CADS) program running on a Payload and General Support laptop computer (PGSC). Ground telemetry is downlinked via a separate path through the Payload Data Interleaver (PDI).

The unit outputs a raw range between itself and any of a number of laser reflectors mounted around the ISS docking interface. The CADS sends this data to the Rendezvous/Prox Ops Propagator (RPOP) program which blends it with other sources (radar, hand-held laser marks, etc) to provide true interface-to-interface values more useful to the crew. Conversely, the CADS can receive data from RPOP (i.e., seed range) and can be set to automatically attempt target acquisitions at a specified range. The GNC officer is generally responsible for TCS/CADS operations; the Rendezvous GPO is responsible for RPOP. Further details of TCS hardware and CADS can be found in the TCS Systems Brief.

TCS is usually flown as a single unit, however, a second unit (with its own PGSC and RS422 cabling) may be flown as mission constraints dictate. The units are designated TCS 1 (identified on the downlinked data by P77xxxxx MSID's) and TCS 2 (P78xxxxx MSID's). If only a single unit is flown it usually occupies the TCS 2 slot in telemetry. The TCS1-2 distinction is important since each unit uses unique initialization parameters (contained in the *cad.ini* file) which assume a unique location in the payload bay. Should the units be swapped (as happened on STS-88), inaccurate interface-to-interface measurements may result.

MCC MONITORING

TCS is unique among the various GNC systems in that the data is downlinked in the PDI data stream (similar to other payloads). In order for the MCC to receive the data, a PDI Telemetry Format Load (TFL) that supports TCS data must be loaded (either by the crew or by INCO). These TFL's are built preflight and can be found in the flight-specific Orbit Ops Flight Supplement (COMM/INST Section). Typically two TFL's to support TCS are built, one prime and one backup incase the prime PDI Decommutator (Decom) fails.

MCC tools for monitoring TCS include MSKView, ELOG, CRANS, and RTPlot. In order to display the data, ISP servers for each TCS must be started (GNC > ISP > Start TCS Servers) on any workstation. Once TCS monitoring is complete the servers may be shut down (GNC > ISP > Stop TCS Servers).

TCS is also unique in that a second method exists to monitor data independent of the workstations. Early in the TCS development program the MCC was unable to process the TCS downlink. A workaround was found in a program call PCDecom running on a PC platform (the TSTAC) which stripped and formatted the TCS downlist from the orbiter 128 kb data stream. The data was then sent to users via dedicated data lines for display on another PC running a ground-based version of TCS CADS. Ground CADS emulates the onboard CADS and can display (and record) any of the data the crew sees. Although this is not required for missions, Ground CADS can supplement the MCC displays by showing parameters not currently available to the MCC stream (e.g., seed range). Data ports from the TSTAC exist behind the GNC Support console, on the right side of the GNC console, and also at the Rendezvous GPO and GPO Support positions (the GPO's are also in charge of the TSTAC). The MER also has a port for use by the TCS engineering team.

Operators interested in using Ground CADS should check out a laptop PC prior to their flight (DA9/Ron Wyrick at x32658 has PC's laptops available for checkout) and see Dave Weiler (x32666) for a copy of the Ground CADS software. NOTE: Due to the limitations of the TCS SMS model it is not recommended to run Ground CADS for simulations.

NOMINAL PROCEDURES

TCS procedures are flown in the flight-specific Rendezvous Checklist (Rendezvous Tools Section 7). There are three main procedures – TCS Activation, Manual Acquisition and Deactivation. TCS Activation powers up the CADS/TCS and sets it up to automatically acquire at a specific range (as determined by RPOP). TCS Manual Acquisition is for use as an any-time acquire when RPOP may or may not be available. TCS Deactivation secures the unit for entry and powers it off. Additionally a TCS Limits info-only page shows the alert/autosafe limits that are set in the unit by the *cad.ini* file.

Other procedures which may be of interest include the PGSC Setup pictorial and the Rndz Tools Troubleshooting page (section 7) which the crew uses to verify/troubleshoot their PGSC setup. The ISS Approach Cue Card (Section 9) is also useful in that it gives both interface-to-interface and raw TCS ranges to target. This is very useful for monitoring DAP configs, etc. (including PCT) in the late stages of docking.

TCS Activation

1. CADS Bootup

Crew : The crew checks that the PGSC is on and configured per the Setup pictorial. The CADS is started prior to turning on the TCS unit. If the TCS unit is powered prior to CADS , the initialization parameters which are normally passed to the unit as part of its powerup would not be available and would have to be sent manually.

MCC : The MCC has no insight into step 1.

2. TCS Pwrup/Initialization

Crew : The TCS power switch (location is flight specific but is usually on the L12 Standard Switch Panel) is activated and the associated talkback is checked. The unit will go through an internal self test and will unlock the Z-axis latch which is normally locked to prevent movement during ascent/entry. Assuming the CADS is running when TCS is powered, the unit will request initialization parameters (PGSC time, new temperature and voltage limits, etc.) from the *cad.ini* file. After initialization is complete, the crew checks that the systems are nominal.

MCC : After the TCS is powered on, active telemetry should be seen on the MCC displays (check that the TCS server(s) is running). TCS ELOG should also begin logging messages as part of the initialization sequence. Note any items not in the config listed in step 2.

3. Time reference Select

Crew : The time sent to the TCS unit in step 2 is whatever time the PGSC is set to. In order to synchronize messages onboard (and in telemetry), the crew sets the unit time to MET.

MCC : ELOG should log a 'TCS Clock has been Set' message and the ELOG timetags should begin to correspond to MET.

4. Enable Auto Acquisition

Crew : The crew usually performs this step so that TCS can be left in a "hands-off" config during the rendezvous. At the entered range (as determined by RPOP) TCS will open its shutter and begin trying to acquire the target. It will continue to attempt acquisitions until it locks on to the target or until it is commanded to stop. As it tries to acquire the target, TCS will continue to get the latest range info (i.e., seed range) from RPOP.

If RPOP is not running, a manual acquisition at the desired time will have to be performed since CADS would not know the current range to target. Manual attempts would need to be repeated as required.

MCC : The MCC has no insight into this step, although the crew should voice down what range was entered. At that range, the MCC should see the TCS shutter open and acquisitions begin. ELOG will generate messages periodically updating the status (i.e., not tracking, acquiring, tracking, etc.).

TCS Manual Acquisition

This procedure is typically performed any time RPOP may be unavailable to provide good seed ranges. Prior to undocking and before good sensor updates occur, RPOP typically will be initialized with an orbiter c.g.- to- ISS c.g. range which would cause the TCS to search for a target at a greater range (on the order of 50 feet) than desired (around 4 feet). This would cause the laser gain to be larger than required and would probably saturate the laser receiver (APD). For this reason, the manual acquisition procedure is desired for TCS operations while docked.

The Manual Acquisition Step 1 can also be performed if there is a delay in docking to ISS and TCS has been powered off at the switch in order to stabilize temperatures. Once TCS has been powered back up, the crew can then perform Manual Acq. Step 1.

1. Acquire

Crew : The crew checks the system config (the continuous-wave (CW) should be the default laser when the unit is in Standby, and the skin tracking and attitude determination functions are currently deactivated in the *cad.ini* file). The Acquisition Macro command is selected, which brings up a window requesting info on where to start the target search. The crew enters their best estimate at range (they can enter "0" for Az and El) and checks that the 95% range gate option is not selected. If checked, the range gate option would mean that whatever TCS locks on to must be within $\pm 5\%$ of the estimated range or it will be rejected. It is recommended that this option be disabled.

The crew sends the target info and the TCS begins the sequence. If the shutter is closed it will be commanded open and acquisition attempts will begin. If the TCS does not acquire, the crew should periodically reissue the command in order to update the target estimate.

MCC : The MCC should verify the TCS shutter opening (if closed) and acquisitions begin. ELOG will generate messages periodically updating the status (i.e., not tracking, acquiring, tracking, etc.).

2. Enable RPOP TCS Nav

Crew : Once good tracking data is acquired, the crew enables RPOP to receive the data. If RPOP is not available then this step does not need to be performed.

MCC : No GNC insight, although the Rendezvous GPO may be able to tell from their data if this has been done.

3. Enable Auto Acquisition

Crew : This step is only performed if RPOP is available to provide seed range updates after TCS is initially locked on. Should TCS drop lock on the target, it can then use RPOP range to automatically get the best estimate of range in an attempt to reacquire. The crew sets both the Auto Seed Update and Auto Acquisition options to occur until the orbiter is out of practical TCS range (typically approximately 5000 ft).

If RPOP is not available, this step does not need to be performed. If TCS drops lock, it will continue reacquire attempts using its last valid range. The crew can also manually update the range estimate if needed.

MCC : No insight.

TCS Deactivation

1. Shutdown

Crew : The crew issues the Shutdown macro command which terminates tracking, modes the unit to Standby, and closes the shutter.

MCC : Tracking will cease, and the TCS display and ELOG should reflect the unit mode and shutter status.

2. Secure Z Axis

Crew: This step secures the TCS for entry and only needs to be performed if this is the final deactivation for the flight. **Note** : If the TCS unit is powered on after this procedure is complete, the unit firmware will unlock the latch. The PGSC/CADS will need to be reconnected to secure the latch again.

MCC : The TCS display and ELOG will reflect the status of the latch.

3. Powerdown

Crew: The crew powers off the TCS unit at the switch and closes the CADS on the PGSC.

MCC : Once the TCS is unpowered, active telemetry on the displays will ceased. ELOG may show a message that the associated PDI Decom has lost lock.

OFF-NOMINAL PROCEDURES

TCS has no published malfunction procedures. The following represent suggestions of things to try, although mission events may dictate otherwise. The TCS program has generated a number of Ops Notes (currently available via the GNC Section web page) which may be helpful in some of these situations. TCS Engineering representatives in the MER (who monitor the GNC COORD loop) can also be consulted on any of these scenarios.

1. TCS Pwr tb – bp when should be tb-gray (or vice-versa)

a) This could be indicative of a real power problem, a switch failure or a talkback failure. Procedures call to cycle switch to see if problem clears.

- 1) If activation, check to see if valid telemetry is being received on CADS and MCC displays. If so, the TCS unit is receiving good power and the problem is likely the talkback.
- 2) If activation and no valid telemetry (crew or ground), assume either a switch problem or an internal TCS power problem. TCS power is isolated from the orbiter via 7A and 1A fuses (see SSSH 9.12); if either of these fuses blow TCS would be unrecoverable. EGIL should be consulted on bus signatures (could possibly try a switch scrub to clear the switch contacts) but TCS will probably be unrecoverable.
- 3) If deactivation, check to see if telemetry was lost when the switch was taken off (a nominal signature). If so, assume a talkback fail.
- 4) If deactivation and unit appears to be on when the switch is off, problem is probably at the switch. Scrub switch and consult with EGIL on possibly unpowering bus at its source.

2. TCS Self Test Failures

a) **“Transit” status displayed for shutter:** Could be indicative of shutter movement not completing successfully (slow motor, shutter jammed, etc.) or shutter physically opened/closed but microswitch failed.

- 1) Have a crewmember check status of the shutter by looking out the window. This will give you an indication if it is an actual shutter problem or microswitch failure.
- 2) If it is a shutter problem then send the command to open/close shutter. (Commands > Open (Close) Shutter). If it is a microswitch failure then there is no further troubleshooting.
- 3) If no joy in open/close command of the shutter, no further action. A partially open shutter may allow TCS to track when reflector in unobscured portion of field of view. Leaving the shutter open, when wanting it close, permits FOD and

dust to get inside the unit. This is not the best situation but if the unit does not respond to commands, we will bring it home in this configuration.

b) **“Transit” status displayed for Z-Latch:**

1) Commands > Lock (Unlock) Z Axis Latch

c) **“Dilemma” status for shutter:** Could be indicative that the movement did not complete successfully. The indications in a dilemma are Open = 1 AND Close = 1.

1) Override > Shutter Status

2) Commands > Open (Close) Shutter. NOTE: Motor drive time will be 2 sec. per command since Override command is present.

3) Can verify status of shutter (Open/Close) by having a crewmember look out the window

4) If needed, send several commands out until shutter is in desired position. A crewmember can look out the window after each command to see if (desired) movement is detected.

5) Override > Shutter Status

Removing the Override command and pressing on with nominal operations avoids the possibility of driving the shutter with the Override command and possibly damaging the hardware.

d) **“Dilemma” status for Z-Latch:** Could be indicative that the movement of the Z-Latch did not complete successfully.

1) Override > Z Axis Status

2) Command > Lock (Unlock) Z Axis Latch

NOTE: If needed, send one more command. This should be sufficient to lock/unlock latch. Failing to unlock/lock assumes mechanism is broken.

3) Override > Z Axis Status

Removing the Override command and pressing on with nominal operations avoids the possibility of damaging the hardware.

e) **CW/Pulse Laser : Indicative of either CW or pulse laser subsystem failure.**

1) After a 1-2 minute warm-up period, Power cycle to have the sensor(firmware) restatus all subsystem elements and/or to clear the problem. A reset can also be attempted but engineering community prefers a power cycle as it is the best and easiest troubleshooting.

- 2) If laser still failed, Override status (Override > Pulse Laser (CW laser) – status should change to ****Avail****). Attempt to press with nominal procedures. Possible performance degradation if problem is real.
- 3) Command > Acquire
 - ◆ If Pulse Laser failed, TCS may not be usable until range <1300 feet. If CW Laser failed, TCS may not be usable until range <66 feet.

c) Other Subsystems (galvanometers, APD, etc.)

- 1) Unit must be in STBY before commanding Self-Test (√ Commands > STBY).
- 2) Execute up to three self tests (Commands > Self Test) to attempt to clear problem. Press with nominal procedures, but if problem exists TCS may be unuseable.

3) Shutter Fails to Close/Open or Z Axis Latch Fails to Lock/Unlock

See procedures under Self Test Failures

4) TCS Not Acquiring Target

- a) Check nominal telemetry (shutter open, good calibrations).
- b) Check with the Rendezvous GPO that the target (and its retroreflectors) are in the TCS field of view (20 deg cone) or that relative rates are within limits (? deg/sec). Consider waiting until target is within 1000 ft if geometry is good but still no tracking.
- c) If receiving seed ranges from RPOP, check with Rendezvous GPO that RPOP performing nominally and that RPOP range estimates are valid (not saturating the APD). Command to Standby (Commands > Standby) and try to reacquire (Commands > Acquire, use the default range that appears in the dialog box). If RPOP seed ranges are suspect, Commands > Acquire and manually input a valid range via the resulting dialog box.
- d) If performing Manual Acquisitions, try to reacquire with a different range estimate. Make sure the 95% range gate feature is disabled.
- e) If no joy on all, consider power cycling unit (run TCS Deactivation and then Activation) and try again.

5) Temperature Limit Violations

- a) TCS has historically demonstrated an approximately 3.5 hr run time prior to violating its upper thermal limits. Lower limits have never been encountered operationally. The unit is initialized to mode to Autosafe (a subset of Standby) if the Autosafe temperature is exceeded for one minute. An alert pop-up window will begin warning the crew when a temperature hits 5 degrees C below the autosafe limit. Once Autosafed, the unit will have to be deactivated (powered off) until it cools below the limit again. The autosafe temperature limits are documented in the crew procedures.
- b) If desired, the pop-up messages may be inhibited (Override > Popups > Temperature). This does NOT inhibit the autosafe feature.
- c) The run time is usually accounted for in the timeline callouts of the Rendezvous checklist (i.e., a nominal timeline should not violate the limits). If docking is delayed for a significant period, consider Deactivating the unit until it is needed. RTPlots have been built to aid in temperature trending.
- d) If it appears the unit is about to autosafe itself, autosafing can be overridden (Override > Auto Safing) or changed (Commands > Send TCS Limits). Operating the unit above the set temperatures could cause degraded outputs and/or hardware damage so only use these feature if the TCS data is absolutely required.

6) MCC Not Receiving TCS Data

- a) Check to see if the crew has data. Since they receive their data through a different path, a loss of both MCC and crew data would indicate a TCS unit problem. If the crew does not have data, consider power cycling the unit and re-running the Activation or Manual Activation procedures.
- b) If the crew has data, check with the Rendezvous GPO (or TCS engineering support in the MER) to see if the TSTAC is receiving and outputting TCS data. Loss of both TSTAC and ISP data could indicate an MCC problem or a PDI problem. INCO should be able to tell if the problem is with the PDI – consider using a backup TFL if needed. If the PDI is nominal and the correct TFL is loaded, the problem is probably in ISP or somewhere else in the MCC. Contact the GNC GA if needed, but as long as the crew has good data consider doing nothing.

7) Crew Not receiving TCS Data

- a) See 6a.
- b) If MCC is receiving good data, send the crew to Rndz Tool Troubleshooting (TCS CADS Not Receiving TCS Data) in Section 7 of the Rendezvous checklist. Step 2 of this procedure will have the crew check their PGSC port configuration (Config > Com port). This will bring up a window showing comm port, baud rate, parity, byte size, and stop bits. Typically these values should be COM 2, 19200 baud rate, 8 data bits, no parity, and 1 stop bit (SMS values are same except for baud rate is 9600). The correct comm port can also be verified in the PGSC Setup pictorial.

Case	Problem	Troubleshooting
1	<p>“Transit” status displayed for shutter or Z-Latch</p> <p>**Possible failures:</p> <p>1) Mechanism did not physically open/close (lock/unlock) (slow motor, shutter jammed, etc.)</p> <p>2) Mechanism physically opened/closed (locked/unlocked) but microswitch failed</p>	<p>TCS C&DI</p> <p>Shutter: √ Shutter Status - have crewmember look out the window. If shutter in desired position, possible microswitch problem, no action. Commands > Open (Close) Shutter</p> <p>Z-Latch: Commands > Lock (Unlock) Z Axis Latch</p> <p><i>Ref: TCS OPS NOTE 1 and TCS Engineering</i></p>
2A	<p>“Dilemma” status for shutter</p>	<p>TCS C&DI</p> <p>Override > Shutter Status Commands > Open (Close) Shutter Verify Shutter Open/Close by having crew look out window. If needed, send repeated commands until shutter is in desired position. Crewmember looks out window after each command to see if (desired) movement is detected. Override > Shutter Status (Removing Override avoids possibility of damaging the hardware)</p> <p>*NOTE: With OVERRIDE present, motor only drives for ~2 sec. for each cmd.</p> <p><i>Ref: TCS OPS NOTE 2</i></p>
2B	<p>“Dilemma” status for Z-Latch</p>	<p>TCS C&DI</p> <p>Override > Z Axis Status Commands > Lock (Unlock) Z Axis Latch If needed, send 1 more command. This should be sufficient to lock/unlock latch. Failing to lock/unlock assumes mechanism is broken. Override > Z Axis Status (Removing Override avoids possibility of damaging the hardware)</p> <p><i>Ref: TCS OPS NOTE 2 and TCS Engineering</i></p>
3	<p>“Unrecognized Command - Ignored”</p>	<p>Ignore Message. TCS performance not affected.</p> <p><i>Ref: TCS OPS NOTE 3</i></p>
4	<p>Time off one minute</p>	<p>Commands > Set Time</p> <p>TCS performance not affected. Not critical, used as a convenience for post-flight analysis.</p> <p><i>Ref: TCS OPS NOTE 4 and TCS Engineering</i></p>

Case	Problem	Troubleshooting
5	Avalanche Photo Diode (APD) may become saturated at a close range, resulting in an invalid range value. (May occur while tracking distances of less than 5 feet.)	The error can NOT be corrected by the user. Data values should be disregarded if occurs when the range decreases to 5 feet or less. Other instances of APD saturated error should be ignored. <i>Ref: TCS OPS NOTE 5</i>
6	Pulse Laser Failed at initial start-up CW Laser Self-Test Failure	TCS C&DI Pulse Laser : Power cycle to have the sensor (firmware) restatus all subsystem elements and/or to clear the problem. NOTE: A reset command can also be attempted but power cycle is best and easiest TCS Power to OFF then ON If Pulse Laser still failed Override > Pulse Laser If needed, Commands > Acquire TCS may not be usable until range < 1300 feet CW Laser: Same as above. If no joy, TCS may not be usable at range < 66 feet. *If CW Laser Fail, expect possible data drop-outs at ~1300 feet when the Pulse and CW laser are attempting to hand-off to one another. <i>Ref: TCS OPS NOTE 6 and TCS Engineering</i>
7	Loss of all data updates on the CAD	Error can not be corrected by user; however, a power cycle can be attempted to correct the hardware failure, and if no joy, sensor will be declared failed. <i>Ref: TCS OPS NOTE 7</i>
8	TCS Temp rates increasing and docking time is delayed	Power OFF TCS. Power ON TCS and run TCS Manual Acq. Step 1 <i>Ref: TCS Engineering</i>
9	Talkback bp when should be gray	If valid telemetry on CADS and MCC display - Good power, possible problem with talkback. If activation and NO valid telemetry (crew or ground) - assume either a switch problem or an internal TCS power problem. TCS power is isolated from orbiter via 7A and 1A fuses; if either of these fuses blow TCS unrecoverable. Consult EGIL on possible switch scrub to clear switch contacts; but, TCS will probably be unrecoverable.

Case	Problem	Troubleshooting
9a	Talkback gray when should be bp	<p>If deactivation and telemetry lost when switch taken off (nominal signature) - Assume talkback failure</p> <p>If deactivation and unit appears to be ON when switch is OFF - problem probably at the switch. Scrub switch and consult EGIL on possible unpowering bus at its source.</p>
10	Other Subsystem Self-Test failures	<p>TCS C&DI</p> <p>Perform up to 3 self tests to clear failed indication. Unit must be in STBY before commanding self-test.</p> <p style="padding-left: 40px;">√ Commands > Standby Commands > Self Test</p> <p>Press with nominal procedures, but if problem exists TCS may be unusable.</p>
11	TCS Not Acquiring Target	<ol style="list-style-type: none"> 1) Check Nominal Telemetry (Shutter open, good calibrations). 2) Check w/ RNDZ GPO that the retroreflectors in the TCS field of view 3) If receiving seed ranges from RPOP, check with RNDZ GPO that RPOP performing nominally and RPOP range estimates valid. <ul style="list-style-type: none"> Commands > Standby Commands > Acquire (use default range in dialog box OR if RPOP seed range suspect, manually input a valid range via the resulting dialog box 4) If performing Manual Acq., try to reacquire with a different range estimate 5) If no joy, consider power cycling unit and try again (Run TCS Deactivation and Activation)
12	MCC not receiving TCS data	<ol style="list-style-type: none"> 1) If crew has data, no action and ask for occasional updates (MCC or PDI problem - could try using a backup TFL) 2) If crew does NOT have data, consider power cycling the unit and re-running Activation or Manual Activation procedures
13	Crew not receiving TCS data	<p>If MCC has good data, send crew to RNDZ Tools Troubleshooting (TCS CADS Not Receiving TCS Data) Section 7 of RNDZ book Step 2 to check their PGSC port configuration (Config > Com Port)</p> <p>If MCC also does not have good data, consider power cycle and re-running Activation or Manual Activation procedures.</p> <p>COM = 2, BAUD RATE = 19200(9600 SIM), PARITY = None, BYTE = 8 bits, STOP BITS = 1</p>

Title

SRTM Fly-Cast Ground Procedure

Purpose

This Standard Console Procedure (SCP) is to provide the GNC console operator with guidelines for the determination of the specific type of "Fly-Cast" burn and its associated parameters.

Background

It is assumed that the reader is familiar with the fly-cast single pulse and multi pulse methods and the general technique, involving use of DAP A and DAP B and the timing of RHC commands. Using a special "dummy" set of mass property I-loads, the Alt mode is used to cause firings of the +X jets to provided a desired delta-V (ΔV) while minimizing loads on the SRTM mast.

Further discussion of the DAP use for fly-casting may be found in:

1. R. Barrington, L. Sackett, M. Sarafin, "SRTM Fly-Cast Maneuver," STS-99 Orbit Flight Techniques Panel #1, February 26, 1999.
2. L. Sackett, "Fly-cast Loads Analysis Data," Draper Lab memo, SSV-98-027, August 19, 1998.
3. L. Sackett, R. Barrington, J. Hamelin, "Fly-casting DAP Recommendations, RHC Single Pulse, RHC Multi-Pulse, and Doublet/Triplet Procedures," Draper Lab presentation, May 21, 1998.
4. M. Sarafin, "SRTM Fly-Casting Burn Feasibility Study Results," Orbit Flight Techniques Panel #163, August 22, 1997.

The fly-cast procedure is designed to produce firings of the +X jets such that the deployed mast's yaw bending mode is not excessively excited. For purposes of the fly-cast, only this one mode and its period, P, are considered. The period is expected to be about 10.4 sec as indicated from pre-flight analysis/testing. Since the DAP has a cycle time of 0.08 sec, many values are rounded off to multiples of 0.08 sec. For example, one-sixth period (P/6) for the nominal period is rounded to 1.76 sec. It is convenient to use intervals that are multiples of the P/6 value and it is assumed that provides sufficient accuracy. The period is expected to change in the event of damper failures and by adding some margin, a range of P/6 from 1.52 to 2.64 sec will be assumed to be possible.

Tables are provided for finding DAP parameter values and RHC commands for both the single- and the multi-pulse fly-cast methods, and for producing doublets and triplets.

(L. Sackett, R. Barrington, J. Hamelin, "STS-99 SRTM Fly-Cast Delta-V Tables", Draper Lab memo, SSV-99-018A, June 30, 1999, Revised August 11, 1999)

All tables depend on the vehicle mass or weight in pounds and a value of one-sixth period of the yaw bending mode in seconds. Two vehicle weights are assumed, a heavy orbiter at 239018 lb. and a light orbiter at 236155 lb. The weights represent those expected at about 25% and 75% into the SRTM operations, using beginning and final weights taken from the STS-99 SODB amendment for events E-14 and E-22, respectively ("Shuttle Operations Data Book. Amendment 355", NASA/JSC, NSTS-08934, Vol.11, Amendment 355, October 30, 1998). The nominal value of one-sixth period is 1.76 sec.

The single pulse DAP I-loads are contained in category 0A6 and 0A7 (CA=6, CA=7). DAP configurations A14 and B 14 will be loaded with the required DAP parameter values (some of which must be changed depending on the desired delta-V).

The multi pulse DAP I-loads are contained in category 0A8 and 0A9 (CA=8, CA=9). DAP configurations A 15 and B 15 will be loaded with the required DAP parameter values (some of which must be changed depending on the desired delta-V).

Procedure

The following procedure is intended to be used with the tables provided in the Draper Lab memo SSV-99-018A "STS-99 SRTM Fly-Cast Delta-V Tables" noted above.

1. Determine desired burn type

Using the attached "GNC SRTM Burn Type Selection Worksheet" perform the following:

A. In the "Input" section of the worksheet:

Enter the orbiter weight, and desired ΔV from FDO (due by TIG - 1:30 hrs. Input P/6. (One sixth of the yaw period obtained from PRCS Pulse Test results.)
Select the best tables to use based on orbiter weight. (Heavy or light.)

B. In the " ΔV Available Options" section of the worksheet:

Evaluate the range of ΔV available for each burn type.

CAUTION

There are 30 versions of each table available to evaluate the burn criteria. One set each for a "heavy" and "light" orbiter. Each set contains 15 versions of each table based on a P/6 from 1.52 to 2.64 sec in 0.08 sec steps. Use care when selecting the appropriate tables.

CAUTION

Some tables have data that exceed the allowable ranges for P/6, rotation pulse size (RPS), and ALT delay time. Use care when selecting the minimum and maximum ΔV for each burn type. The worksheet provides the constraints to these parameters for each burn type.

Determine which burns are candidates based on required and available ΔV .

C. In the "Final Burn Selection" section of the worksheet:

Using Flight Rule X2.1.5-12.D, Fly-Cast Maneuver Constraints, select the appropriate burn type.

2. Complete worksheet for selected burn type

A. In the "Input" section of the worksheet:

Enter the orbiter weight, and desired ΔV from FDO.
Input P/6. (One sixth of the yaw period.)
Select the best tables to use based on orbiter weight. (Heavy or light.)

- B. Review the "Notes" section of the worksheet.
 - C. Complete the "Calculate Burn Parameters" section of the worksheet.
Carefully evaluate the required burn parameters per the worksheet instructions.
3. Data input to FDO (Due by TIG -00:45)
- A. Provide FDO with selected burn type.

Doublet, Triplet, General Single-Pulse, or General Multi-Pulse.
This allows FDO to select the appropriate burn pad.
 - B. Provide specific parameter data.

DAP A and B parameters as determined by the appropriate worksheet.
 - C. Provide any special pad notes as required on a case by case basis.
4. Review Burn Pad
- When FDO publishes the burn pad, review for correctness.

GNC SRTM Burn Type Selection Worksheet

Burn Name: _____ TIG: MET ___ / ___ : ___ : ___ . ___

----- **Inputs** -----

Weight from FDO: _____ , _____ lb P/6: ___ . ___ sec

Selected tables: 239,018 lb (heavy) Desired ΔV : ___ . ___ ft/sec
236,155 lb (light)

----- **ΔV Available Options** -----

Candidate?
Yes No

General Single-Pulse

minimum ΔV : ___ . ___ ft/sec (table 3, ALT on time: DAP B = 0.08 sec)

maximum ΔV : ___ . ___ ft/sec (table 3, RPS: DAP A = 1.00 deg/sec)

Single Pulse Doublet

minimum ΔV : ___ . ___ ft/sec (table 1 doublet, ALT on time: DAP A = 0.08 sec)

maximum ΔV : ___ . ___ ft/sec (table 1 doublet, ALT on time: DAP A = P/6 sec)

Single Pulse Triplet

minimum ΔV : ___ . ___ ft/sec (table 2, ALT on time: DAP A = 0.08 sec)

maximum ΔV : ___ . ___ ft/sec (table 2, ALT on time: DAP A = P/6 sec)

General Multi-Pulse

minimum ΔV : ___ . ___ ft/sec (table 4, RHC 1 with RPS: DAP B: = 0.01 deg/sec)

maximum ΔV : ___ . ___ ft/sec (table 4, RHC 3 with RPS: DAP B: = 1.00 deg/sec)

----- **Final Burn Selection** -----

Per Flight Rule X2.1.5-12.D, Fly-Cast Maneuver Constraints, select the appropriate burn type.

General Single-Pulse

Single-Pulse Doublet

General Multi-Pulse

Single-Pulse Triplet

Approved by:
GNC _____

General Single-Pulse Burn Worksheet

Burn Name: _____

TIG: MET ___ / ___ : ___ : ___ . ___

----- Inputs -----

Weight from FDO: ___ , ___ lb

P/6: ___ . ___ sec

Selected tables: 239,018 lb (heavy)
236,155 lb (light)

Desired ΔV : ___ . ___ ft/sec

----- Notes -----

- For the general single-pulse method, only one RHC +pitch command is required.
- The general single-pulse can be used for a wide range of ΔV s.
- **For a given P/6, the table should only be used for DAP B Alt on-times \geq to P/6.**
- For the general single-pulse method, the first firing is equal to P/6, then no firing for P/6, then a middle firing greater than or equal to P/6, then no firing for P/6, then a final firing for P/6.
- **Only values of RPS (rotation pulse size) equal to or less than 1.00 deg/sec are allowed.**
- **For STS-99, the ALT on-time keyboard item entry limit has been increased from 9.99 to 30 sec.**
- The DAP A Alt on-time and Alt delay time, and the DAP B Alt delay time should be set to P/6
- Use DAPs A14 & B14. DAP switching during the burn is required.

----- Calculate Burn Parameters -----

Step numbers in the following procedure refer to SINGLE-PULSE FLY-CAST MANEUVER: +X
RCS BURN (ORB OPS 99 FS, FLY-CAST MNVRS)

- A. Select the appropriate table 3 for orbiter weight and P/6. Use Draper Fly-Cast Delta-V Table page _____.
- B. Record the closest value of ΔV (DV) with respect to the FDO requested ΔV under "DV". Do not interpolate.

ΔV selected = ___ . ___ ft/sec

- C. Record the following associated values from the selected row and record in the burn pad for entry into the crew procedure:

Enter the following from Table 3 or noted source	Value	Enter value in crew procedure Steps 3 & 5*
RPS DAP A	__ . __ __	PRI ROT PLS - ITEM 53 + _____ EXEC
Alt on-time DAP A <i>Enter known value of P/6</i>	__ . __ __	ALT ON TIME - ITEM 61 + _____ EXEC
Alt delay DAP A <i>Enter known value of P/6</i>	__ . __ __	ALT DELAY - ITEM 62 + _____ EXEC
RPS DAP B <i>Enter DAP A RPS**</i>	__ . __ __	PRI ROT PLS - ITEM 53 + _____ EXEC
Alt on-time DAP B	__ . __ __	ALT ON TIME - ITEM 61 + _____ EXEC
<i>Enter known value of two time P/6 (P/6* 2 = _____)</i>		While SECOND PULSE FIRING or TIG + _____ sec
Enter Total On Time (Same as DAP A reselect time)		After SECOND PULSE STOPS FIRING or TIG + _____ sec

* Data is recorded in burn pad for read up to crew.

** Used in Single-Pulse crew procedure to determine both DAP A and DAP B RPS settings (ITEM 53), even though listed as DAP A only in Draper Tables.

Approved by: GNC _____

Doublet Burn Worksheet

Burn Name: _____ TIG: MET ___ / ___ : ___ : ___ . ___

----- Inputs -----

Weight from FDO: _____ , _____ lb P/6: ___ . ___ sec

Selected tables: 239,018 lb (heavy) Desired ΔV : ___ . ___ ft/sec
 236,155 lb (light)

----- Notes -----

- **For a given P/6, the table should only be used for Alt on-times less than or equal to P/6.**
- For the single pulse method, only one RHC +pitch command is required.
- Doublets can be used for smaller ΔV s.
- The possible ΔV s may overlap with Triplet and General Single-Pulse methods.
- For a doublet, the leading edges of the sequential firings occur approximately every half period (P/2).
- Use only DAP A14. DAP switching during the burn is not required.

----- Calculate Burn Parameters -----

Step numbers in the following procedure refer to DOUBLET/TRIPLET FLY-CAST MANEUVER:
+X RCS BURN (ORB OPS 99 FS, FLY-CAST MNVRS)

- A. Select the appropriate table 1 (Doublet) for orbiter weight and P/6. Use Draper Fly-Cast Delta-V Table page _____.
- B. Record the closest value of ΔV (DV) with respect to the FDO requested ΔV under "Doublet DV RHC1". Do not interpolate.

ΔV selected = ___ . ___ ft/sec

- C. Record the following associated values from the selected row and record in the burn pad for entry into the crew procedure:

Enter the following from Table 1 or noted source	Value	Enter value in crew procedure Steps 3 & 5*
RPS	___ . ___	PRI ROT PLS - ITEM 53 + _____ EXEC
Alt on-time DAP A	___ . ___	ALT ON TIME - ITEM 61 + _____ EXEC
Delay DAP A	___ . ___	ALT DELAY - ITEM 62 + _____ EXEC
Total Procedure time	___ . ___	✓ Burn complete in ___ sec

* Data is recorded in burn pad for read up to crew.

Approved by: GNC _____

Triplet Burn Worksheet

Burn Name: _____ TIG: MET ___ / ___ : ___ : ___ . ___

----- **Inputs** -----

Weight from FDO: _____ , _____ lb P/6: ___ . ___ sec

Selected tables: 239,018 lb (heavy) Desired ΔV: ___ . ___ ft/sec
236,155 lb (light)

----- **Notes** -----

- For the single-pulse method, only one RHC +pitch command is required.
- Triplets can be used for smaller ΔVs.
- The possible ΔVs may overlap with Doublet and General Single-Pulse methods.
- For a given P/6, the table should only be used for Alt on-times less than or equal to P/6.
- For a triplet, the adjoining leading edges are separated by P/3.
- Use only DAP A14. DAP switching during the burn is not required.

----- **Calculate Burn Parameters** -----

Step numbers in the following procedure refer to DOUBLET/TRIPLET FLY-CAST MANEUVER:
+X RCS BURN (ORB OPS 99 FS, FLY-CAST MNVRS)

A. Select the appropriate table 2 for orbiter weight and P/6. Use Draper Fly-Cast Delta-V Table page _____.

B. Record the closest value of ΔV (DV) with respect to the FDO requested ΔV under "DV". Do not interpolate.

ΔV selected = ___ . ___ ft/sec

C. Record the following associated values from the selected row and record in the burn pad for entry into the crew procedure:

Enter the following from Table 2 or noted source	Value	Enter value in crew procedure Steps 3 & 5*
DAP A RPS	___ . ___	PRI ROT PLS - ITEM 53 + _____ EXEC
DAP A Alt on-time	___ . ___	ALT ON TIME - ITEM 61 + _____ EXEC
DAP A Alt delay	___ . ___	ALT DELAY - ITEM 62 + _____ EXEC
<i>Enter 3 times on_time plus 2 times the delay_time (3*ON_TIME)+(2*DELAY)</i>	___ . ___	✓Burn complete in _____ sec

* Data is recorded in burn pad for read up to crew.

Approved by: GNC _____

General Multi-Pulse Burn Worksheet

Burn Name: _____

TIG: MET ___ / ___ : ___ : ___ . ___

----- **Inputs** -----

Weight from FDO: ___ , ___ lb

P/6: ___ . ___ sec

Selected tables: 239,018 lb (heavy)
236,155 lb (light)

Desired ΔV : ___ . ___ ft/sec

----- **Notes** -----

- For the general multi-pulse method, four or more RHC commands are required (2,N, 1), where N is an integer of one or greater.
- The general multi-pulse can be used for large ΔV s.
- **For the general multi-pulse method, the first firing is equal to P/6, then no firing for P/6, then a middle firing greater than P/6, then no firing for P/6, then a final firing for P/6.**
- **Only values of RPS (rotation pulse size) equal to or less than 1.00 deg/sec are allowed.**
- **The DAP A Alt on-time and Alt delay time, and the DAP B Alt delay time should be set to P/6**
- Use DAPs A15 & B15. DAP switching during the burn is required.

----- **Calculate Burn Parameters** -----

Step numbers in the following procedure refer to MULTI-PULSE FLY-CAST MANEUVER: +X
RCS BURN (ORB OPS 99 FS, FLY-CAST MNVRS)

- A. Select the appropriate table 4 for orbiter weight and P/6. Use Draper Fly-Cast Delta-V Table page _____.
- B. Record the closest value of ΔV (DV) with respect to the FDO requested ΔV under "DV". Typically, pick the fewest number of RHC commands necessary for a particular DV. Do not interpolate.

ΔV selected = ___ . ___ ft/sec

Number of RHC commands: ___

- C. Record the following associated values from the selected row and record in the burn pad for entry into the crew procedure:

Enter the following from Table 4 or noted source	Value	Enter value in crew procedure Steps 3 & 5*
RPS DAP A	__ . __ __	PRI ROT PLS - ITEM 53 + _____ EXEC
RPS DAP B	__ . __ __	PRI ROT PLS - ITEM 53 + _____ EXEC
Alt on-time DAP B	__ . __ __	ALT ON TIME - ITEM 61 + _____ EXEC
Enter known value of two time P/6 (P/6* 2 = _____)	__ . __ __	While SECOND PULSE FIRING or TIG + ____ sec
Enter selected number of RHC Pulses (RHC#N)	_____	_____ PULSES (+ PITCH) per burn pad
Enter calculated value of $\{[4*(P/6)]+[(#N)*(B ALT_ON_TIME)]\}$	__ . __ __	After LONG PULSE STOPS FIRING or TIG + ____ sec

* Data is recorded in burn pad for read up to crew.

Approved by: GNC _____

TITLE

ISS-DOCKING RATE MONITORING

PURPOSE

To document expected IMU Derived Body Rates just after docking with the International Space Station and phenomena which affect these rates.

PROCEDURE

IMU derived body rates at docking from past flights are provided for reference. The effects of stuck Androgynous Peripheral Docking System (APDS) docking dampers and environmental torques (centripetal acceleration, gravity gradient) interaction are discussed.

A. DOCKING MECHANISM DESCRIPTION

The APDS achieves capture, dynamic attenuation, alignment and hard docking of two spacecraft through the use of essentially identical mechanisms attached to each vehicle. The primary components of each docking mechanism include 12 pairs of structural hooks, an extendable guide ring with three petals, motor driven capture latches and guide petals and three low and three high energy electronic brakes (aka: dampers).

Three high energy dampers (HEDs) mounted on the APDS damp out relative axial motion induced by docking. Each docking pedal also includes a low energy damper to damp out yaw and pitch motion. Dampers may remain activated for up to five minutes following capture before power down is required to prevent overheating. For information on dampers, reference MMACS System Brief 16.1.2 Electromagnetic Dampers.

Five seconds after capture, APDS avionics energize the six dampers which cause six clutch mechanisms to engage with the ring drive and ball screw/nut gearing. The dampers slowly rotate an eddy current device which resists rotation in the ring kinematic system to reduce relative motion between the docking vehicles. Centering springs in the ring drive mechanism also apply a small force to maintain/regain ring alignment. Relative motion should be sufficiently damped within a minute of capture to allow the ring to retract to the final position (if aligned) or extended to the forward position (if not aligned). Since the dampers act against the centering springs to damp out relative motion when the ring is not aligned, alignment may not be achieved when the dampers are on. Visual cues and on-board telemetry can also detect when motion is damped out.

Once motion is damped, the ring is retracted for hard mating. After about 3 minutes 15 seconds of retraction, the Ready-to-Hook sensors are activated which initiate hook closure while the ring finishes retraction and secure interface pressure seals. MMACS System Brief 16.3.7 has a detailed docking mechanism sequence with rationale.

B. EXPECTED IMU DERIVED BODY RATES AT DOCKING

Figure 1.11-1 shows IMU Derived Body Rates for STS-110 docking. The x-axis is elapsed time of docking which occurs 00:00. These rates represent a nominal docking with no stuck dampers.

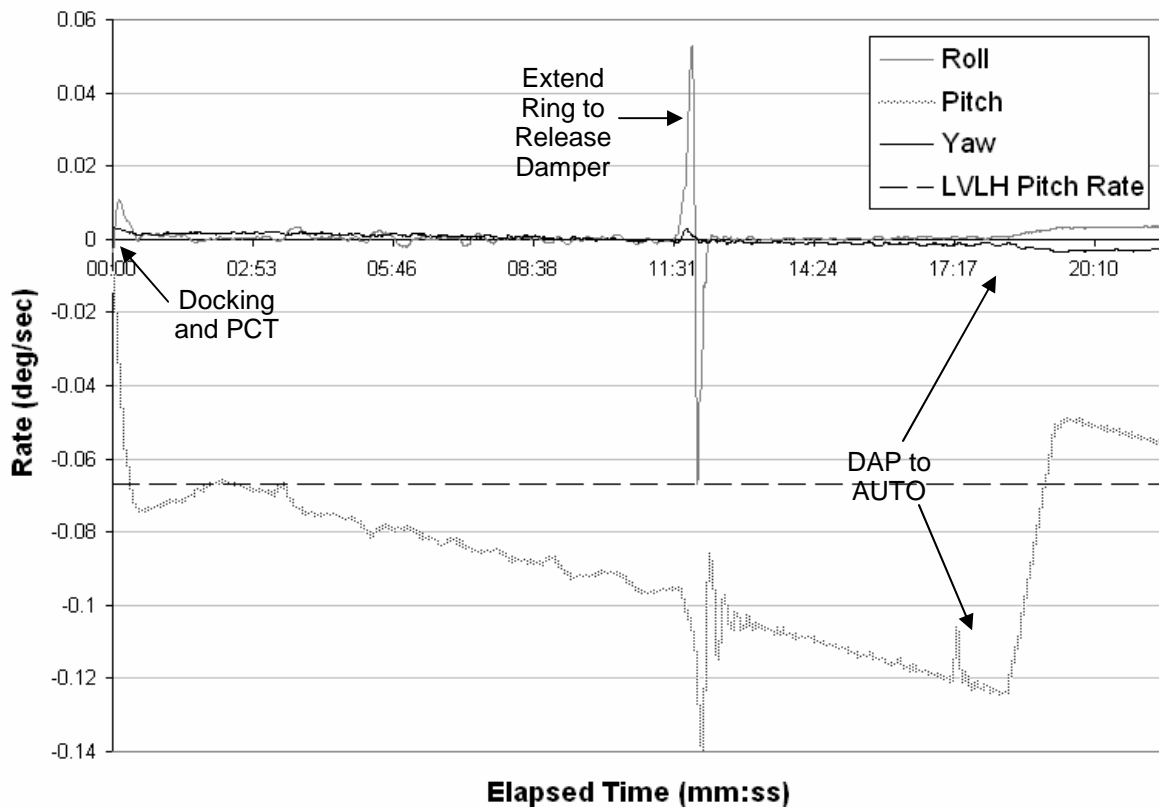


Figure 1.11-1. STS-110 IMU Derived Body Rates after ISS Docking.

C. EFFECT OF STUCK DAMPERS

Design limitations of the HEDs have led to a significant number of dockings with ring misalignment. Normally, the dampers are disengaged from the docking ring drive train prior to ring drive. However, damper clutches often remain engaged after the solenoid power is removed causing high resistive load and rapid misalignment of the guide ring. This resistance results in oscillations evident in the IMU Derived Body Rates with magnitudes near 0.15 deg/s and an initial period of about two minutes. Figure 1.11-2 shows example IMU derived body rates with a stuck damper from STS-114.

Table 1.11-1 lists which dampers have stuck on past ISS dockings and the axis of the resulting oscillations. From this data it is evident that a stuck number one damper tends to yield a roll oscillation and a stuck number two damper tends to yield a pitch oscillation. The only exception to this trend is STS-114 which had roll oscillations and a stuck number two damper. However, damper number one failed to fully lock right away which may have allowed roll movement.

Since MMACS APDS data is downlisted through Russian Capabilities GNC will notice oscillations about 5 seconds before MMACS can see a stuck damper. Figure 1.11-3 shows three examples of roll axis oscillations due to damper number one sticking on STS 102, 108,

111. Figure 1.11-4 shows three examples of pitch axis oscillations due to damper number two sticking on STS 97, 100 and 104. Note that STS-97 was a +Rbar docking.

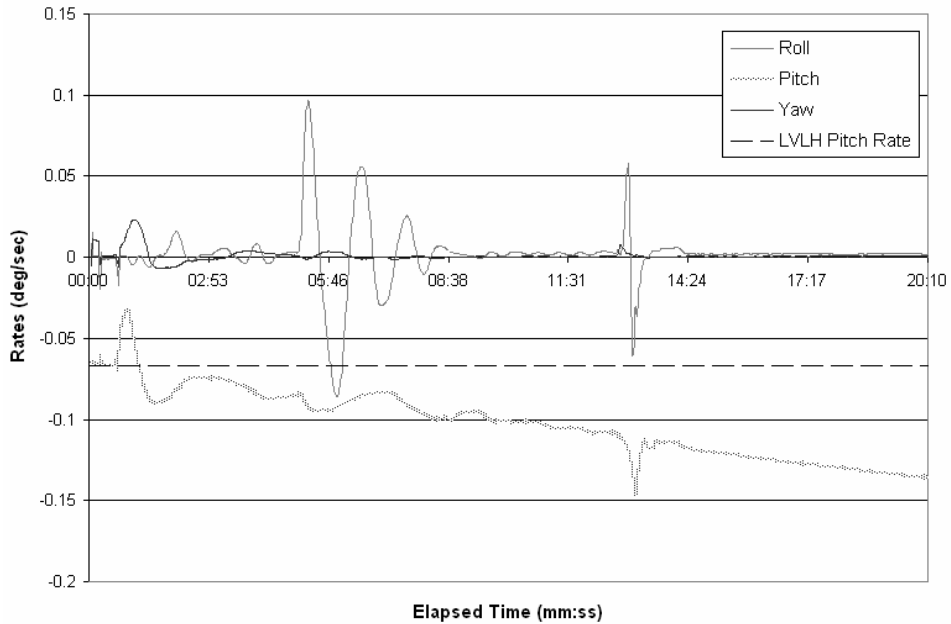


Figure 1.11-2. STS-114 IMU Derived Body Rates after ISS Docking.

OV	Mission	Oscillation Axis	Stuck Damper
103	92	Pitch	N/A
103	96	Small Pitch & Roll	N/A
104	98	Small Roll	N/A
104	101	Small Pitch	N/A
104	106	Small Pitch	N/A
104	110	None	N/A
105	113	Pitch	N/A
103	102	Roll	1
103	105	Roll	1
105	111	Roll	1
104	115	Roll	1
104	112	Roll	1, 3
103	121	Roll	1, 3
105	108	Roll	1, 2
103	114	Roll	2
105	100	Pitch	1, 2
104	104	Pitch	1, 2
105	97	Pitch	2

Table 1.11-1. Stuck damper history of ISS Dockings

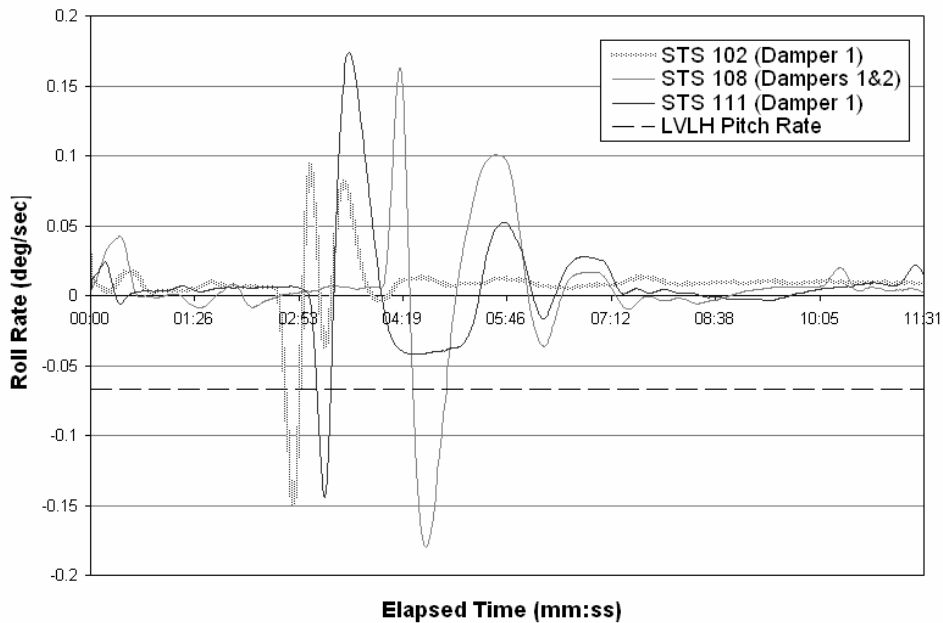


Figure 1.11-3. Roll oscillations examples due to stuck damper number one.

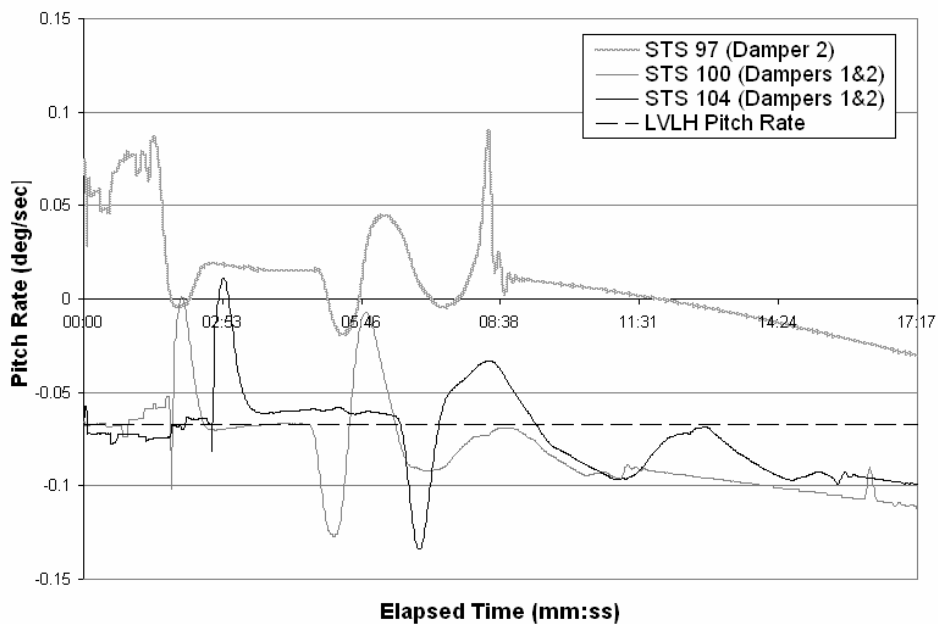


Figure 1.11-4. Pitch oscillations examples due to stuck damper number two.

D. CENTRIPETAL/ GRAVITY GRADIENT FORCES FOR VBAR DOCKING

Gravity gradient forces between the Shuttle and ISS can cause stack rotation for Vbar dockings. When the two vehicles are in free drift, they rotate about the combined center of gravity. With the Vbar docking, the orbiter c.g. begins at near a 70° angle with the combined c.g. and the Earth (the exact angle is mission specific). With a Rbar docking, the orbiter c.g. starts out at a smaller angle resulting in a smaller swing arc. The Vbar forces, those after 30 minutes and Rbar forces can be seen in Figure 1.11-5.

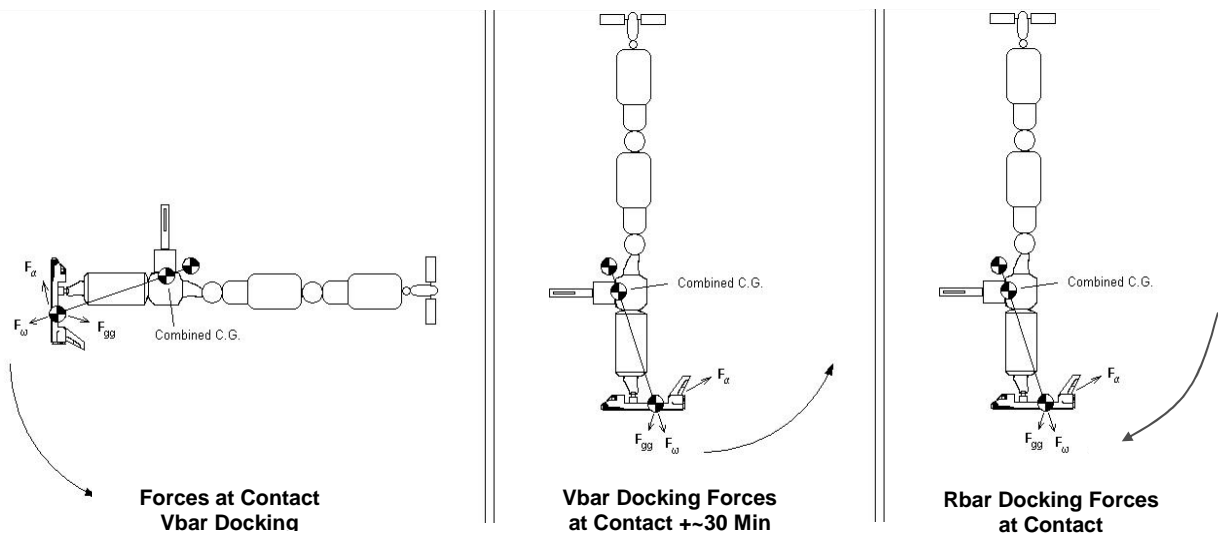


Figure 1.11-5. Mated Stack Dynamics.

The greatest torque occurs when the ISS and Orbiter c.g.s align along the gravity vector causing gravity gradient and centripetal force to be additive during the first 180° of the sinusoidal swing when the LVLH frame rotation adds with the LVLH pitch rate. These LVLH rates approximately cancel during the last 180° back swing reducing centripetal acceleration. This causes the orbiter to pitch tail down and roll slightly to port. The full period of the stack swing observed on STS-105, -108, and -111 was approximately two hours (one hour to swing through one arc). Analysis presented at OFTP #204 showed angular acceleration, aerodynamic, Euler, Venting torques have reliable affect on stack dynamics. Approximated torque on the APDS and resulting pitch from STS-111 docking are shown in Figure 1.11-5.

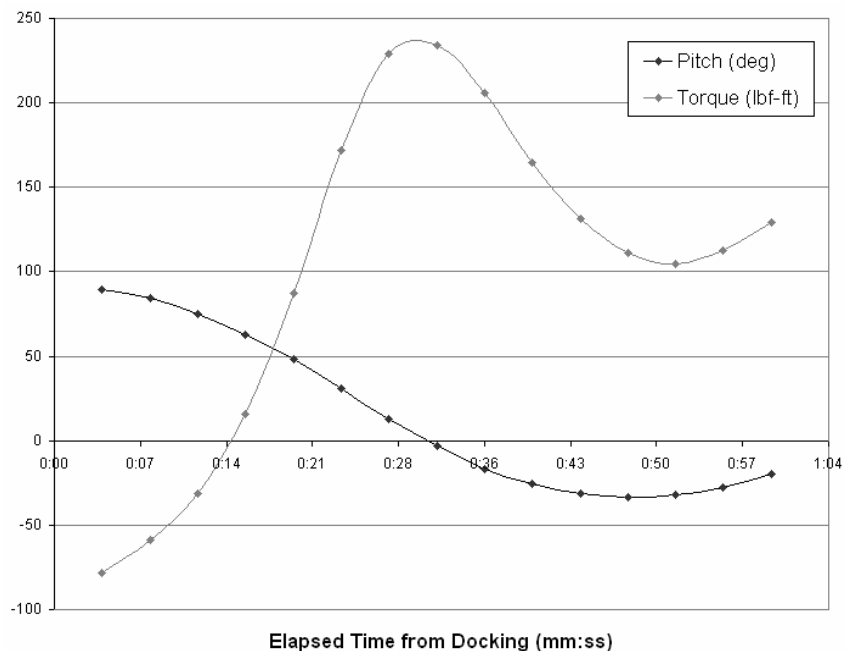


Figure 1.11-5. STS-111 approximate centripetal/GG torque on APDS and resulting Orbiter pitch (V-bar docking).

The reader should note that there are several additional sources of environmental torques on the mated stack. These include angular acceleration, aerodynamic forces, and venting to name the major sources. However, these effects were found to be an order of magnitude or less than the centripetal acceleration, Euler torques and gravity gradient torque and have therefore been ignored in this analysis.

REFERENCES

1. MMACS System Briefs. Section 16; Docking. JSC-28922
Section 16.1.2 - Androgynous Peripheral Docking System Mechanical
Section 16.3.7 - Docking Sequence Rationale
Section 16.3.10 - Docking Oscillations
Section 16.4 - Stuck Damper Signatures and History
2. Post Docking Mated Dynamics. Orbit Flight Techniques Panel, Meeting #204. Aug. 23, 2002.
3. GNC and MMACS ODRC Data for listed flights.

TITLE

NOMINAL IMU GROUND MONITORING

INTRODUCTION

This procedure contains recommended monitoring practices that should enable Flight Controllers to detect off-nominal IMU performance long before onboard redundancy management (RM) thresholds are reached. It also contains the corresponding corrective actions necessary for proper recovery and/or reconfiguration.

PROCEDURES

- A. Monitor IMU gyro Δ 's (attitude) and accelerometer Δ 's (velocity) on the ASCENT/ENTRY SENSORS, or GNC ORBIT display.
- B. Nominally, gyro drift rates and accelerometer Δ 's will be maintained at or below 1σ values.
- C. Alert Symptoms - Noticeable growth in a "common" IMU (gyro Δ 's or accel Δ 's), regardless of the status of the IMU threshold values.
 1. If gyro Δ 's, then select the suspect IMU as a reference. (pbi_comp)

NOTE: For a noticeable change in the drift rate of an IMU, then a restart of the Gyro Drift computations will be required. Because the IMU drift data displayed from the drift computation are averaged from the time the drift comps were restarted via the pbi, the values will not accurately reflect the new drift rate.

 - a. If the reference IMU exhibits a drift rate greater than 3σ , then compute a Gyro Drift bias compensation using SCP 2.4 (See GNC Flight Rule A8-110 part E and F).
 - b. If gyro drift rates suggest more than a single IMU is drifting significantly, then an IMU star alignment should be performed as soon as possible.
 2. If accel Δ 's, then restart the Velocity computations with the suspect IMU selected as a reference (verify the vehicle is in a zero-g condition; i.e., no jet firings or substantial venting).
 - a. Any IMU's with constant accelerometer biases can be compensated by algebraically adding the null accelerometer values (on ASCENT/ENTRY SENSORS display) to the current accelerometer bias loads.
- D. Redundancy Management Failures - Should an RM failure be declared due to a sudden shift in IMU data beyond existing thresholds, perform SCP 2.3 to determine whether errors are due to attitude or velocity problems. This SCP will evaluate possible recovery from Gyro, Resolver, or Accelerometer anomalies.

- E. Subtle Failures - There are a number of potential IMU failures whose symptoms can be misleading.
1. Gyro Torquer Scale Factor Error - The symptoms of this error suggest a gyro drift bias; however, apparent compensation results in a residual bias that remains. SCP 2.12 will correct the situation.
 2. Accelerometer Scale Factor Error - The impact of this error is visible only during high-g environment (Ascent). If no RM thresholds are exceeded (no alarms), the failure condition must be detected by noting unusually high accelerometer Δ 's during the Ascent phase. Playback data must be used to compute the scale factor error using SCP 2.13. Should an accelerometer scale factor shift while in orbit, it would look like a small accelerometer bias (percent scale factor error times compensation loaded) and could only be verified as a scale factor error during an OMS burn, where fairly high g-levels might exist.
 3. Small 8X Resolver Errors - These errors will not set the Resolver Limit BITE indication and may not trip RM if below the existing threshold. The symptom will be a sudden change in the Gyro Δ comps as well as subsequent redistribution of Gyro Δ 's between axes, relative to vehicle rotations. It is essential that we do not perform an IMU alignment with this IMU as the error would be masked thereafter, with the platform skewed by the offset amount. If it is not feasible to correct the 8X resolver error (via a Read/Write procedure), this IMU can be maintained for velocity use, only, by maintaining a reasonable platform alignment via ground management (gyro bias manipulation to cancel drift errors). Unit can be used for attitude (entry) if 8X resolver error is below 0.4°.
 4. Multi-Axis Errors - When multi-axis biases occur (involving the Z-axis Gyro or accelerometers), IMU RM may declare the wrong IMU failed, as it does not anticipate simultaneous failure of two independent hardware. At best, we can expect RM to declare a dilemma situation.
- F. Commfaulted IMU's - IMU's that are no longer in contact with their assigned general purpose computer (GPC) (for whatever reason) will not (in most cases) receive their prescribed pulse torquing required to compensate for known gyro drift characteristics. Thus, a commfaulted IMU will drift at its uncompensated rate. It is always desirable to recover a commfault within minutes; however, it is not necessary since most HAINS IMUs have relatively small uncompensated drift rates. There are some complicated DPS problems that could cause longer delays in reconfiguration. The resultant platform error due to uncompensated drift time should not exceed RM attitude thresholds: however, if the commfault occurs for an extended amount of time an RM declared failure may occur and realignment will be required.
- G. Loss of OPERATE Command - Should MDM power cycling (during DPS troubleshooting) cause an IMU to lose its OPERATE CMD (and thus indicate STANDBY), the unit should be deselected prior to clearing the resultant BCE IMU commfault. When returned to the OPERATE mode, the IMU will be caged and must therefore be realigned relative to another IMU prior to reselection.
- H. Loss of Slew Capability - When an IMU's slew capability is lost (either due to the Transmission Word 2 GPC commands or a physical torquer problem) that IMU cannot be aligned via the IMU-to-IMU method, as slew commands (72 deg/min) are normally used

until the platform reaches within approximately one degree of its desired reference stable member matrix (REFSMMAT) orientation. Star tracker alignments (no slew commands) will maintain satisfactory orientation of this IMU (its performance should not be hampered by the slew problem). However, should this IMU become grossly misaligned (due to caging or a high gyro drift condition), it could require an extremely long period of star align torquing to re-align it, depending on the magnitude of the misalignment. GNC MAL SSR-2 Matrix (Torque) Align Using HUD Star Data, GNC MAL SSR-3 Matrix Align Using Star Tracker Star Data, or GNC MAL SSR-4 Matrix Align Using IMU Data can be used to recover the attitude reference. If stars are not available, GNC MAL SSR-4 should be used. To regain optimal 2-level RM skew, perform one of the options in SCP 2.9 Platform Skew Recovery. After the completion of a matrix align, the Current REFSMMAT should be retrieved from telemetry and uplinked to the Desired slot. This will allow a normal star tracker star align to be used to maintain the IMU alignment, since the torquing angles are referenced to the Desired REFSMMAT. The preferred method for retrieving the REFSMMAT from telemetry and building the uplink is to use SCP 2.10 IMU REFSMMAT Normalization.

- I. Loss of Pulse Torquing- The loss of gyro pulse torquing (due either to the TRANSMISSION WORD 1 GPC commands or a physical torquer problem) will cause that IMU to drift away from its desired REFSMMAT orientation at a rate equal to its uncompensated drift rate for any given axis. As this IMU is still capable of slewing, IMU-to-IMU alignments can be performed periodically to bring the platform back to within approximately 1.0° of its desired orientation. The remaining misalignment (between 0.65° and 1.05°) may be eliminated on orbit by use of matrix alignments using star tracker star data, or by matrix alignments using IMU data when stars are not readily available.

Since the drift rate of the failed IMU is precisely known, and its instantaneous misalignment can be measured (relative to star data or another IMU), we can predict the total platform misalignment at any desired time in the future. Uplinking a REFSMMAT that corresponds to that total misalignment will essentially eliminate all errors for the specific time selected. This IMU could therefore be considered usable (as a last resort) during a specified time span surrounding the target point (determined by the size of its drift rate). With the use of IMU to IMU matrix alignments (OI-32 and subs), in addition to uplinking a future REFSMMAT, an IMU with loss of pulse torquing could be considered usable throughout entry, provided that another IMU with good attitude reference is available. Refer to SCP 2.11, Loss of IMU Pulse Torquing Recovery, which describes the procedure recommended to recover and maintain this IMU.

NOTE: At the three level, where an IMU-to-IMU alignment is required, it is good practice to align two units with respect to the desired unit, since RM thresholds are reset to small attitude errors. This will preclude possible failures of a good unit that had nominally drifted beyond those thresholds.

TITLE

HAINS IMU HARDWARE AND SOFTWARE BITES

PURPOSE

The purpose of this SCP is to provide a list and explanation of the different inertial measurement unit (IMU) hardware and software BITES. The HAINS IMU hardware BITES are designed to detect an IMU failure with a minimum probability of 95 percent. The combination of hardware and software BITES provides assurance that an HAINS IMU failure is detected with a minimum probability of 98 percent (reference SODB Vol. 1 paragraph 4.5.1.2.3.q). The PASS IMU BITE logic is active in all OPS modes, including OPS 9, anytime an IMU is in the Operate mode. No provision for crew annunciation of an IMU BITE is made in OPS 9, but the BITE parameters are available on downlist for ground monitoring. A description of the BITES, crew annunciation, hex status word indication, cause, possible impact, etc., are also included.

BACKGROUND

HARDWARE BITES

Hardware BITE signals are issued by the IMU to provide external indications of the status of the IMU. The hardware BITES provide a capability of self-detection of internal malfunctions during warmup/standby mode and operate mode. For a list of all hardware BITES reported in the MODE/STATUS word please refer to SCP 1.3. However, from a PASS and BFS perspective all hardware BITES are reported through the HAINS Good Bit.

HAINS Good Bit

The HAINS Good bit is the first bit in the IMU MODE/STATUS word. This bit is set to the failed state anytime one of nine hardware built in tests is failed. These nine BITES are as follows:

- A/D FAIL
- PLATFORM FAIL
- DC/DC FAIL
- DISCRETE POWER SUPPLY FAIL
- DIGITAL SUBSYSTEM FAIL
- CIRCUIT CARD OVERTEMPERATURE
- MUX FAIL
- RESOLVER FAIL
- WATCHDOG TIMER FAIL

The HAINS Good bit is internally set and reported to the GPCs via the first bit in the MODE/STATUS Word. This bit is set by the MUX using inputs from the software and hardware. The software provides the BITE SUM Good Discrete, which indicates the status of all of the BITE routines listed above. The hardware provides the hardware Digital Subsystem Good discrete to the MUX, which indicates the status of the CPU Watchdog timer. The MUX uses the BITE SUM Good discrete, the hardware Digital Subsystem Good discrete and the End Around Transmission Fail discrete to set the HAINS Good Bit (see Figure 2.2-1).

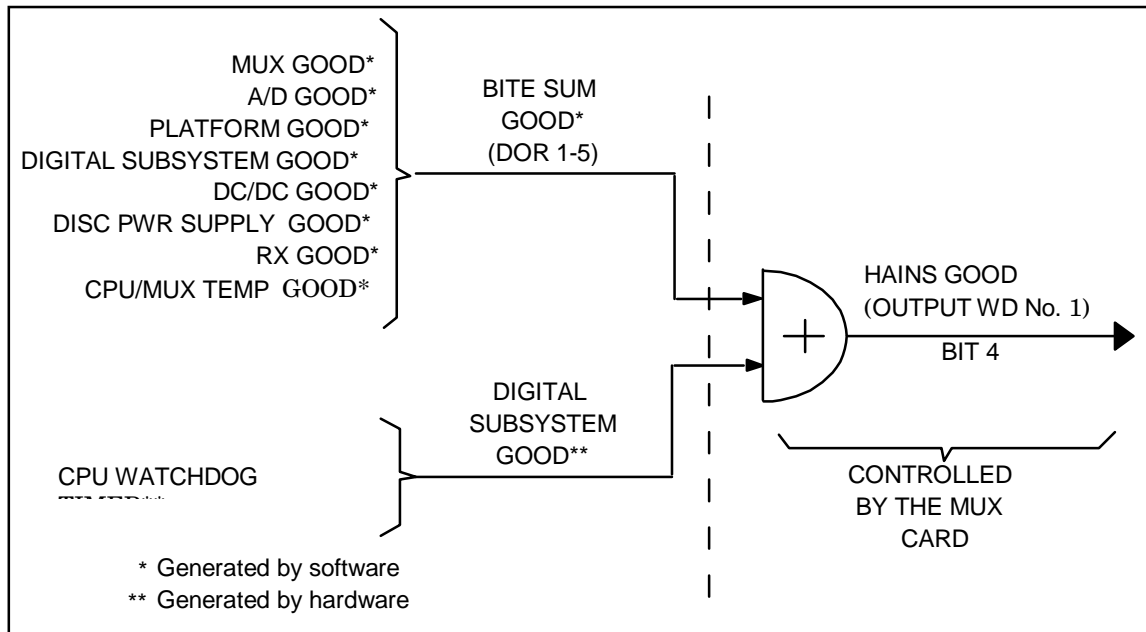


Figure 2.2 -1. HAINS GOOD BIT FUNCTIONAL FLOW

Software BITES

The software BITES, even though they are generated by the general purpose computer (GPC) IMU subsystem operating program (SOP), provide the capability of detecting a malfunction in the performance of the IMU by comparing the IMU data against I-Loaded parameters. There are seven software BITES; Redundant Rate Fail, Inner Roll Null Fail, Resolver Limit Fail, Velocity Limit Fail, Echo 2 Fail, Echo 1 Fail and Accelerometer Scale Factor Fail.

It should be noted that Software BITES can not be false! However, it is possible to annunciate nuisance software BITE indications due to a commfault (See PASS FSW User Note #43940 for Redundant Rate Fail, Velocity Limit Fail, and Accel SF Fail; and PASS FSW User Note #47741 for Inner Roll Null Fail, (referenced later in this SCP)).

IMU BITE WORD

The IMU BITE Word consists of the hardware driven HAINS Good bit, numerous software BITES and the Platform Temp Ready and Platform Temp Safe discrettes. The makeup of the IMU BITE Word is shown in Table 2.2-1. In the PASS, anytime one of the bits in the IMU BITE WORD is set to its failed state and the bit has not been masked by the crew, the IMU will have its RM fail flag set true. This flag will be used when at the 2 level for IMUs and the RM threshold is violated. In this case if only one IMU has its RM fail flag set true, the GPCs will fail out the IMU with the RM fail flag.

TABLE 2.2-1 – IMU BITE WORD

<u>NAME</u>	<u>BIT NUMBER</u>	<u>SOURCE</u>	<u>Hardware / Software</u>
HAINS GOOD	1	IMU Serial I/O	IMU Hardware
TRANS 2 FAIL	2	IMU Serial I/O	IMU Hardware
TRANS 1 FAIL	3	IMU Serial I/O	IMU Hardware
RED RATE FAIL	4	GPC	Software
IR NULL FAIL	5	GPC	Software
RES LIM FAIL	6	GPC	Software
VEL LIM FAIL	7	GPC	Software
ECHO 2 FAIL	8	GPC	Software
ECHO 1 FAIL	9	GPC	Software
ACCEL SF FAIL	10	GPC	Software
PLAT TEMP LOW	11	FF MDM Discrete	IMU Hardware
PLAT TEMP HIGH	12	FF MDM Discrete	IMU Hardware
CAPRI TEMP LOW*	13	FF MDM Discrete	IMU Hardware
CAPRI TEMP HIGH*	14	FF MDM Discrete	IMU Hardware

* Hardwired and set to a non failed state anytime power is supplied to the IMU. (a carry over from the KT-70 to HAINS IMU upgrade - used for HAINS transparency.)

Crew Insight

The IMU BITE Word is displayed to the crew on SPEC 21. The following table can be used to decode which BITE the crew sees when they read down the HEX values. For example, if the crew sees A348, from the table below, we would determine that they have the following BITES:

IMU GOOD FAIL
TRANS 1 FL
VEL LIM FL
ECHO 2 FL
ACCEL SF FL
TEMP LOW

TABLE 2.2-II – SPEC 21 IMU BITE WORD DECODE

BITE	BITE CODE HEX CHARACTER VALUE			
	W	X	Y	Z
IMU GOOD FAIL	8,9,A,B,C,D,E,F			
TRANS 2 FAIL	4,5,6,7,C,D,E,F			
TRANS 1 FAIL	2,3,6,7,A,B,E,F			
RED RATE FAIL	1,3,5,7,9,B,D,F			
IR NULL FAIL		8,9,A,B,C,D,E,F		
RES LIM FAIL		4,5,6,7,C,D,E,F		
VEL LIM FAIL		2,3,6,7,A,B,E,F		
ECHO 2 FAIL		1,3,5,7,9,B,D,F		
ECHO 1 FAIL			8,9,A,B,C,D,E,F	
ACCEL SF FAIL			4,5,6,7,C,D,E,F	
PLAT TEMP LOW			2,3,6,7,A,B,E,F	
PLAT TEMP HIGH			1,3,5,7,9,B,D,F	
CAPRI TEMP LOW*				8,C
CAPRI TEMP HIGH*				4,C

* Hardwired and set to a non failed state anytime power is supplied to the IMU.

BITES MASKING

In the PASS, the crew has the ability to mask any BITE which is present in the IMU BITE WORD. On SPEC 21 'IMU ALIGN', the crew can see the IMU BITE WORD and can MASK any BITE which is present with an ITEM 24, 25 or 26 for IMU 1, 2, or 3, respectively. BITE masking can be performed for two reasons. First, if a BITE is determined to be caused by a failure within the BITE circuitry and therefore does not effect performance then the BITE should be masked. This type of failure is called a false BITE. The other cases where BITE masking can be used is if the BITE is determined to be real and having little to no effet on performace, or if the IMU problem is managable (via uplink, matrix align, etc). In all cases, once the BITE has been masked the PASS software will ignore those BITES when determining if a IMU should be failed out when RM is violated. Note that the software will only mask the BITES that were present in the IMU BITE Word at the time the mask was issued. Any additional BITES annuciated after the BITE mask will result in a BITE indication, and will need to be masked (if

desired) by toggling the mask off, then reinvoking the mask. Also, once the HAINS Good Bit has been masked, all hardware BITEs are masked.

No BITE masking can be performed in the BFS.

MASK WORD (ONE FOR EACH IMU)

(MSB) BIT 1	M1	IMU_GOOD
	M2	TRANS_2_FAIL
	M3	TRANS_1_FAIL
	M4	FAIL_RED_RTE
	M5	FAIL_IR_NULL
	M6	FAIL_RES_LIM
	M7	FAIL_VEL_LIM
	M8	FAIL_ECHO_2
	M9	FAIL_ECHO_1
	M10	FAIL_ACCEL_SF
	M11	PLAT_TEMP_RDY
	M12	PLAT_TEMP_SAFE
	M13	TEMP_RDY
(LSB) BIT 14	M14	TEMP_SAFE

The mask word must be in a memory location that can be accessed by the memory read/write function. The mask word must be initialized to all ones. It shall remain the same across all ops sequences unless the crew modifies it.

TABLE 2.2.-III. - HAINS IMU BITE QUICK LOOK

BITE	STAT	H/S	BFS↓	POSSIBLE IMPACTS
MUX FL	4000	H	Y	Bad MUX card, IMU may fail, Real if ECHO 1 FAIL, false if not
A/D FL	2000	H	Y	Bad resolver data, IMU fail
PLATFORM FL	1000	H	Y	Degraded gyro and accel data Possible IMU failure
DIGITAL SUBSYSTEM FL	0800	H	Y	Degraded IMU performance Could cause MUX FAIL BITE Possible IMU failure
DC/DC FL	0400	H	Y	Degraded gyro and accel data Could cause other BITES
DISCRETE PWR SUP FL	0200	H	Y	IMU may go to STBY Could cause other BITES
RSLVR FL	0100	H	Y	Bad resolver angles, IMU may fail
CIRCUIT CARD OVERTEMP	0080	H	Y	Degraded IMU performance IMU may fail
WATCHDOG TIMER FL	0000	H	Y	CPU stops processing (IMU fails)
TRANSMISSION WD 1 FL	8040	H	N	Loss of pulse torquing
TRANSMISSION WD 2 FL	8020	H	N	Loss of slew (IMU/IMU align) capability
COMMUNICATION GOOD	8000	H	N	Bad data transfer from MDM to HAINS IMU may be bypassed
PLATFORM TEMP RDY FL	8000	H	N	Degraded gyro and accel data
PLATFORM TEMP SAFE FL	8000	H	N	Degraded gyro and accel data
TEMP READY FL	8000	H	N	DSC PWR SUP FL BITE if real pwr prob.
TEMP SAFE FL	8000	H	N	DSC PWR SUP FL BITE if real pwr prob.
REDUNDANT RATE FL	8000	S	N	Redundant rate > 0.7 deg/hr High drift rate in X and/or Y axes Possible IMU failure
INNER ROLL NULL FL	8000	S	N	1X: No impact if -14° < ERROR < +14° 8X: IMU fail if ERROR > RM THOLD Attitude data bad, don't align
RESOLVER LIMIT FL Note: Also generates PLATFORM FL	8000	S	N	1X: No impact if: ERROR < 22.5 deg Attitude data bad & RM FL if: ERROR > 22.5 deg 8X: IMU fail if ERROR > RM THOLD or if ERROR > 0.7° Attitude data bad, don't align
VELOCITY LIMIT FL	8000	S	N	May fail if ΔVEL > RM THOLD
ECHO 1 FL	8000	S	N	Bad data transfer between IMU/GPC Possible IMU failure
ECHO 2 FL	8000	S	N	Bad data transfer between IMU/GPC Possible IMU failure
ACCEL SCALE FACTOR FL	8000	S	N	Output 10X sensed accel Possible IMU failure

NOTE: Possible impacts are for real BITES only. All BITES will cause downmode at the 2-level for miscompare.

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BITE: MUX FAIL
TYPE: Hardware
SOURCE: MUX AND SOFTWARE
FUNCTION: IMU Check Failure

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES
STAT IN SPEC 21 and 51: "BITE"
TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 4000

DOWNMODE BFS: YES (real or false bite; cannot mask in BFS)

CAUSE:

MUX Fail (bit 5) shall be set to logic 1 when either a failure is detected in the end-around transmission test performed on output words, or when the MUX BITE detect a failure in the MUX start-up test, the DMA parallel test, and the DMA controller BITE.

BITE TESTS:

Multiplex Terminal Unit (MUX) FAIL signal is the result of one or more of the following BITE Tests failing:

- a) MUX Start-up Test Fail (once at pwr-on)
- b) DMA Parallel Test Fail (25 Hz)
- c) DMA Grant Test Fail (25 Hz)
- d) DMA Request Test Fail (25 Hz)
- e) End-Around Transmission Fail (at message in)

OVERALL IMPACT:

A true MUX FAIL will indicate a bad MUX unit. The two IMU input data words from the GPC and the 16 IMU output data words to the GPC (only words 1 thru 14 are read by the GPC) may be corrupted. This can result in failure of the IMU. A false MUX FAIL will have no impact on IMU operation (PASS); however, it will cause downmoding in a dilemma situation.

COMMENTS:

The MUX card interfaces between the HAINS and the orbiter MDMs. It provides the interface for transmitting, receiving and formatting the data between the HAINS' internal parallel data bus and the MDM external serial data bus. The MUX BITE tests are performed (excluding the MUX start-up test and the end around transmission test) every time the message-in discrete is set to logic '0'. The end around transmission test is performed after each data word is transmitted to the MDM.

This signal is a candidate for false BITE if the comparator should fail creating a constant MUX FAIL indication. This BITE, whether false or real, will reset (to logic 0) the IMU GOOD BIT (bit 4 of the mode status word).

BITE: A/D FAIL
TYPE: Hardware
SOURCE: A/D Card and Software
FUNCTION: Conversion Failure

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES
STAT IN SPEC 21 and 51: "BITE"
TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 2000

DOWNMODE BFS: YES (Real or false BITE; cannot mask in BFS)

CAUSE:

A/D Fail (bit 6) shall be set to logic 1 when the A/D converter BITE detects a failure in PROM, RAM, AC/DC channels, 1X and 8X resolvers, and the A/D interrupt.

BITE TESTS

A/D FAIL signal is the result of one or more of the following BITE Tests failing:

- a) Gimbal Angle Checksum Test (S/W) (100 Hz)
- b) DC Channel Accuracy Test (S/W) (25 Hz)
- c) AC Channel Accuracy Test (S/W) (25 Hz)
- d) A/D Performed BITE Test (A/D) (25 Hz)
- e) A/D Converter Interrupt Goodness Check (S/W) (25 Hz)

OVERALL IMPACT:

A failed A/D converter may not be able to accurately convert the resolver readings into the appropriate angle. Bad resolver angle data supplied to the GPC may result in failure of the IMU. A false A/D FAIL BITE will have no impact on IMU operation (PASS); however it will cause downmoding in dilemma situation.

COMMENTS:

All of the A/D BITE tests verify that the A/D dedicated microprocessor calibrates, corrects and formats the converted AC & DC input data accurately.

The AC data includes the fine/coarse azimuth angles, the fine/coarse pitch angles, and the fine/coarse roll angles. The DC data includes the fine/coarse inner roll, inner roll pick off

excitation, rate gyro monitor, 10Vdc reference, DAL temperature, DAL +5Vdc & ±15Vdc, and the offset calibration data. An error in any of the AC or DC input data, A/D microprocessor or the A/D memory, will result in an A/D BITE.

The gimbal angle checksum test is not performed if there is a RX FAIL BITE. The AC or DC channel accuracy tests are not performed if there is a RX FAIL BITE or a MUX FAIL BITE due to a DMA Fail.

The A/D performed BITES include:

- (1) A/D PROM test
- (2) A/D RAM test - executed at power on only
- (3) DC offset check
- (4) AC offset check
- (5) DC gain check
- (6) AC gain check

This BITE does not get latched.

BITE: WATCHDOG TIMER FAIL

TYPE: Hardware

SOURCE: Input/Output (I/O) Card

FUNCTION: CPU Failure

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 0000

DOWNMODE BFS: YES (Real or false BITE; cannot mask in BFS)

CAUSE:

The CPU Watchdog Timer (WDT) fail bit is set to logic 1 if it is not reset at a 1 Hz rate by the Operational Flight Program (OFP).

POSSIBLE IMPACT:

The HAINS CPU will stop processing and the IMU will not operate.

COMMENTS:

The OFP resets the WDT by executing a WDT reset command once a second. The WDT overflows at 1.8 ± 0.3 seconds. The WDT is clocked by a 1.875 Hz nominal square wave derived from the Gyro Wheel Supply (GWS) card. A WDT failure sets the H/W Digital Subsystem fail discrete to bad, which sets the HAINS GOOD bit to zero. An overflow of the WDT also generates a CPU fail flag and inhibits the CPU. The WDT is inhibited when the OFP detects an I/O or Memory failure to prevent erroneous CPU fail flags. This is the one failure which will only set the HAINS Good bit to bad.

A CPU WDT failure results in the transmission of a fail Digital Subsystem (DIG SSFL) indication to the MUX card. The MUX uses the BITE SUM GOOD discrettes and this hardware generated DIG SSFL to set the HAINS GOOD bit.

NOTE: The software generated DIG SSFL BITE (bit 8 of the Mode Status Word) is OR'ed in the BITE SUM GOOD discrete and does not get set for a WDT failure.

BITE: PLATFORM FAIL

TYPE: Hardware

SOURCE: PE #1 Card/ Software/ A/D Card/ GWS Card

FUNCTION: Platform Failure

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 1000

DOWNMODE BFS: YES (Real or false BITE; cannot mask in BFS)

CAUSE:

Platform Fail (bit 7) shall be set to logic 1 when:

- (1) the speed or position of the induction motor (which drives the wheel of the gyros) is incorrect,
- (2) the gimbal loop does not null azimuth or inner roll gyro errors,
- (3) the inner roll and accelerometer pickoff excitation is below the threshold level,
- (4a) the time from issuing the OPER MODE DISC (logic reset) to setting the D9 sequencer discrete exceeds 60 sec,
- (4b) the time from issuing the OPER MODE DISC (logic reset) to setting the D11 sequencer discrete exceeds 107 sec,
- (5) the +5Vdc or ± 15 Vdc DAL regulated voltages exceed their allowable tolerance of $\pm 5\%$,
- (6) the difference between the 1X and 8X resolver angle exceeds 0.7° ,
- (7) the inner roll angle is greater than ± 1 arcmin (except when the platform is near or in the gimbal flip region), or lastly,
- (8) the sine and cosine of each resolver angle are both greater than or both less than 0.707° .

BITE TESTS:

The PLATFORM FAIL signal is the result of one or more of the following BITE Tests failing:

- a) Sequencer Test (once @ pwr on)
- b) Pulse Accumulator Test (100 Hz)
- c) Gyro Wheel Supply Fail (1 Hz)
- d) Gimbal Loop Fail (5 Hz)
- e) DAL Regulated Voltages Test (25 Hz)
- f) Missing RSLV Input / 1X, 8X RSLV Fail (25 HZ)
- g) Inner Roll Reasonableness (25 Hz)

OVERALL IMPACT:

A PLATFORM FAIL may degrade the IMU gyro and accelerometer performance which, depending on the cause, could result in an unrecoverable failure of the IMU. A false platform fail BITE will have no impact on IMU operation (PASS); however, it will cause downmoding in a dilemma situation.

COMMENTS:

The Gyro Wheel Supply BITE test is inhibited until the D11 discrete is issued during the IMU start-up sequence.

BITE: DIGITAL SUBSYSTEM FAIL

TYPE: Hardware

SOURCE: Memory Card / Software

FUNCTION: CPU, Memory or Vel Accumulator failure

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 0800

DOWNMODE BFS: YES (Real or false BITE; cannot mask in BFS)

CAUSE:

Digital Subsystem Fail (bit 8) shall be set to logic 1 when:

- (1) the velocity pulse accumulator fails,
- (2) memory mapped addresses are not properly decoded,
- (3) the DOR & DIR registers malfunction,
- (4) the MUX tag timer does not update,
- (5) the read, write & storage capability of the memory card is lost,
- (6) single/multiple bit errors cannot be detected at power on,
- (7) a multiple bit error is detected,
- (8) the CPU microcode fails, or
- (9) the CPU encounters a floating point overflow, divide by zero or the square root of a negative number.

BITE TESTS:

DIGITAL SUBSYSTEM FAIL signal is the result of one or more of the following BITE Tests failing:

- a) Pulse Accumulator Test (once @ pwr on)
- b) DOR Wraparound (25 Hz)
- c) MTU Tag Time (25 Hz)
- d) RAM Pattern Test (RAM Self-Test) (once @ pwr on)
- e) Multiple Bit Error (25 Hz)
- f) Memory Error Correction (once @ pwr on)
- g) CPU Instruction Test (1 Hz)
- h) Floating Point Divide by Zero Trap (25 Hz)
- i) Arithmetic Floating Point Overflow (25 Hz)
- j) Square Root of a Negative Number (25 Hz)
- k) EEPROM/PROM Checksum Fail (once @ pwr on / 1 Hz)

OVERALL IMPACT:

A Digital Subsystem FAIL may degrade the IMU gyro and accelerometer performance, which could result in an unrecoverable IMU. A false digital subsystem fail BITE will have no impact on IMU operation (PASS); however, it will cause downmoding in a dilemma situation.

COMMENTS:

This Digital Subsystem Fail (bit 8 of the Mode Status Word) is generated by software and is or'ed into the BITE SUM GOOD discrete. A CPU WDT failure will not set this BITE, but will set the hardware generated DIG SSFL flag which causes the HAINS GOOD bit (bit 4) to go bad (logic 0).

Following the detection of a Multiple bit or Single bit error, the software clears the discrettes by issuing a reset.

A Digital subsystem fail indication is latched and then reset when the CPU WDT resets (once a second).

BITE: DC/DC FAIL

TYPE: Hardware

SOURCE: DC/DC card

FUNCTION: +5 V dc, ±15 V dc, ±19 V dc out of SPEC or Clock failure

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 0400

DOWNMODE BFS: YES (Real or false BITE; cannot mask in BFS)

CAUSE:

A DC/DC Fail (bit 9) shall be set to logic 1 for any of the following:

1. The DC/DC card output voltages (+5 Vdc, ±15 Vdc, ±19 Vdc) exceed ±10% about their regulation.
2. The 1.2288 MHz clock stops functioning.

POSSIBLE IMPACT:

A DC/DC FAIL BITE may degrade the IMU's gyro and accelerometer performance since proper gyro and accelerometer excitation may be affected. These voltages and the clock are also used for other BITE tests, potentially resulting in other BITES such as RX Fail, DSC PWR SUP FL, Platform FL (gyro wheel supply failure), COMM good, MUX FL and A/D FL. A false DC/DC FAIL BITE will have no impact on IMU operation; however, it will cause downmoding in a dilemma situation.

COMMENTS:

The DC/DC fail BITE is not a latched signal.

BITE: DISCRETE POWER SUPPLY FAIL

TYPE: Hardware

SOURCE: Input Power Conditioner (IPC) Card

FUNCTION: +5 Vdc isolated out of SPEC

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 0200

DOWNMODE BFS: YES (Real or False BITE; cannot mask in BFS).

CAUSE:

A DISCRETE POWER SUPPLY FAIL (bit 10) shall be set to logic 1 when the +5 Vdc isolated power supply, used to power the IMU Output discretes, is not within +5 Vdc $\pm 10\%$ of its regulated value (+4.5 Vdc to +5.5 Vdc).

POSSIBLE IMPACT:

A complete failure/loss of the +5Vdc isolated power supply will cause all IMU Output discretes to be set low. The IMU will go to STBY and the IMU should be considered failed.

IMU OUTPUT DISCRETES: TEMPERATURE SAFE
TEMPERATURE READY
COMMUNICATION GOOD
PLATFORM TEMPERATURE SAFE
PLATFORM TEMPERATURE READY
IN OPERATE MODE
OPERATE COMMAND
HAINS GOOD DISCRETE (not used on orbit)

A degraded +5 Vdc isolated power supply could cause any of the following BITE annunciations:

- (1) DSC PWR SUP FL BITE with no other BITES,
- (2) DSC PWR SUP FL BITE with any combination of output discretes set low (except for the operate command), or
- (3) DSC PWR SUP FL BITE with all 8 output discretes set low.

A false DSC PWR SUP FL BITE will have no impact on IMU operation (PASS); however, it will cause downmoding in a dilemma situation.

COMMENTS:

Only the TEMP SAFE and TEMP READY discretes are directly wired to the +5 Vdc isolated power. The other discretes are optically isolated from the +28 Vdc filter ground and referenced to the +5Vdc isolated ground.

The following table gives the voltage levels at which the MDM will set the appropriate output discrete to true or false:

TABLE 2.2-IV. - HAINS POWER SUPPLY FAIL VOLTAGES

TRUE (V dc)	FALSE (Vdc)	BITE	IMPACT
+4.0 TO +6.0	-0.5 TO +0.5	Comm Good	loss of indication
+4.0 TO +6.0	-0.5 TO +0.5	In-Oper Mode	loss of indication
+4.0 TO +6.0	-0.5 TO +0.5	Plat Temp Safe	loss of indication
+4.0 TO +6.0	-0.5 TO +0.5	Plat Temp Ready	loss of indication
+4.0 TO +6.0	≤ +3.9 or ≥ +6.1	Temperature Safe	loss of indication
+4.0 TO +6.0	≤ +3.9 or ≥ +6.1	Temperature RDY	loss of indication
+4.0 TO +6.0	-0.5 TO +0.5	HAINS Good DSC	not used in flight
+3.5 TO +6.0	-0.5 TO +0.5	Operate Command	IMU to STBY **

** If the Operate Command gets set low, only the IMU sees the false state of this command. The GPC CMD is still being issued, the TLM will show the OPER CMD as GOOD, but the IMU will mode to STBY.

Note: The voltage levels between the true and false levels, are in a grey area. The MDM may or may not set a true discrete to false or a false discrete to true.

BITE: RX FAIL (RX = RESOLVER)
TYPE: Hardware
SOURCE: Input Power Conditioner (IPC) Card
FUNCTION: 7 V ac Load Failure

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES
STAT IN SPEC 21 and 51: "BITE"
TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 0100

DOWNMODE BFS: YES (Real or False BITE; cannot mask in BFS).

CAUSE:

A Resolver Current Fail (bit 11) shall be set to logic 1 when the +7 Vac signal is either out-of-voltage regulation ($7 \text{ Vac} \pm 11\%$ of its regulated value) or out-of-current regulation ($< 150 \text{ mA}$ or $> 350 \text{ mA}$).

POSSIBLE IMPACT:

Improper resolver excitation may result in incorrect resolver angles which may fail the IMU, depending on the magnitude of the error. The A/D fail bit should not get set to logic 1 since the three A/D BITE tests which depend on the 7Vac 400 Hz signal for proper conversion of the resolver angle (A/D DC Channel Test FL, A/D AC Channel Test FL, and the Gimbal Angle Checksum FL) are not performed if there is a 7Vac power supply failure. A false RX current Fail BITE will have no impact on IMU operation (PASS); however, it will cause downmoding in a dilemma situation.

COMMENTS:

The IPC card generates the 7Vac signal which is used to excite the resolvers. The Resolver Excitation Fail discrete is then sent to the I/O card. This is not a latched BITE

BITE: CIRCUIT CARD OVERTEMP

TYPE: Hardware

SOURCE: Platform Electronics Card #1

FUNCTION: Monitor circuit cards continuously for overtemp

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 0080

DOWNMODE BFS: YES (Real or False BITE; cannot mask in BFS).

CAUSE:

Circuit Card Overtemperature (bit 12) shall be set to logic 1 when any of the temperature sensors located on the Platform Electronics #1 Card has exceeded either the upper or lower temperature limits which are stored as Tag constants in EEPROM.

POSSIBLE IMPACT:

Prolonged operation of any one of the cards at a high temperature may cause certain components within the card to fail impacting the performance of the IMU. Failure of the IMU is possible. A false CIRCUIT CARD OVERTEMP BITE will have no impact on IMU operation (PASS); however, it will cause downmoding in a dilemma situation.

COMMENTS:

Circuit Card Overtemp BITE is not a latched signal. A failure in the A/D converter or EEPROM could result in a CC Overtemp BITE since the temperature sensor voltage output is converted by the A/D converter card into a digital word which is compared, by software, to the limits stored in EEPROM.

Can be caused by a permanent failure of the card or a loss of airflow. If airflow has not been lost, BITE is likely false unless there has been a local short within the card. If BITE is not false and airflow has not been lost, other failures and BITEs will likely accompany this BITE.

If airflow is lost at room temperature, the IMU will last approximately 90 minutes before failure occurs.

BITE: TRANSMISSION WORD 1 FAIL

TYPE: Hardware

SOURCE: I/O card

FUNCTION: Transmission Error

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 8040

DOWNMODE BFS: NO

CAUSE:

TRANSMISSION WORD 1 FAIL (BIT 13) is set when the I/O electronics detects a failure of parity, gap or Manchester coding in the first GPC word (torquing commands) received by the IMU each transmit cycle.

POSSIBLE IMPACT:

IMU will not use (implement) the GPC torquing commands sent by the GPC, causing the IMU to drift at the uncompensated rate. This BITE will cause downmoding in a dilemma situation.

If the BITE is false, the GPC will still save and retransmit the pulses to the IMU. Since the BITE is false, the GPC is retransmitting pulses that the IMU has already received. The result is that the IMU is "overtorqued" and will misalign very rapidly, giving the IMU a large redundant rate and causing it to fail.

COMMENTS:

See SCP 2.19 “Recovery of IMU With Trans Word 1 Fail BITE” for either true or false Trans Word 1 BITES.

Signal resets after each transmission cycle.

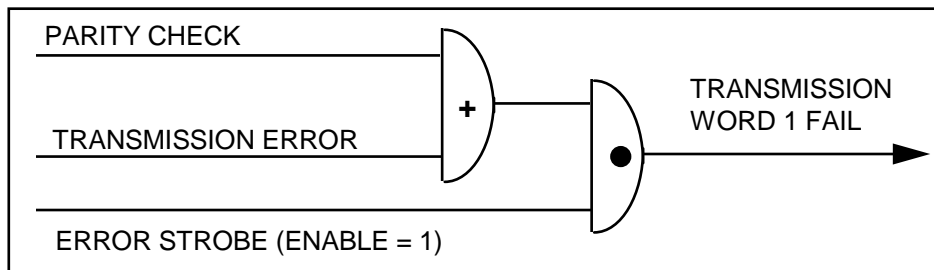


Figure 2.2-2. - TRANSMISSION WORD 1 Fail logic.

If the IMU detects a TRANSMISSION WORD 1 FAIL, the GPC will compensate for such an error by saving and retransmitting any pulses lost due to the transmission error, adding the pulses that were not received by the IMU to the torquing pulses of the next cycle.

BITE: TRANSMISSION WORD 2 FAIL

TYPE: Hardware

SOURCE: I/O card

FUNCTION: Transmission Error

REW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 8020

DOWNMODE BFS: NO

CAUSE:

TRANSMISSION WORD 2 FAIL (bit 14) is set when the I/O electronics detects a failure of parity or manchester coding in the second GPC word (slew commands) together with the proper gap between words 1 and 2, as received by the IMU.

POSSIBLE IMPACT:

IMU will not use (implement) the GPC slew commands, thereby disabling IMU/IMU torquing alignments. This BITE will cause downmoding in a dilemma situation. A false TRANSMISSION WORD 2 FAIL BITE will have no impact on IMU operation; however, it will cause downmoding in a dilemma situation.

COMMENTS:

Resets after each transmission cycle. Normal slew commands to the IMU are 0000 except during IMU/IMU alignments.

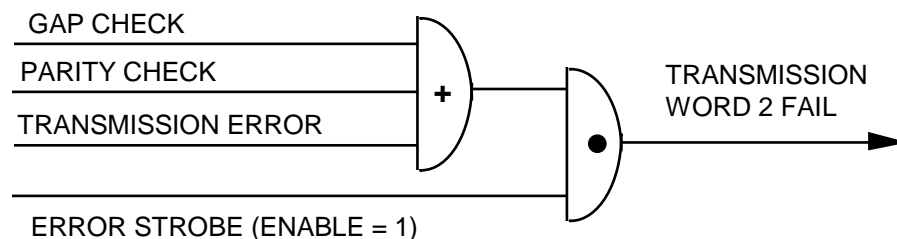


Figure 2.2-3. - TRANSMISSION WORD 2 FAIL logic.

GNC MAL SSR-2 Matrix (Torque) Align Using HUD Star Data, GNC MAL SSR-3 Matrix Align Using Star Tracker Star Data, or GNC MAL SSR-4 Matrix Align Using IMU Data can be used to recover the attitude reference for an IMU that has lost slew capability. If stars are not available, GNC MAL SSR-4 should be used, provided another IMU with good attitude reference is available. To regain optimal 2-level RM skew, perform one of the options in SCP 2.9 Platform Skew Recovery.

After the completion of a matrix align, the Current REFSMMAT should be retrieved from telemetry and uplinked to the Desired slot. This will allow a normal star tracker star align to be used to maintain the IMU alignment, since the torquing angles are referenced to the Desired REFSMMAT. The preferred method for retrieving the REFSMMAT from telemetry and building the uplink is to use SCP 2.10 IMU REFSMMAT Normalization.

BITE: PLATFORM TEMP READY FAIL

TYPE: Hardware

SOURCE: Platform Electronics #2 Card

FUNCTION: Platform Undertemp Sense

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE" on SPEC 51 only

TEMPERATURE INDICATION: "LO" on SPEC 21 only

GROUND CRT IMU HEX STATUS WORK INDICATION: 8000

DOWNMODE BFS: NO

CAUSE:

PLATFORM TEMP READY is set to logic 1 when the Vertical gyro temperature is $> 146.5^{\circ} \pm 3^{\circ} \text{ F}$ and/or when the Azimuth gyro temperature is $> 150.0^{\circ} \pm 3^{\circ} \text{ F}$.

POSSIBLE IMPACT:

The IMU's gyro restraint and the accelerometer bias and scale factor will be affected for every degree below the nominal operating temperature. A false PLATFORM TEMP READY FAIL BITE will have no impact on IMU operation (PASS); however, it will cause downmoding in a dilemma situation.

COMMENTS:

This BITE is a candidate for a false BITE indication. The nominal platform operating temperature is between 151.5° F and 153° F . Following thermal stabilization, the gyro restraints and accelerometer bias and scale factor shifts can be compensated in order to restore the IMU to nominal operation, after which the BITE may be masked.

This discrete remains false following the application of 28Vdc, until the temperature of the Vertical and Azimuth gyros reaches the specified range.

May lose insight into the Platform Temperature Ready discrete if the +5Vdc isolated power supply degrades or fails (see Discrete Power Supply Fail BITE for more details).

BITE: PLATFORM TEMP SAFE FAIL

TYPE: Hardware

SOURCE: Platform Electronics #2 Card

FUNCTION: Platform Overtemp Sense

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE" on SPEC 51 only

TEMPERATURE INDICATION: "HI" on SPEC 21 only

GROUND CRT IMU HEX STATUS WORD INDICATION 8000

DOWNMODE BFS: NO

CAUSE:

PLATFORM TEMP SAFE is set to logic 1 when the Vertical gyro temperature is $< 156.5^{\circ} \pm 3^{\circ} \text{ F}$, regardless of the HAINS mode.

POSSIBLE IMPACT:

The IMU's gyro restraint and the accelerometer bias and scale factor will be affected for every degree above the nominal operating temperature. A false PLATFORM TEMP SAFE FAIL BITE will have no impact on IMU operation (PASS); however, it will cause downmoding in a dilemma situation.

COMMENTS:

This BITE is a candidate for a false BITE indication. The nominal platform operating temperature is between 151.5°F and 153°F. Following thermal stabilization, the gyro restraints and accelerometer bias and scale factor shifts can be compensated in order to restore the IMU to nominal operation, after which the BITE may be masked.

May lose insight into the Platform Temperature Safe discrete if the +5Vdc isolated power supply degrades or fails (see Discrete Power Supply Fail BITE for more details).

Hardware damage due to this BITE is unlikely. Bimetal safety switches are installed which will remove power to components when temperatures rise above 185°F, however failures of the switches have occurred at Kearfott (this function is not tested outside the vendor). IMU components have been tested to 200°F and above.

Both vertical and azimuth gyros have heaters which individually regulate their temperatures.

BITE: TEMP READY FAIL

TYPE: Hardware

SOURCE: MUX Card

FUNCTION: N/A

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE" on SPEC 51 only

TEMPERATURE INDICATION: "LO" on SPEC 21 only

GROUND CRT IMU HEX STATUS WORD INDICATION: 8000

DOWNMODE BFS: NO

CAUSE:

TEMP READY is set to logic 1 following the application of +28 Vdc to the HAINS and does not change.

POSSIBLE IMPACT:

N/A

COMMENTS:

The Temperature Ready discrete is directly wired to the +5Vdc isolated power supply. This BITE may indicate a failure of the +5Vdc isolated power supply (see discrete Power Supply Fail BITE for more details).

This discrete does not provide any monitoring of HAINS functions, but was required for transparency of KT-70/GPC interface.

BITE: TEMP SAFE FAIL

TYPE: Hardware

SOURCE: MUX Card

FUNCTION: N/A

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE" on SPEC 51 only.

TEMPERATURE INDICATION: "HI" on SPEC 21 only.

GROUND CRT IMU HEX STATUS WORD INDICATION: 8000

DOWNMODE BFS: NO

CAUSE:

TEMP SAFE is set to logic 1 following the application of 28 Vdc to the HAINS and does not change.

POSSIBLE IMPACT:

N/A

COMMENTS:

The Temperature Safe discrete is directly wired to the +5Vdc isolated power supply. This BITE may indicate a failure of the +5Vdc isolated power supply (see Discrete Power Supply Fail BITE for more details).

This discrete does not provide any monitoring of HAINS functions, but was required for transparency of KT-70/GPC interface.

BITE: COMMUNICATION GOOD

TYPE: Hardware

SOURCE: MUX Card

FUNCTION: Serial Data Request/Transfer from MDM to HAINS

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: NO

STAT IN SPEC 21 and 51: NONE

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 8000

DOWNMODE BFS: NO

CAUSE:

A Communication Good bit is set to logic 0 when the timing gap between the Message-In Discrete and a Word Discrete or between the Word Discretes (set low and high) have exceeded specified values. This BITE indicates that an error condition has been detected during the message-in serial data transfer from the MDM to HAINS (loss of MDM to HAINS communication).

A Communication Good bit is also set to logic 0 during ground testing when the MUX is commanded by the test equipment into its AUTO Diagnostic Mode or the System Analyzer MUX Mode (SAMM).

POSSIBLE IMPACT:

IMU may be bypassed.

COMMENTS:

This BITE cannot be masked. It is not used by the PASS to downmode an IMU in a dilemma situation.

Can get a COMM GOOD BITE if an MDM serial I/O Card 3 channel 0 has failed.

Loss of COMM GOOD by itself indicates an MDM problem.

Loss of COMM GOOD with any combination of the following Software BITES indicates a problem with the HAINS:

ECHO WORD 1/2 FAIL

INNER RESOLVER NULL FAIL, OR
RESOLVER LIMIT FAIL

May lose insight into this output discrete if the +5Vdc isolated power supply degrades or fails (see Discrete Power Supply Fail BITE for more details).

BITE: REDUNDANT RATE FAIL

TYPE: Software

SOURCE: IMU_BITE Processing Module in the IMU SOP

FUNCTION: High drift on redundant gyro

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 8000

DOWNMODE BFS: NO

CAUSE:

Redundant gyro axis drift rate (compensated and filtered by the RGM_COMP module) exceeds 0.7 deg/hr. This BITE will be set as soon as the redundant gyro exceeds such limit.

POSSIBLE IMPACT:

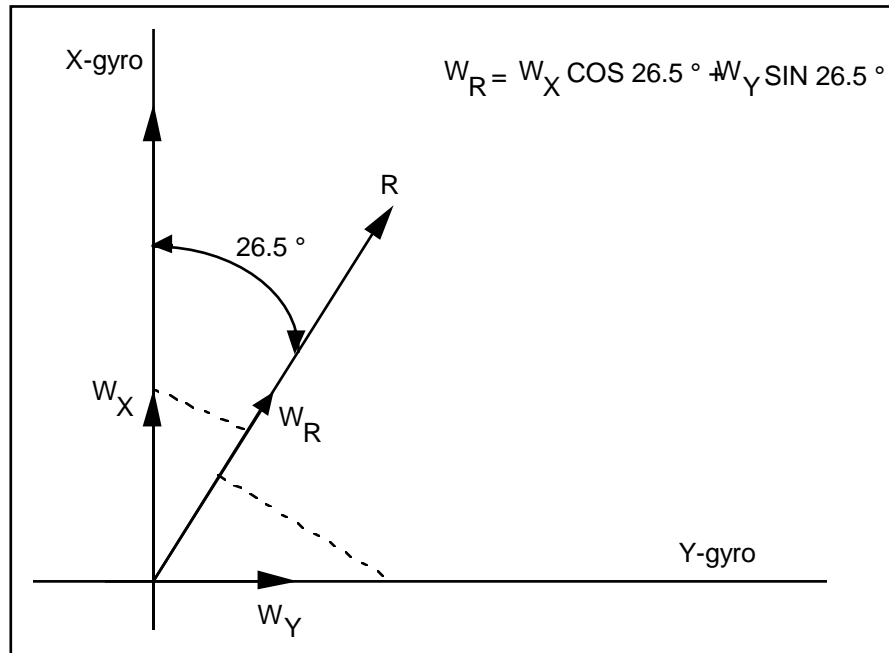
High drift in the IMU X and/or Y axes which may eventually cause the IMU to fail. This BITE will cause downmoding in a dilemma situation.

COMMENTS:

A logic 1 in bit 1 of the redundant axis rate word (IMU data word #2) indicates a voltage saturation which invalidates the redundant axis rate data word. The range of the redundant axis rate is ± 120 deg/hr. The redundant gyro monitor (RGM_COMP) module measures the inertial drift of the IMU platform about the redundant axis of the dual Z axis gyro.

The redundant axis nominally lies on the plane formed by the X and Y gyros and 26.5° from the X gyro input axis for HAINS IMU (see Figure 2.2-4). The test by RGM_COMP on the drift rate of the redundant gyro is not performed while in OPS transition catch up torquing or if on orbit alignment slewing/torquing is in progress. There cannot be a false BITE indication for the REDUNDANT RATE FAIL BITE.

An erroneous BITE indication can be generated when an IMU is moded from STBY to OPER and when it is recovered from a COMMFAULT. This occurs because the flight software extrapolates redundant gyro data from the last two good values. These BITES are transient and will clear when the redundant rate filter output drops below the BITE limit. Reference PASS User Note #43940.



Where : W_X = GPC commanded X-gyro torquing rate
 W_Y = GPC commanded Y-gyro torquing rate

Figure 2.2-4. - HAINS IMU redundant rate axis

BITE: INNER ROLL NULL FAIL

TYPE: Software

SOURCE: IMU_BITE Processing Module in the IMU SOP

FUNCTION: Inner Roll Resolver Out of Limits

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 8000

DOWNMODE BFS: NO

CAUSE:

The inner roll linear pickoff is measuring an angle greater than ± 3 deg.

Since the inner roll linear pickoff emulates an 8X resolver, the value of its reading represents 8 times the true mechanical angle. The measured (uncompensated electrical) angle would have to be between the angles $24 \text{ deg} < \text{IRL} < 336 \text{ deg}$ (the software inner roll null limit 1 and inner roll null limit 2 used by the IMU_BITE module).

POSSIBLE IMPACT:

The IMU inner roll gimbal uses a linear pickoff to measure gimbal angles. The linear pickoff is excited by a 19.2 kHz source which is conditioned by the Platform Electronics No. 1 card for a coarse (1X) A/D input and by the Platform Electronics No. 2 card for a fine (8X) A/D input. The coarse (1X) signal is used to drive the outer roll gimbal torquer in response to motion sensed by the inner roll linear pickoff, which causes the inner roll gimbal to remain at its null position. The fine (8X) signal is used by the GPCs to determine the inner roll gimbal angle.

If the resolver angle shift is only in the 1X resolver signal, the IMU may (depending on the magnitude of the bias) remain inertially stable as the outer roll gimbal rotates the platform in order to compensate for the fictitious movement of the inner roll resolver.

If the shift is only in the 8X resolver signal, the platform will remain inertially stable; however, since the GPC only uses the 8X resolver signal for its attitude computations, it will believe that the platform is misaligned and depending on the magnitude of shift and the present magnitude of the RM threshold, may cause the IMU to fail RM. This BITE will cause downmoding in a dilemma situation.

COMMENTS:

The INNER ROLL NULL FAIL test will be performed only if the IMU 1X pitch resolver is outside the gimbal flip region of 80 to 100 deg or 260 to 280 deg. The inner roll gimbal is physically restrained to ± 14 to 16 deg. Only the 8X resolver signal (which is what we see on our IMU Summary display) is sent to the GPC for attitude computations.

A shift in the 8X inner roll resolver signal can be compensated (via a G-MEM write procedure) if we are sure the shift is a constant bias. However, a shift in the 1X resolver signal cannot be compensated since it gets acted upon by the outer roll gimbal; it will be a problem only if it exceeds the inner roll freedom of travel. There cannot be any false BITE indication for the INNER ROLL NULL FAIL BITE.

An erroneous INNER ROLL NULL BITE indication can be generated when an IMU is commfaulted. This occurs because the flight software extrapolates all resolver data from the last two good values for commfaulted IMUs. If the last two good Inner Roll resolver values differ when an IMU is commfaulted (e.g. moded from OPER to STBY), a false Inner Roll Null BITE may be declared during a long commfault period. An erroneous annunciation of this BITE has occurred in flight (e.g. STS-52, STS-80, STS-96, STS-114, and STS-121). Reference PASS User Note #47741.

BITE: RESOLVER LIMIT FAIL

TYPE: Software

SOURCE: Resolver Processing (RES_PROC) Module in the IMU SOP

FUNCTION: 1X/8X Resolver Miscompare

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 8000 (1000 for Platform Fail BITE)

DOWNMODE BFS: NO (YES for Platform Fail BITE)

CAUSE:

The HAINS A/D card firmware performs a resolver reasonableness test and annunciates a Platform Fail BITE when the difference between the internally computed resolver angle ($1X_{LO} + 8X$) and the 1X resolver reading (except for the inner roll gimbal) is greater than the resolver limit of 0.7° . In addition to setting the Platform Fail BITE, 5° will be added to the 1X resolver value sent to the GPC to ensure the GPC 1° resolver limit is exceeded and the Resolver Limit Fail BITE is annunciates.

POSSIBLE IMPACT:

An IMU will fail RM if the 1X error is large enough to cause the internally computed resolver angle to be in the wrong octant or if the 8X resolver shift is greater than the IMU RM threshold. A 1X resolver error $> 0.7^\circ$ will be reflected as a 5° error in the 1X-H/W value on the IMU Summary Display, regardless if the IMU SOP computed gimbal angle is in error or not. Any 8X resolver shift will impact the computed angle which will show up as a misalignment of the IMU in the MCC gyro delta comps. Depending how long it has been since the last alignment (since the RM threshold grows in time), a shift in an 8X resolver may be large enough to cause the IMU to fail RM. An IMU with an 8X resolver shift, in any gimbal, should not be aligned until the shift has been compensated by using an unapproved G-MEM write procedure. If an IMU alignment has been made since the 8X resolver shift had occurred, then another IMU alignment will be required before reselecting the affected IMU after the resolver shift compensation has been performed. This BITE will cause downmoding in a dilemma situation. The Platform Fail BITE will cause downmoding in the BFS.

Compensations are possible only for 8X resolver shifts. 1X resolver shifts will render the IMU inoperative only if the shift is >22.5 deg. The HAINS A/D card firmware performs an octant check just like the GPC; where 45 deg is added/subtracted to/from the new computed resolver angle if it differs from the hardware 1X resolver reading by more than 22.5 deg..

COMMENTS:

The GPC computed mechanical angle is computed as follows:

$$\text{Computed mechanical angle} = 1XLO + 8X - \text{OFFSET.}$$

Where:

- 1XLO = lowest octant value of the 1X resolver.
- 8X = the 8X resolver whose values range from 0 to 45 degrees.
- OFFSET = measured offset of the hardware mounting between the 1X and 8X resolvers (I-load, factory calibrated parameter stored and applied at the HAINS. GPC I-LOADs are zero).

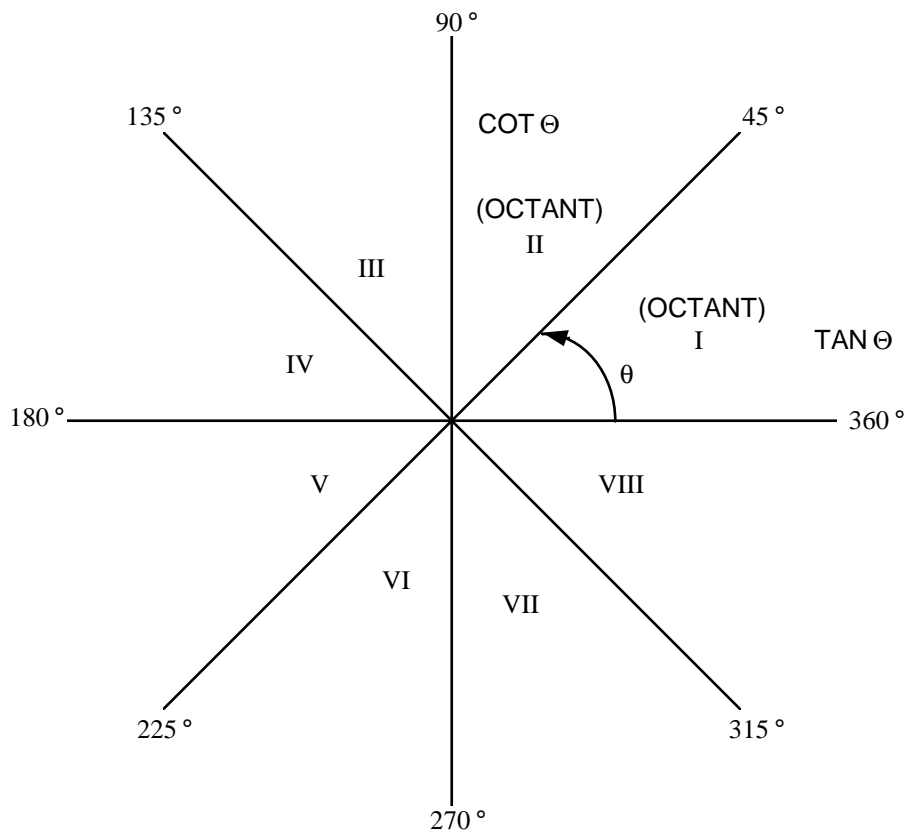


Figure 2.2-5. - IMU resolver octants

The computed angle is used by the IMU SOP for attitude determination. There cannot be any constant false BITE indication for the RESOLVER LIMIT FAIL signal.

BITE: VELOCITY LIMIT FAIL

TYPE: Software

SOURCE: Accelerometer Pulse Transformation (ACP_TRSF) Module in the IMU_SOP

FUNCTION: Velocity Out of Limits

CREW ON-BOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 8000

DOWNMODE BFS: NO

CAUSE:

The VELOCITY LIMIT FAIL is set if the software detects either an underlimit or overlimit velocity indication. The underlimit flag will be set if the following conditions are true:

- A. On the previous cycle, at least two IMUs sense a normalized acceleration > 1.93 ft/sec².
- B. On the present cycle, one or more IMU's sense a normalized acceleration > 1.93 ft/sec².
- C. On the present cycle, one and only one IMU senses the normalized acceleration to be < 1.61 ft/sec².

The overlimit flag is set if the sensed normalized acceleration compared to the previous cycle is in excess of approximately 4.6 g's. This BITE is set as soon as the threshold is exceeded.

POSSIBLE IMPACT:

A velocity limit flag is set because of a velocity overlimit indication will assist RM in failing the IMU. An IMU with a VELOCITY LIMIT FAIL due to a low sensed acceleration may fail RM if its delta velocity (compared to the other IMU's) exceeds the velocity RM threshold. At the two level, a delta velocity greater than the RM threshold may cause an IMU dilemma. This BITE will cause downmoding in a dilemma situation.

COMMENTS:

The 4.6 g's is computed as follows:

$$(0.0344488 \text{ ft/sec/pulse}) * (4300 \text{ pulses/sec}) = 148.1 \text{ ft/sec}^2$$

$$\frac{148.1 \text{ ft/sec}^2/\text{g}}{32.2 \text{ ft/sec}^2} = 4.6 \text{ g's} \quad 4300 \text{ pulses} = \text{low gain (inertial) velocity limit.}$$

If FCOS has detected a commfault, the IMU SOP will compensate for that IMU lost data by using the delta velocity computed the previous cycle (assuming a constant acceleration), therefore causing the velocity of the commfaulted IMU to eventually exceed the BITE limit. If subsequent to the BITE, the GPC/IMU communication is reestablished, then the BITE will be reset.

In the two-IMU's-selected-by-RM case, it is possible for the velocity under limit (VUL) test (IMU BITE processing) to annunciate an IMU BITE/T message for the wrong IMU.

If a "good" IMU correctly senses a normalized change of velocity below the fail limit (1.61 ft/sec) and the "bad" IMU senses a normalized change of velocity above the enable limit (1.93 ft/sec), an IMU BITE/T message will be annunciated for the "good" IMU by IMU BITE processing. This condition will exist as long as the change of velocity remains below the enable limit.

In the above case, if the third IMU is reselected, it will not be included in the VUL test as long as the change in velocity remains below the enable limit (1.93 ft/sec²); i.e., validity of an IMU BITE/T annunciation cannot be resolved by reselecting the third IMU unless the velocity enable limit is exceeded by at least two IMU's.

An erroneous BITE indication can be generated when an IMU is moded from STBY to OPER and when it is recovered from a COMMFAULT. This occurs because the Flight Software extrapolates accelerometer pulses from the last two good values. These BITE's are transient and will clear on the next cycle. Reference PASS User Note #43940.

BITE: ECHO 1 FAIL

TYPE: Software

SOURCE: IMU_BITE Processing Module in the IMU SOP

FUNCTION: GPC Echo Check Failure

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 8000

DOWNMODE BFS: NO

CAUSE:

The ECHO 1 FAIL is set to logic 1 when word 13 (which should be the same word as the GPC transmitted command word 1) does not compare exactly to the GPC transmitted command word 1, IMU pulse torquing commands. This ECHO 1 FAIL will be set if a miscompare (from above) exists, and a transmission word 1 failure has not been annunciated previously on the same cycle.

POSSIBLE IMPACT:

The IMU data word 13 may have been changed in the transmission through the MDM to the GPC receiver, indicating perhaps an MDM (transmitter or receiver) or GPC receiver problem. If this is the case, then some of the other IMU data words may be changed during transmission, which depending on the error, may make the IMU fail RM. This BITE will cause downmoding in a dilemma situation.

COMMENTS:

The ECHO FAIL test was implemented to detect any transmission errors from the IMU to the GPC. This check is done strictly at the GPC. The possibility of a false ECHO 1 FAIL BITE being set is very remote. The IMU will torque out any commands sent by the GPC in the same cycle in which the ECHO 1 FAIL BITE was set (as long as a transmission word 1 fail is not set).

In the SMS, multiple IMU ECHO 1/2 BITE annunciations indicates a timing problem between the IMU and GPC which may result in the SMS going down.

BITE: ECHO 2 FAIL

TYPE: Software

SOURCE: IMU_BITE Processing Module in the IMU SOP

FUNCTION: GPC Echo Check Failure

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 8000

DOWNMODE BFS: NO

CAUSE:

The ECHO 2 FAIL is set to logic 1 when word 14 (which should be the same word as the GPC transmitted command word 2) does not compare exactly to the GPC transmitted command word 2, IMU slewing commands. This ECHO 2 FAIL will be set if a miscomparison exists and a TRANSMISSION WORD 2 FAIL has not been annunciated previously on the same cycle.

POSSIBLE IMPACT:

The IMU data word 14 may have been changed in the transmission through the MDM to the GPC receiver, indicating perhaps an MDM (transmitter or receiver) or GPC receiver problem. If this is the case, then some of the other IMU data words may be changed during transmission which depending on the error, may make the IMU fail RM. This BITE will cause downmoding in a dilemma situation.

COMMENTS:

The ECHO FAIL was implemented to detect any transmission errors from the IMU to the GPC. This check is done strictly at the GPC. The possibility of a false ECHO 2 FAIL BITE being set is very remote. The IMU will slew to the GPC commands in the same cycle in which the ECHO 2 FAIL BITE was set (as long as a TRANSMISSION WORD 2 FAIL is not set).

In the SMS, multiple ECHO 1/2 BITE annunciation indicates a timing problem between the IMU and GPC which may result in the SMS going down.

BITE: ACCELEROMETER SCALE FACTOR FAIL

TYPE: Software

SOURCE: Accelerometer Processing (ACP_ACUM) Module in the IMU SOP

FUNCTION: Erroneous Accelerometer Scale Factor

CREW ONBOARD ANNUNCIATION

IMU BITE/T MESSAGE: YES

STAT IN SPEC 21 and 51: "BITE"

TEMPERATURE INDICATION: N/A

GROUND CRT IMU HEX STATUS WORD INDICATION: 8000

DOWNMODE BFS: NO

CAUSE:

The ACCELEROMETER SCALE FACTOR FAIL is set to logic 1 when the D1/D8 bit of the IMU output data word 1 (bit 11) is not equal to the last GPC transmitted gain setting as shown in the GPC IMU slew command word 2 (bit 0).

POSSIBLE IMPACT:

A gain change (to high gain) whenever the IMU is sensing an acceleration (ascent, OMS burns or entry), may cause the IMU to fail since the acceleration data from the IMU will now be 10 times greater than in low gain. A change in the gain will be seen at the GPC as a shift in the IMU velocity (all axes). In orbit with no change in velocity (zero g's), a change to high gain should not impact IMU performance; however, whatever null accel bias is present in that IMU will again be multiplied by 10. A false ACCELEROMETER SCALE FACTOR FAIL BITE will have no impact on IMU operation, however, it will cause downmoding in a dilemma situation.

COMMENTS:

Accelerometer high gain will only be used during calibration so as to provide a higher resolution on the accelerometer performance.

LOW GAIN (logic 0) = 935 PPS/G (PPS = Pulses per second)

HIGH GAIN (logic 1) = 9350 PPS/G

If it has been determined that the IMU has upmoded to high gain, we can recover the IMU by performing out unapproved G-MEM to change the software accelerometer scale factor by 90 percent, or in other words multiply the sensed acceleration by 10 percent. An ACCELEROMETER SCALE FACTOR FAIL by itself or accompanied by an ECHO 2 Bite (data

word #14 is not equal to the command word #2) may indicate an upmode of the IMU to high gain. A change in the command word 2 at the MDM may produce a transmission word 2 fail (if bad parity).

A transient (erroneous) ACCELEROMETER SCALE FACTOR BITE message can be received during prelaunch activities under certain conditions. If a launch scrub was previously performed while the IMUs were in high gain setting (during the high gain portion of either a preflight calibration, preflight alignment, or while the IMU was in term/idle), an ACCEL SF BITE message can be received by one or more IMUs when the IMUs are brought from STANDBY to OPERATE for the preflight calibration. The erroneous BITE message is caused because the IMUs last commanded gain setting was high gain (during the previous launch attempt), but when the IMU was brought to OPERATE during the current launch attempt, it was commanded to the nominal (low) gain setting. If an ACCEL SF BITE annunciation does occur after moding the IMU from Standby to Operate, it could be this transient BITE condition and should clear during the next processing cycle when the D1/D8 bit of the IMU output data word 1 (bit 11) is again equal to the last GPC transmitted gain setting as shown in the GPC IMU slew command word 2 (bit 0). If the BITE does not clear after one cycle, further investigation is required. This erroneous BITE message occurred during the STS-76 Prelaunch shift.

REFERENCE

1. Engineering Directorate memo EH6-68/81, IMU Performance at Over Temp/Under Temp.
2. Reference Primary Avionics System Software, User Note number 43940.
3. GNC Systems Briefs (JSC-18863), Section 6, Inertial Measurement Unit (IMU).
4. STS-76 Prelaunch data.

TITLE

IMU REDUNDANCY MANAGEMENT (RM) FAILURE VERIFICATION AND DILEMMA RESOLUTION

PURPOSE

To describe the procedures to be performed by the console operator in order to verify/isolate an inertial measurement unit (IMU) failure at the two or three level, as well as to resolve an IMU dilemma situation.

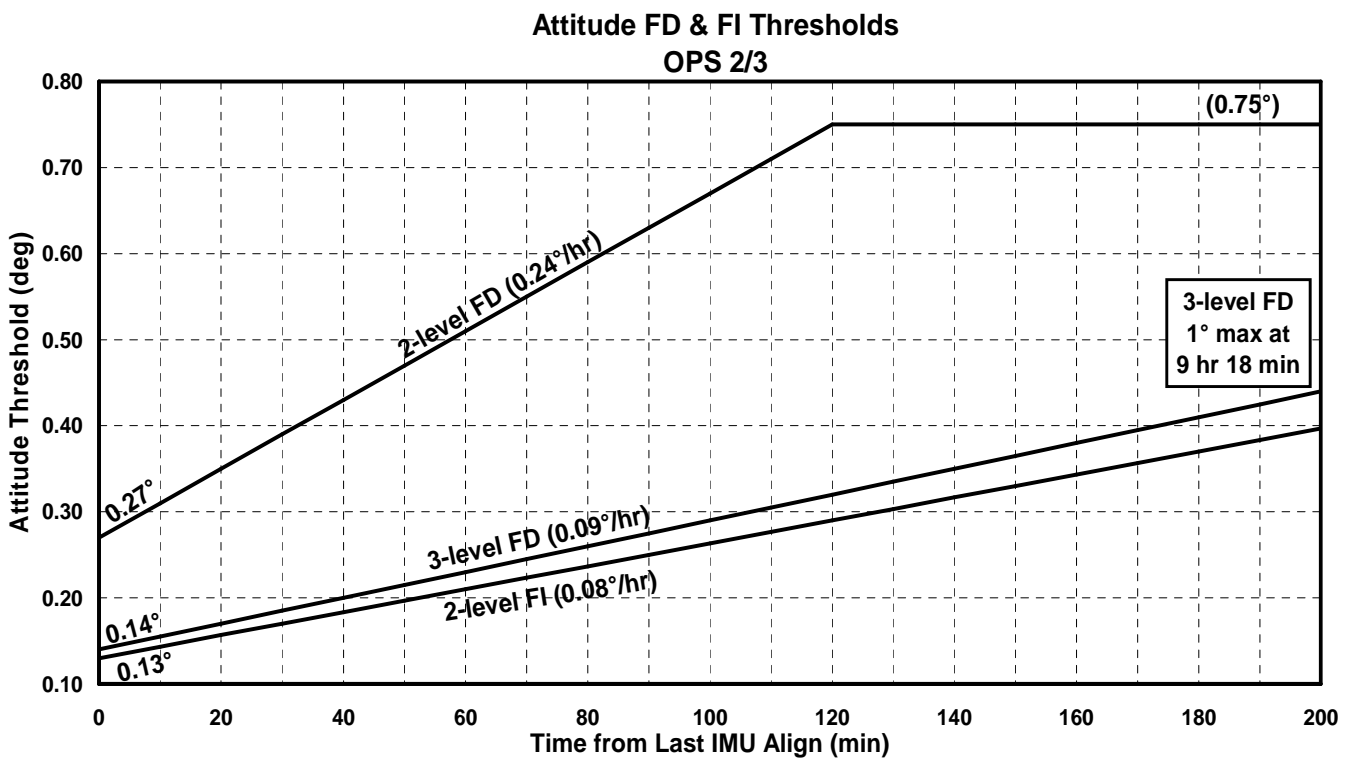
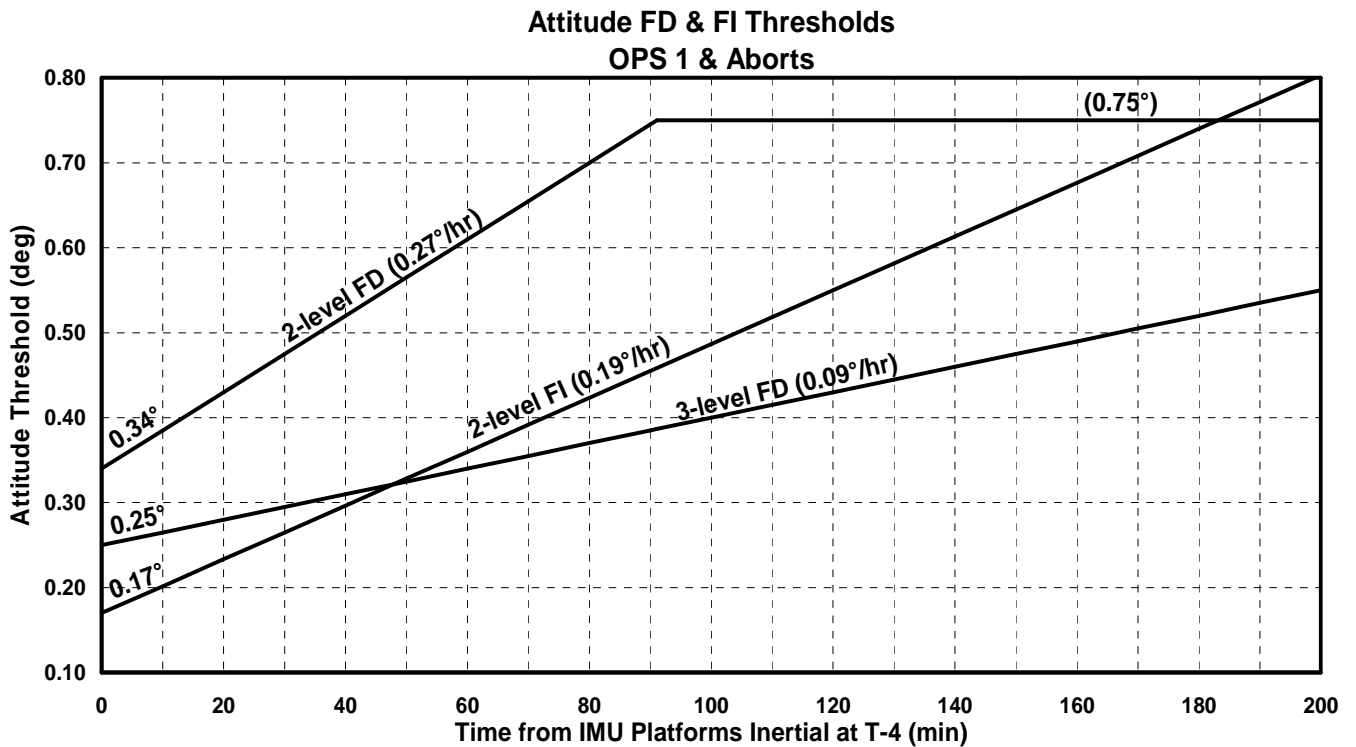
PROCEDURES

NOTE: If the IMU failure occurred at the two-level, and the failed IMU has a BITE, make certain that RM did the right thing; i.e. the IMU with the BITE is really the bad IMU.

A. IMU FAILURE VERIFICATION

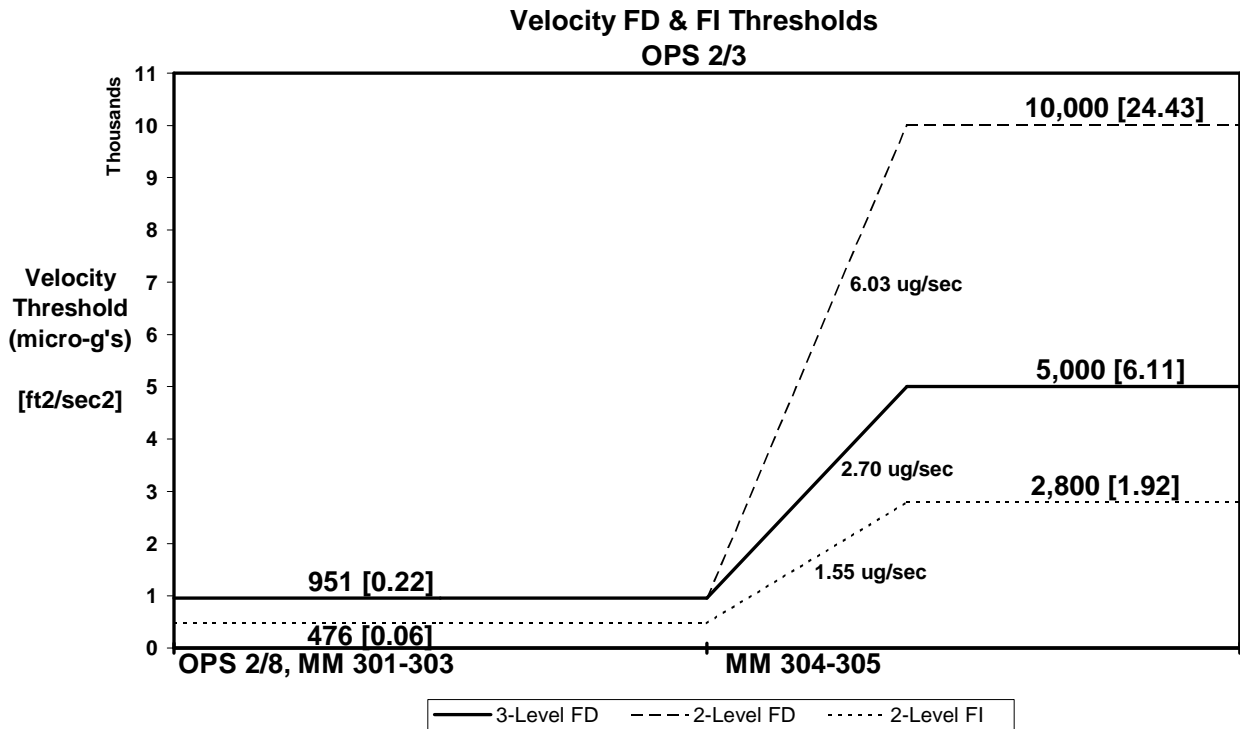
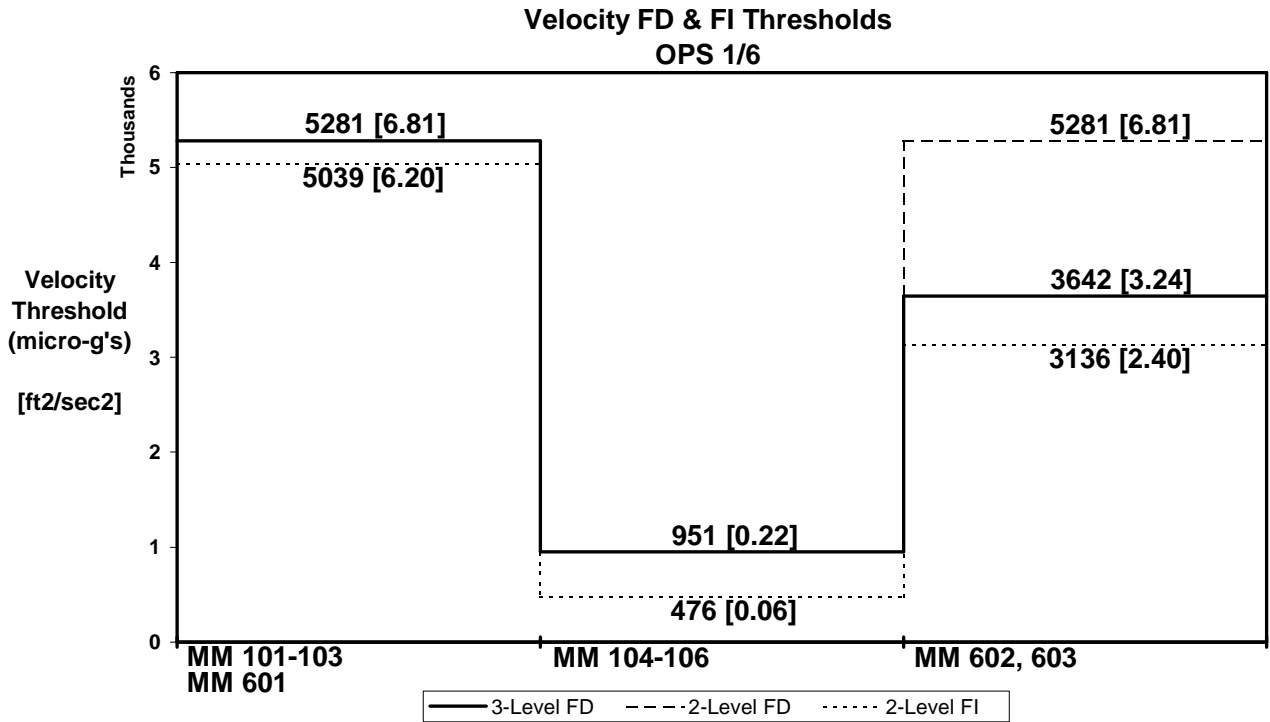
These procedures should be followed when an RM-declared failure occurs at the two or three level in any OPS. (Use Figures 2.3-3 and 2.3-4 as a reference for IMU Attitude RM and IMU Velocity RM in PASS respectively).

1. Determine which IMU has been failed by RM using the primary displays, ELOG and the CRANS event lights. The GNC ORBIT display contains the necessary data. The IMU SUMMARY display may be used as a backup data source (See section D to verify an RM declared failure at the two level.)
2. Once the RM-failed IMU has been identified, select that IMU as reference. Reinitialization of the acceleration and drift computations may be required to accurately reflect the failure magnitude.
3. Evaluate the gyro deltas to determine whether the problem with the RM-failed IMU is an attitude problem, a velocity problem, or both.
 - a. Determine if both root sum square (RSS) for the GYRO Δ 's associated with the RM failed IMU exceed the RM threshold. The IMU RM thresholds for both attitude and velocity are illustrated in Figures 2.3-1 and 2.3-2.
 - b. If the RM attitude threshold is violated, the problem is in attitude. Proceed to section B, IMU Attitude Failure Isolation. If no RM attitude threshold is violated, proceed to section C, IMU Velocity Failure Isolation.



Note: Correct isolation is not guaranteed at the 2-level, for single or multiple axis failures, and a ground call may be required.

Figure 2.3-1. - Attitude RM Thresholds



Note: Correct isolation is not guaranteed at the 2-level, for single or multiple axis failures, and a ground call may be required.

Figure 2.3-2. - Velocity RM thresholds

B. IMU ATTITUDE FAILURE ISOLATION

This section of the procedure is used to verify, isolate, and compensate for an attitude failure.

1. Advise Guidance, Navigation and Control (GNC) that the RM-failed IMU is not usable for flight control. The IMU will not be useable if the failure is gyro related, until the gyro is compensated and the IMU is aligned. The IMU should be useable for NAV (as a last IMU) if the failure is a resolver, and not an Inner roll resolver.
2. Evaluate resolvers by analyzing the data on IMU SUMMARY for the appropriate RM-failed IMU. Take hardcopies of IMU SUMMARY and compare each of the raw 1X resolvers and its associated axis (roll, pitch, azimuth) computed resolver angle. If these two corresponding values are not approximately equal ($\pm 0.3^\circ$), there exists a resolver error in that axis.

A Resolver Limit Fail BITE and a Platform Fail BITE should have also occurred if the difference is greater than 0.7° . Go to B.3.

If no resolver error is indicated, assume a gyro bias exists and continue below.

- a. Conclude that the failure is a gyro problem (either single or dual axis). Perform gyro error compensation as described in SCP 2.4, IMU Drift Calculation.
 - b. After compensation is performed, review the gyro data on the IMU SUMMARY display. Report results to GNC and recommend realignment/reselection of the RM-failed IMU, if appropriate.
3. Comparison of the raw 1X resolver angle with its appropriate axis computed resolver angle will identify the resolver or resolvers with an error.

NOTE: An IMU with an 8X resolver problem should not be aligned until the resolver problem is fixed.

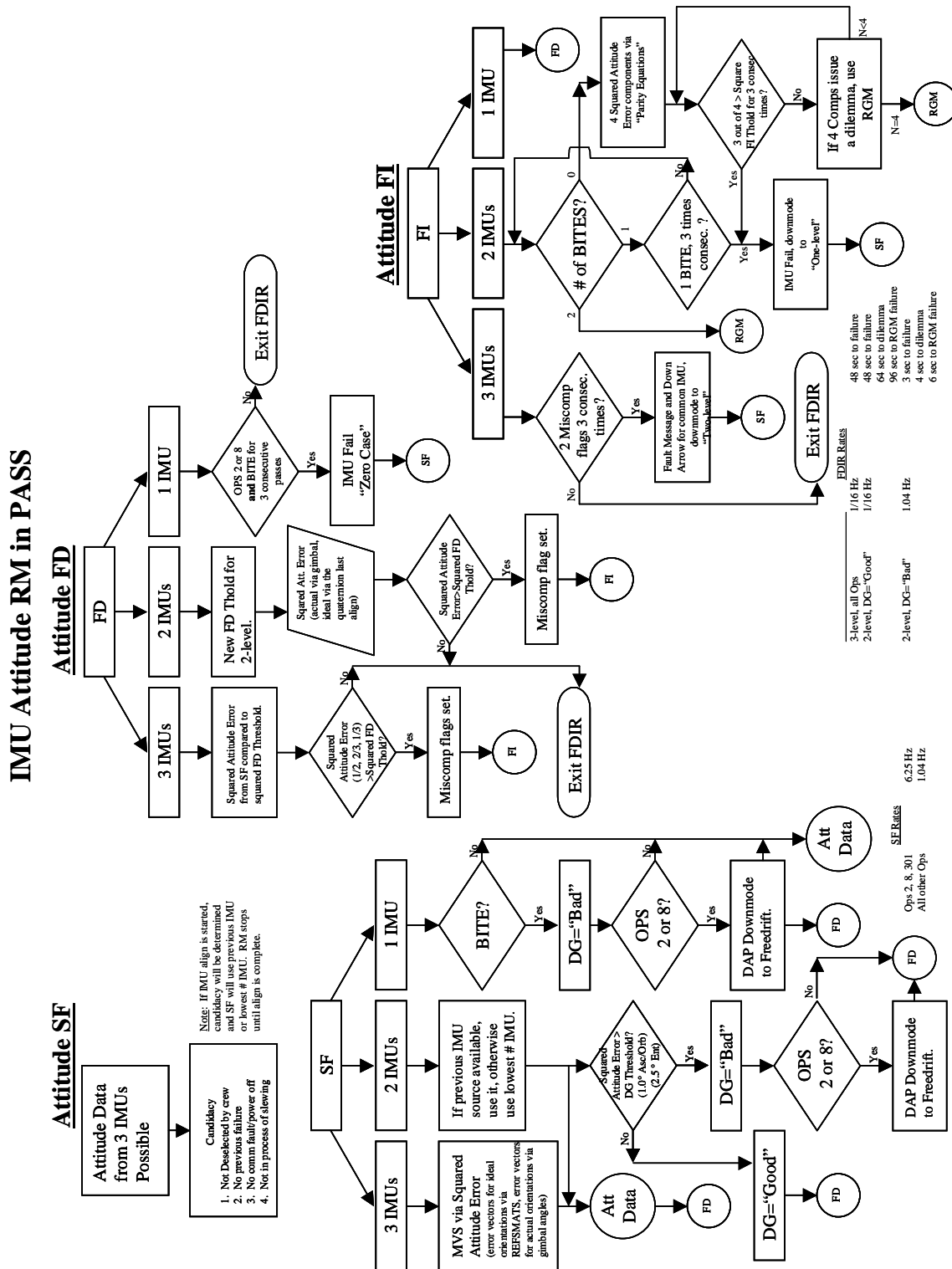


Figure 2.3-3. – IMU Attitude RM in PASS

C. IMU VELOCITY FAILURE ISOLATION

This section of the procedure is used to verify, isolate, and compensate for a velocity failure.

1. Evaluate the accelerometer deltas to determine whether the problem with the RM-failed IMU is a velocity problem.
 - a. Observe the values on the I/J ACC Δ comps from the IMU SUMMARY display. Compare these values with the RM velocity threshold found in Figure 2.3-2. If the vehicle is not accelerating, i.e., on orbit, also check the NULL ACC comps.
 - b. If the RM-failed IMU exceeds the threshold, note the axis exceeding the threshold and proceed to section C.2. If the threshold was not exceeded, the RM failure was transient. Advise GNC to have the crew reselect the failed IMU. Observe all facets of the IMU SUMMARY display after IMU is reselected for possible repetition of the RM failure annunciation.
2. Once the axis or axes exceeding the RM velocity threshold have been identified, continue with this section.
 - a. If the RM velocity threshold was exceeded only in the X axis, Y axis, or Z axis, then the RM failure is an IMU accelerometer failure. Proceed to section C.3. Otherwise, continue below.
 - b. If the accelerometer deltas are approximately equal in all axes for the RM-failed IMU, then the failure is a triaxial accelerometer bias failure. Proceed to section C.3. Otherwise, continue below.
 - c. If the accelerometer deltas are not equal in all axes, but in more than one axis for the RM-failed IMU, then a multi-axis velocity failure exists. Confirm the failure with radar velocity deltas, if available. Inform GNC of the results. Observe IMU SUMMARY display for further anomalies.
3. If an IMU accelerometer failure has been confirmed from the results of section C.2, proceed as follows:
 - a. If in OPS 2, advise GNC that the RM-failed IMU is good for flight control purposes, if it is required. If in OPS 1 or 3, the accelerometer bias may also cause attitude errors and the IMU may not be good for flight control.
 - b. Perform accelerometer compensation as described in SCP 2.5 IMU Accelerometer Bias Correction.
 - c. Prepare an updated accelerometer bias load. Verify the load and inform GNC when the load is ready.
 - d. Observe the results on the accelerometers after incorporation of load in the vehicle. Advise GNC to have the crew reselect the RM-failed IMU, if appropriate.

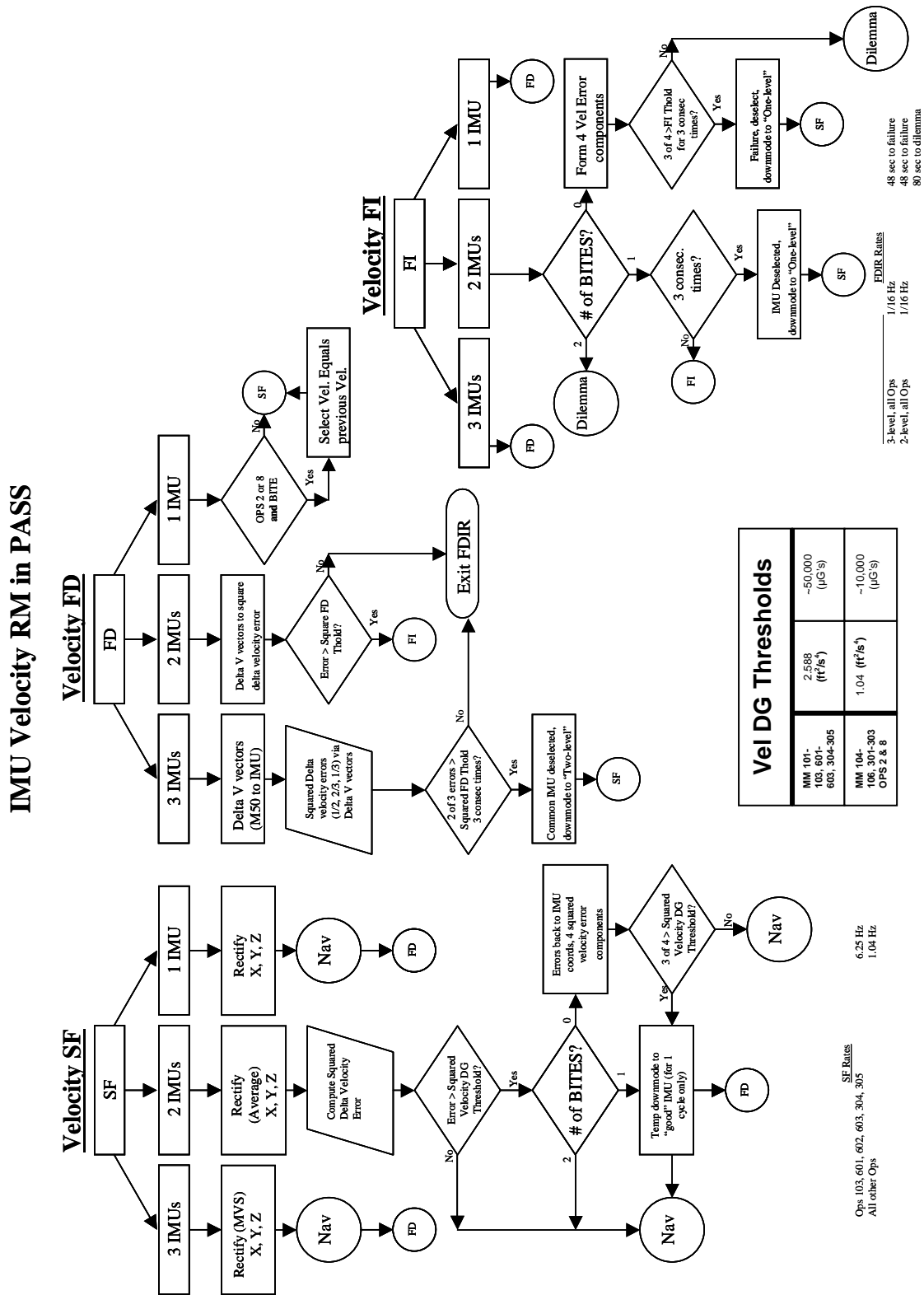


Figure 2.3-4.-IMU Velocity RM in PASS

D. IMU DILEMMA RESOLUTION

This procedure may be used to resolve IMU dilemmas as well as to verify that RM declared the correct failure at the two level.

1. Background

The following three specific type anomalies cannot be isolated by RM and therefore require ground assistance:

- Velocity/attitude errors near the line-of-ambiguity (common line in X/Y plane)
- Triaxial velocity failure, resulting in biased accelerometer outputs in all axes, simultaneously
- Gyro drift rates of less than 0.5 deg/hr (X/Z or Y/Z axes)

During ascent and entry, radar-derived velocity data are available for comparison with IMU data to help flight controllers resolve velocity dilemmas (utilizing a vote not available to onboard RM).

The Guidance and Procedures Officer (GPO) is also able to supply a vote as to which IMU is failed. During ascent, the GPO can compare the PASS state vector (average of last two IMUs) and the BFS state vector (prime selecting one IMU) to ground tracking data. From this comparison, the bad IMU can be identified. During entry, individual state vectors for each IMU are generated and compared to ground tracking data to determine IMU health.

During the on-orbit phase, when ΔV 's should be zero, the ground can monitor IMU velocities and resolve ΔV failures. This procedure will also be employed to identify and resolve the triaxial velocity problem on-orbit.

Gyro drift rates whose magnitudes exceed 0.5 deg/hr should reliably be detected by onboard RM (BITE) unless the failure is a pure Z axis drift. IMU's exhibiting drift rates less than 0.5 deg/hr may be isolated by noting abnormally large redundant rates onboard or by generating ground parity equations. During the orbital phase, verification is possible through star alignment with a probable recalibration attempt, if feasible.

2. Procedures

- a. Exceeding the ISP limit manager limits between two IMU's (attitude and velocity) will result in one or more of the following delta values turning yellow:

IMU 1/2 GYRO Δ IMU 1/2 ACC Δ
IMU 1/3 GYRO Δ IMU 1/3 ACC Δ
IMU 2/3 GYRO Δ IMU 2/3 ACC Δ

NOTE: Onboard RM may not yet have detected this discrepancy, as the ISP limits are set tighter than the RM thresholds.

b. Velocity dilemma - ascent and entry (using ground-derived velocity data)

- (1) Verify RTPLOT with the ground-derived velocity data corresponding to the axis exhibiting off-nominal data is enabled (yellow/red data on ASCENT/ENTRY SENSORS) and monitor the IMU's performance).
- (2) Declare the IMU which exhibits the greatest change in slope from its previously plotted characteristics as failed.
- (3) The GPS COMPARES display can also be used to determine which IMU has failed by monitoring the compares between the IMU velocities and the GPS velocities. The failed IMU will show the larger velocity delta with the GPS. This delta may take 30 seconds or so to show up in the data.
- (4) It may be helpful to monitor the remaining relative RTPLOTS to substantiate the failure decision.
- (5) If the dilemma cannot be resolved within 120 seconds, select the other IMU as a reference for computations (pbi_comp - note IMU REF CRANS event light). This action may result in a greater change in slope on the associated RTPLOTS (an additional 120 seconds may be required to establish a noticeable trend).
- (6) If the dilemma cannot be resolved using the above procedures, the GPO should be consulted as to which IMU is bad.

c. Velocity dilemma - orbital phase

- (1) Call up the GNC ORBIT display containing NULL ACCEL data for each of the IMU's in dilemma.
- (2) Note the IMU displaying any significant change in NULL ACCEL and declare it failed.
- (3) Recommend recalibration of failed IMU, if feasible.

d. Ground-generated parity equations (see general note 3)

If the velocity dilemma cannot be resolved using RTPLOT trend data or digital display data, the following procedure is suggested (applicable in all phases):

- (1) Call up appropriate SENSOR display.
- (2) Note value of IMU I/IMU J Δ data for all (three) axes.
- (3) Select the other IMU as a reference for computations (pbi_comp-note IMU REF).
- (4) Again note value of IMU I/IMU J Δ data for all (three) axes.
- (5) Data analysis: When the failed IMU is selected as the reference for computations, we expect at least one (maybe two) out of the three axis Δ 's

to read near zero, as the failed axis error cannot be projected onto its own perpendicular axes. When the nonfailed IMU is selected as the reference for computations, we expect all three axis to be at some magnitude, none near zero, since the failed IMU axis error is being projected onto all three skewed axes of the good IMU.

e. Attitude dilemma - all phases

- (1) Use procedure described in section d as applicable to attitude data. Check axis Δ 's for resolvers and gyros.
- (2) During ascent and entry phases, if the dilemma cannot be resolved using the above procedures, GPO should be consulted as to which IMU is bad. The attitude problem might cause the platform to be misaligned with respect to M50, causing the state vector for that IMU to have errors. GPO can help us for these cases
- (3) During the on-orbit phase, recommend a star alignment to substantiate MCC dilemma resolution.
- (4) Recommend recalibration of the failed IMU, if feasible.

SUMMARY: Due to the plotting time necessary to distinguish a failed IMU on RTPLOT during ascent and entry, it is recommended that the parity equation technique (procedure d) be employed initially. If the parity equations do not solve the dilemma (e.g., for a triaxial velocity failure), a substantial number of points will have been plotted on RTPLOT when viewed for analysis.

GENERAL NOTES

1. Evaluation of RTPLOT - The radar-derived velocity data contain a substantial error/noise variation whose boundary is evidently proportional to the specific geometry of the radar ground stations. Our ability to determine a directional trend in the radar-IMU velocity is limited by the large number of plotted points required before we can be sure that the true boundaries of the radar data have been sampled. With the fastest RTPLOT update rate set at 2-second intervals, it may take a substantial length of time to determine a significant change in the slope of the average plotted data, following the failure of one of the two units in dilemma.

Due to the above uncertainties, we are not able to guarantee that the small percentage of dilemmas requiring ground assistance will definitely be resolved using radar data. For this reason, the use of parity equations was also described in these procedures.

2. We anticipate a greater level of success using RTPLOT during entry, as radar data is expected to contain a much lower level of error due to improved ground station geometry.
3. Ground-generated parity equations - The console operator has the ability to see IMU data expressed in the reference frame of specific LRU by depressing the IMU REF

pushbutton on the pbi_comp. Delta's between units are computed after this transformation occurs. When an error exists on a given axis of one IMU in dilemma, that error can be projected onto all axes of the second IMU when transformed into its coordinate frame, as all axes of the second IMU are skewed from those of the first. However, the existing error will not be reflected onto its own remaining axes, as they are perpendicular to one another. Therefore, if we select the failed IMU as a display reference, we should see the effects of the error along its failed axis only, with no error along its perpendicular axes (whose delta's with good IMU should read at, or near, zero). However, if we select the good IMU as a display reference, we should see the effects of the failed IMU along all axes due to its projection onto the skewed axes of the good IMU.

Thus a single (or dual X/Y) axis failure is detectable through ground manipulation of displayed parameters. A triple axis failure will, of course, be indistinguishable as errors will appear in all axes regardless of which IMU is selected as reference. In this case other factors (e.g., redundant rates, RTPLOT or orbital ΔV 's must be employed.

REFERENCES

1. Space Shuttle Flight Software I-loads and K-loads, OI-8B.2. Level C Functional Subsystem Software Requirements, STS 83-0013, GNC IMU SOP, sec. 4.5.1.3, June 30 1987.

TITLE

IMU DRIFT CALCULATION

PURPOSE

To describe the calculation and analysis of inertial measurement unit (IMU) gyro drift rates and procedures for uplinking onboard compensations.

GENERAL

WARNING: This procedure is governed by FCOH SOP 3.1, COMMAND POLICY FOR MOD, and cannot be modified without prior approval of the FOIG or the Flight Director (during real-time operations). Safety critical steps are marked by a box.

The general purpose computers (GPC's) store the current IMU gyro drifts for all nine gyros (three per IMU). These values are used to determine the amount of pulse torquing needed to keep the IMU platforms inertial. Increases in the uncompensated drift of individual gyros can be corrected by altering the corresponding onboard drift rate via an uplinked compensation.

Restrictions:

OI Load: all

OPS mode: PASS (OPS 2 and MM 301 of OPS 3) BFS (MM301 of OPS 3)

Major Function: GNC

Vehicles: all

Crew/MCC coordination: information only

Time Constraints: none

Hazardous: This load replaces the values of DFX, DFY, DFZ for each IMU (V99R2560C through 2568C) which are stored in the GPC. If the uplink causes erroneous onboard biases, IMU attitude reference may be lost.

Require safing: no

BACKGROUND

Each IMU contains two two-degrees-of-freedom gyroscopes. These gyros are mounted on a platform such that three of their axes form an orthogonal coordinate system. Friction and mass imbalance of the spinning wheels cause gyroscopes to drift with respect to inertial space. This SCP describes the computation of gyro drift rates. The manipulation of data necessary to perform general analysis of IMU drift characteristics is also described. The features and operation of the program IMUDRIFT are discussed throughout this SCP.

IMU gyro drift manifests itself in the form of rotation about a platform axis this rotation is compensated for by continuously pulse torquing the gyros in the direction opposite the drift. The amount of required onboard compensation is different for each axis of each IMU. These compensations are computed prior to each flight during prelaunch IMU calibrations. Once calibrated, the uncompensated, or measured, drift in each axis generally remains well below 0.012 deg/hr. A shift in gyro performance can occur during flight, though this is not common,

and will result in larger uncompensated drift rates. Since the majority of pulse torquing is performed by the HAINS CPU, a loss of GPC pulse torquing will result in uncompensated drift rates of 0.04 deg/hr/axis or less.

Once on orbit, new compensations can be computed and uplinked. It is nominal procedure to maintain uncompensated rates below 0.006 deg/hr (1 sigma) to 0.012 deg/hr (2 sigma). Uplinks are generally made based on observations of drift rates over a period of 12 hours or more. Rates can be computed from both the platform misalignment and the length of the drift period. Torquing angles, generated from star-sighting data, describe platform misalignment in terms of rotations about each of the platform axis. (Torquing angles indicate the amount of rotation required to realign the platform with M50. Hence, the directions of the misalignments are opposite the directions of the torquing angles.)

The resolvers measure IMU gimbal positions which are used by the GPC to determine vehicle attitude. The resolvers have exhibited an apparent non-linearity in the resolver outputs. In other words, certain locations on the resolvers exhibit small errors from what the gimbal angles should actually read. It should be noted that each IMU is reading different angles because of the $\sqrt{6}$ skew. These errors are sent to the GPC and result in a corresponding error in vehicle attitude (this is a very small error). Each IMU has its own particular resolver characteristics when compared to the resolvers of other IMU's; however, each IMU's resolvers are consistent; i.e., the errors at given gimbal angles are repeatable.

The gyro drift of a HAINS IMU is not affected by orbiter attitude. The three internal heaters are located in the platform with the gyros. There is an azimuth gyro heater, a vertical gyro heater and a (inner roll) gimbal heater. Since the proximity of the heaters with respect to the gyros does not change as the vehicle maneuvers, the gyro drift of HAINS IMUs is not attitude dependent.

To compute accurate values of platform drift rates, the following data is required: (1) exact platform misalignment per axis relative to inertial space (M50) and (2) time since the previous alignment's torquing angles were generated. Two measurement error sources must be considered when determining platform misalignment. The star trackers contribute alignment measurement uncertainty reported to be as much as 0.023 deg/axis (1 sigma). (Refer to SODB, vol. 1, section 4.5.1.2.3.) Platform drift is nominally ≤ 0.006 deg/hr/axis. It is obvious that for several hours after an alignment misalignment uncertainty is as large as the actual platform misalignment! Given this situation, reliable drift rates cannot be computed from torquing angles generated shortly after an alignment. As misalignment grows with time, one can more accurately determine the true drift rate of the platform.

Figure 2.4-1 displays the effect that the variations of actual drift rate and uncertainty have on the time required to guarantee a 10 percent or smaller error. For a specified uncertainty, the time required to reliably achieve a certain level of accuracy decreases with increasing drift rate. Conversely, the length of the required drift period increases as uncertainty increases if a specified level of accuracy is to be guaranteed.

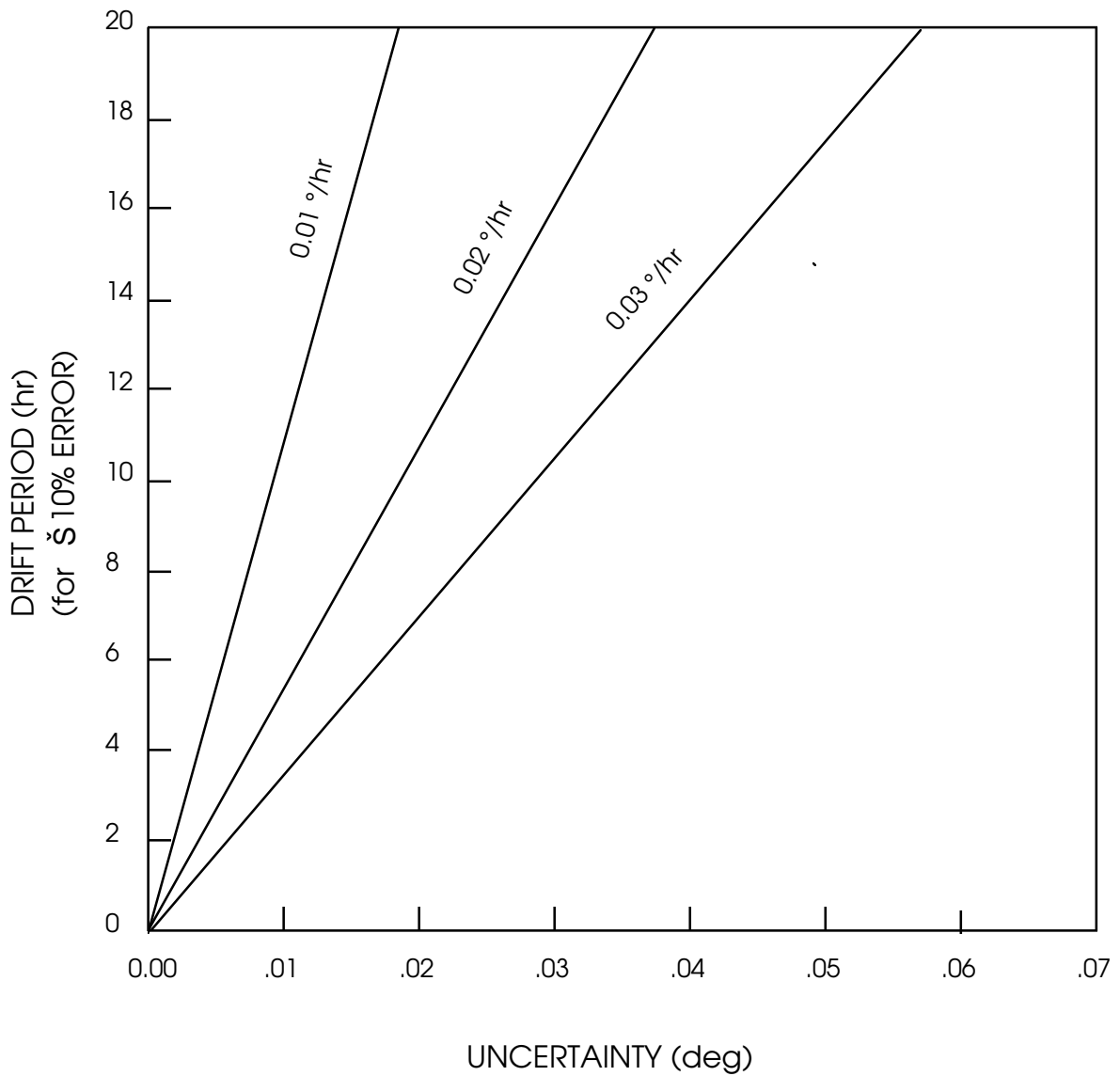


Figure 2.4-1. The effect that position measurement uncertainty has on time required to guarantee ≤ 10 percent error in calculated drift rate. (Actual drift rates of 0.01, 0.02, and 0.03 deg/hr are shown.)

New gyro bias compensations are nominally uplinked given that platform movement has been monitored for many hours (or days) and a constant, 1-sigma or larger (0.006 deg/hr) rate has been identified in any axis.

The new compensation is simply the old compensation plus the measured or uncompensated drift rate. This rate is just the platform misalignment per axis (given by the negative value of the torquing angle) divided by the drift period in hours. The calculation can be slightly complicated for the case in which onboard compensations are adjusted during the drift period. Figure 2.4-2 graphically displays the effect that a compensation uplink has on drift rate computation. In this situation, it is assumed that once the uplink is onboard, the actual drift rate per axis is decreased by exactly the amount of compensation added (θ). Subsequent to the uplink, drift rates are based upon the difference in platform misalignment between the time of uplink and the time of torquing angle generation (t_2).

The details of computing gyro drift rates and of uplinking compensation adjustments are described in the procedure section.

When torquing angles are processed with IMUDRIFT, gyro drift rates are produced. The data are normally stored in a data file. Rates generated from star data to which the platforms were aligned should always be stored. Rates generated from star-of-opportunity (SOO) data should be reviewed before deciding whether or not to store them. SOO data collected within hours of the previous alignment may produce unrealistically large drift rates .

PROCEDURE

The program IMUDRIFT has been developed to facilitate a per axis analysis of IMU gyro drift characteristics. Drift rates and gyro compensation biases can be displayed in graphical and tabular formats for a current or a previous flight. For specific information on the use of the program, refer to the IMUDRIFT User's Guide section on page 2.4-11.

If the IMUDRIFT program is not available, a manual method is described in section B.

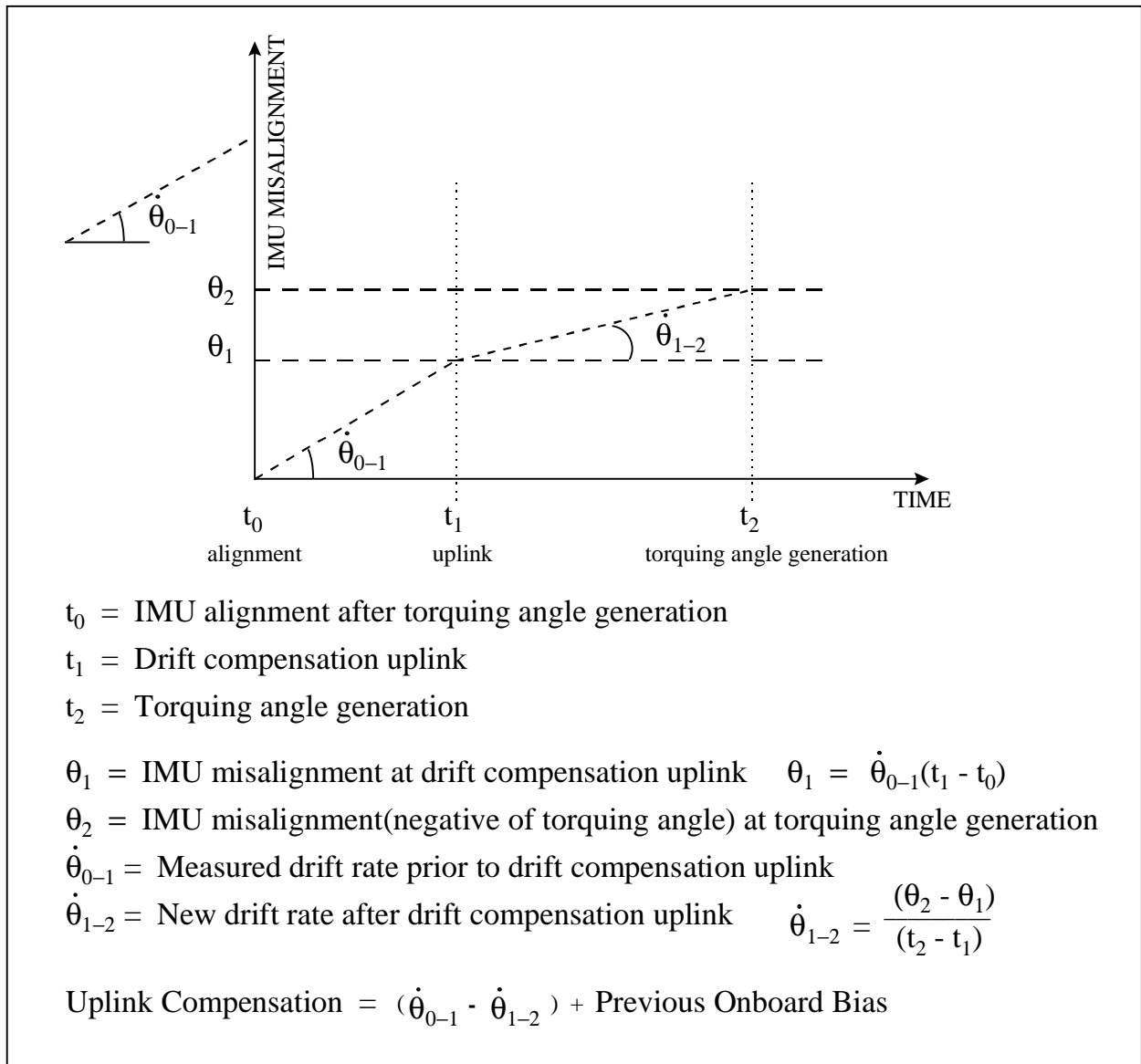


Figure 2.4-2. - Effect of compensation change on drift rate calculation.

A. DETERMINING/BUILDING DRIFT COMPENSATION USING IMUDRIFT

1. Execute IMUDRIFT from GNCMENU.
2. IMUDRIFT must be initialized at the beginning of each flight using the following instructions.
 - a. A data file should be created by selecting the Initialize option on the File pulldown menu. A pop-up input window will then be displayed. If IMUDRIFT has been previously initialized, select Load and pick the desired flight from the list which is displayed.
 - b. Enter Flight, Vehicle, DSM #, IMU serial #'s and the initial gyro bias determined during the preflight calibration. Select the O.K. button to insert the Bias record into the Database.
 - c. If the Real-time feature is active, the initial onboard bias should be automatically retrieved from downlink telemetry and displayed in the Real-time portion of the IMUDRIFT display. If this is the case, just click on the record to highlight (select) it and then move the Bias record into the Database portion of the display by selecting the Accept option on the Menu Bar.
3. The data from the first on-orbit alignment should be accepted into the database but no drift should be calculated from it. This is because the IMU's just went through ascent and therefore the torquing angles should not be used to determine IMU drift. However, this first alignment must be entered to mark the beginning of the drift period for subsequent calculations.
4. IMU align and Star of Opportunity (SOO) torque records will automatically be retrieved from downlink telemetry and displayed in the Real-time portion of the program window as long as the Real-time mode is active. The operator should Accept or Reject the data that has been collected there on a regular basis applying reasonableness criteria and engineering judgment in the process. The Accept or Reject menu bar options will act upon any records that have first been highlighted in the Real-time window.

****CAUTION****

Certification testing has determined that the IMUdrift program may record torquing angle records with incorrect values for MET, star tracker ID, or star tracker angle offset ("delta-ang"). Also, fictitious records may be registered.

To manually enter Torque or Align records, select the Insert option on the Edit pulldown menu. Enter the time of torquing angle generation, the torquing angles, the star data, and the type of the record (Torque, Align, Drift, Bias).

NOTE: Do not enter torquing angles that are less than 2 hours old. The resulting drift rate calculation may be in error due to resolver noise and the short drift period. Refer to the Background section for more discussion on this topic.

5. Calculation of drifts can be performed automatically if the Auto Drift Calc option is enabled on the Edit pulldown menu. A Drift record will automatically be inserted into the database after a Torque or Align record has been manually entered or accepted from the real-time telemetry. If Auto Drift Calc is not enabled, a Drift record can be calculated by selecting the Calc-Drift option on the menu bar.
6. As data is collected, the entire database can be viewed on the screen by manipulating the horizontal and vertical scroll bars on the Database and Real-time windows. A printout of the database can be requested with the Print option on the File pulldown menu and plots of each IMU's drifts can be called up using the Plot option on the menu bar. Control over the types of records to be displayed and printed is provided on the View pulldown menu. Any combination of Torque, Align, Drift, or Bias records can be displayed or printed.
7. To save the data and exit the program, select the Save and Exit options on the File pulldown menu respectively.

B. BUILDING THE COMMAND MANUALLY

New biases can be computed using the ground comps available on the high density displays (GNC Orbit or IMU Summary). This procedure is straightforward and reliable when only one IMU is drifting at a higher than nominal rate. It is necessary to use this procedure if no torquing angles are available or to reduce a large gyro bias that has occurred before star data is acquired.

1. If the gyro deltas for a common IMU begin to grow noticeably, select that IMU as the ground reference using the PBI application selected from the APPLICATIONS pulldown menu. Restart the drift comps via the PBI.
2. After the comps have settled down (approximately 30 to 40 minutes), compare the DRIFT I/J and DRIFT I/K data for the suspect IMU I. The magnitude of the measured drift will be represented by the number shown. (An average can be taken if the numbers differ, due to IMU J/K variations.)
3. Next, the polarity of the measured drift can be determined, using Table 2.4-I. The polarity of the comp figures (DRIFT I/J, DRIFT I/K) are mapped against the chart, one axis at a time. The combination of the two comp value polarities will define a row on the chart. Following that row across the far right-hand column (Measured drift polarity) will yield the appropriate drift polarity.

TABLE 2.4 - I. - MEASURED DRIFT POLARITY

Drift 1/2	Drift 1/3	Drift 2/3	Measured Drift Polarity
+	+	////////	+
-	-	////////	-
-	////////	+	+
+	////////	-	-
////////	-	-	+
////////	+	+	-

For the case where there are only two IMU's available, the ground comps are again utilized, and one can most effectively deal with a high drift rate on only one of the two IMU's. If a platform is drifting about a vector that has a projection in the X-Y plane, this movement should be detectable in the redundant rate axis. Monitoring this axis may provide confidence as to which unit is drifting. Once assured of which IMU is in need of compensation, repeat steps 1, 2, and 3, selecting as the reference IMU the suspect unit, and observe DRIFT I/J. A similar table of measured drift polarities can be formed for the remaining I and J units. Table 2.4-II is used to establish drift polarities for the remaining I J units. Remember that in checking for the proper sign convention for the drift polarity, the ground comp for GYRO I/J represents IMU I minus IMU J, and therefore, the sign depends on whether the suspect unit is the I or the J unit.

TABLE 2.4-II. - MEASURED DRIFT POLARITY (TWO IMU CASE)

Error in unit	Drift I/J	Measured drift polarity
I	+	+
	-	-
J	+	-
	-	+

- Finally, the new bias is calculated by using the equation:

$$\text{NEW BIAS} = (\text{CURRENT BIAS}) + (\text{MEASURED DRIFT})$$

Where the CURRENT BIAS is taken from IMU Summary. The magnitude of the MEASURED DRIFT is taken directly from the comp (DRIFT I/J, DRIFT I/K) and the polarity is based on the tables in step 3.

NOTE: To verify the correct polarity of the bias adjustment, the following equation can be employed, recalling that the bias adjustment is meant to compensate for the latest shift that has occurred in the hardware bias term.

$$(\text{COMPUTED DRIFT}) = (\text{HARDWARE OUTPUT}) - (\text{NEW BIAS})$$

Recall that GYRO 1/2 represents IMU 1 minus IMU 2. Therefore, a "positive" or "negative" result will suggest the direction that the drifting unit has shifted.

C. *LOADING THE COMMAND INTO THE COMMAND SERVER*

The following steps describe how to prepare a gyro bias uplink load. The decision to uplink new biases is generally based on the identification of a trend in the uncompensated drift rates observed over a period of hours.

NOTE: A Command Manager must be running on any workstation that runs command applications. Start or Stop a Command Manager from the Master DNAV, Global Apps, Command Server menu.

1. Select the IMU GYRO Command display from the GNC DNAV. Any previous gyro load in the command server should be displayed. If no previous load is on the server, use File retrieve to recall the previous saved gyro load (path: /mcc/rw_remote/common/gnc/SSPXXX/MEDS). The IMU GYRO Command display is shown in figure 2.4-3. See IMU log Book for the current onboard bias, identified by DSM 431XX.

NOTE: Command Display inputs are not allowed when the Command Server is in checkpoint.

2. Create DSM 431XY (thus retaining current load in buffer) and add the measured drift rates to the current gyro biases for the applicable IMU axes.
3. Select STORE to send the load to the Command Server.
4. Obtain a hardcopy of the new load.

File																																											
IMU GYRO																																											
DSM #	DSM Title	GMT Gen																																									
<input type="text" value="43101"/>	<input type="text" value="IMU Gyro load"/>	<input type="text" value="310:22:06:02"/>																																									
<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 15%;"></th> <th style="width: 20%; text-align: center;">hex</th> <th style="width: 20%; text-align: center;">deg/hr</th> <th style="width: 45%; text-align: center;">deg/hr</th> </tr> </thead> <tbody> <tr> <td>IMU 1 X</td> <td style="text-align: center;">3aa694aa</td> <td style="text-align: center;">0.00800000</td> <td style="text-align: center;"><input type="text" value="0.00800000"/></td> </tr> <tr> <td style="padding-left: 20px;">Y</td> <td style="text-align: center;">3ad039d4</td> <td style="text-align: center;">0.01000000</td> <td style="text-align: center;"><input type="text" value="0.01000000"/></td> </tr> <tr> <td style="padding-left: 20px;">Z</td> <td style="text-align: center;">bb208909</td> <td style="text-align: center;">-0.02500000</td> <td style="text-align: center;"><input type="text" value="-0.02500000"/></td> </tr> <tr> <td>IMU 2 X</td> <td style="text-align: center;">baf9defe</td> <td style="text-align: center;">-0.01200000</td> <td style="text-align: center;"><input type="text" value="-0.01200000"/></td> </tr> <tr> <td style="padding-left: 20px;">Y</td> <td style="text-align: center;">3abb673e</td> <td style="text-align: center;">0.00900000</td> <td style="text-align: center;"><input type="text" value="0.00900000"/></td> </tr> <tr> <td style="padding-left: 20px;">Z</td> <td style="text-align: center;">bb1b5464</td> <td style="text-align: center;">-0.02100000</td> <td style="text-align: center;"><input type="text" value="-0.02100000"/></td> </tr> <tr> <td>IMU 3 X</td> <td style="text-align: center;">3b18ba11</td> <td style="text-align: center;">0.01900000</td> <td style="text-align: center;"><input type="text" value="0.01900000"/></td> </tr> <tr> <td style="padding-left: 20px;">Y</td> <td style="text-align: center;">babb673e</td> <td style="text-align: center;">-0.00900000</td> <td style="text-align: center;"><input type="text" value="-0.00900000"/></td> </tr> <tr> <td style="padding-left: 20px;">Z</td> <td style="text-align: center;">3a681cea</td> <td style="text-align: center;">0.00500000</td> <td style="text-align: center;"><input type="text" value="0.00500000"/></td> </tr> </tbody> </table>					hex	deg/hr	deg/hr	IMU 1 X	3aa694aa	0.00800000	<input type="text" value="0.00800000"/>	Y	3ad039d4	0.01000000	<input type="text" value="0.01000000"/>	Z	bb208909	-0.02500000	<input type="text" value="-0.02500000"/>	IMU 2 X	baf9defe	-0.01200000	<input type="text" value="-0.01200000"/>	Y	3abb673e	0.00900000	<input type="text" value="0.00900000"/>	Z	bb1b5464	-0.02100000	<input type="text" value="-0.02100000"/>	IMU 3 X	3b18ba11	0.01900000	<input type="text" value="0.01900000"/>	Y	babb673e	-0.00900000	<input type="text" value="-0.00900000"/>	Z	3a681cea	0.00500000	<input type="text" value="0.00500000"/>
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<input type="button" value="Store"/> <input type="button" value="Delete"/> <input type="button" value="Clear"/> <input type="button" value="Exit"/>																																											
Command Advisories																																											

Figure 2.4-3. - IMU gyro bias Command Display.

D. VERIFICATION OF COMMAND SERVER LOAD

1. Verify the correct command has been loaded in the Command Server by comparing the Server feedback on the IMU GYRO display with the load built in step C2.
2. Record new gyro biases into the IMU Log Book.

E. NOTIFICATION AND APPROVAL

1. Advise the GNC FCR by DSM number that the load has been built, verified, and is ready for uplink.
2. The GNC FCR will verify that the load is correct.
3. The GNC FCR will receive Flight Director approval to perform the uplink . The GNC FCR request to INCO for the uplink command will include a confirmation of Flight Director approval for uplink, the GPC major function destination, and the DSM number of the command.
4. The GNC FCR will monitor the loop until all command actions are completed. INCO will notify the GNC FCR when the actions are completed. The GNC FCR will monitor the COMMAND TRACKING display to verify that the correct commands have been executed.

F. VERIFICATION OF UPLINK ONBOARD

1. When uplink is complete, verify the new onboard values on IMU Summary (record uplink time in IMU Log Book).
- NOTE: If uplink causes erroneous onboard biases, request the previous DSM number to be uplinked immediately.
2. Restart drift comps to verify results of new compensation updates.

G. TRACKING OF LOADS BUILD

1. The previous gyro load should be deleted from the Command Server once the load has been uplinked and good IMU performance has been verified.
2. The BFS software is not active on orbit and will not track the compensations made to the onboard gyro biases in the GNC GPC's. Therefore, it is necessary to update these biases. This is planned to occur in MM 301 at deorbit burn minus 46 minutes per the Entry Checklist. The uplink is performed as described above by uplinking the most recent compensations to the BFS GPC. There is no method of verifying that the compensation has been received correctly.

IMUDRIFT USER'S GUIDE

A. INTRODUCTION

IMU drift is a program used for tracking the drifts of the IMUs onboard the orbiter.

Figure 2.4-4 represents the interface that is presented to the user. The application is broken down into three areas (A, B, C), the top area is the menu-bar (A). Under the menu-bar is the main database area (B). This area contains the records which can be saved to the filename specified by the user (or upon initialization). The user has many options for manipulating this data such as Add, Delete, Modify, and Plot. Under the database area is the realtime area (C). When realtime is Active (by selecting the Active/Inactive toggle button) the application will monitor realtime data for changes in the star table and torque records (as well as new bias uplinks).

The next section will discuss each of the areas in more detail.

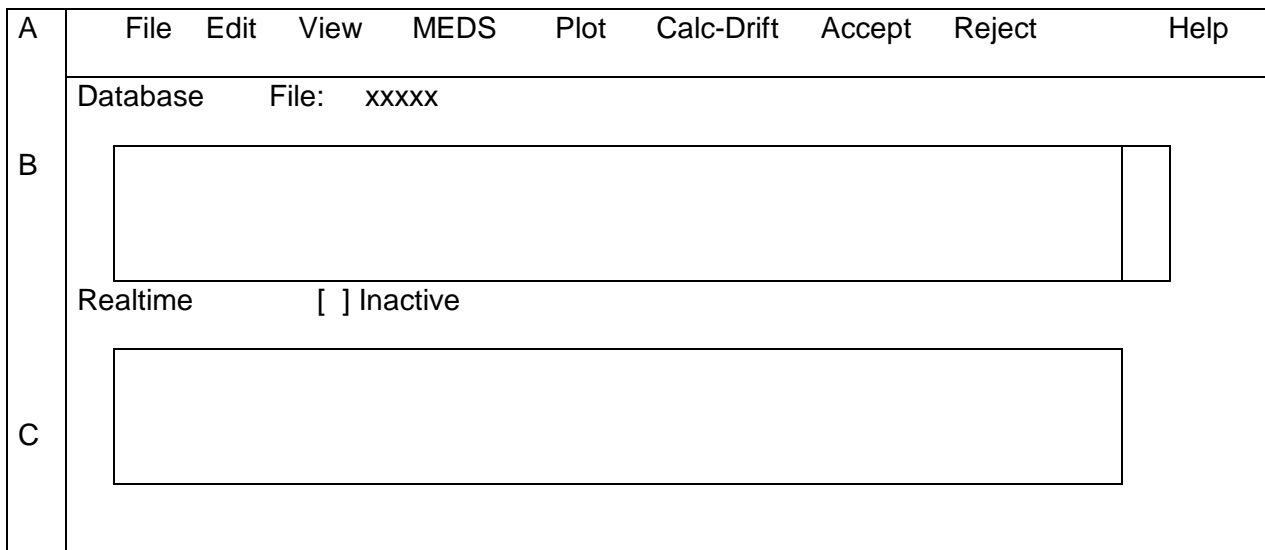


Figure 2.4-4. - IMUDRIFT Program Screen

Initially the user interface has many items which are nonselectable. All items become selectable once the user 'Initializes' IMUDRIFT or another file is loaded.

If the user loads a file that is currently being used, that user is put into a view-only mode. No modification can be done to the database. This assures that only one person can manipulate the database at a given time.

B. GENERAL INTERFACE USAGE

The currently selected text field on a display is identified by a highlighted border. The text fields on a display can be selected in sequence by using the TAB, <Shift> Tab, UP arrow and DOWN arrow keys. Moving the pointer to a text field and pressing the left mouse button will select that field. A status line at the bottom of the display provides

additional information about the selected field. The selected text field can be edited with the following commands:

- Left Arrow - move the cursor one character to the left
- Right Arrow - move the cursor one character to the right
- Del - delete the character left of the cursor
- Backspace - delete the character left of the cursor
- Ctrl-a - move the cursor back one word
- Ctrl-b - move the cursor left one character
- Ctrl-d - delete the character right of cursor
- Ctrl-e - move cursor forward one word
- Ctrl-k - clear entire field
- Esc - clear entire field
- Left Mouse - move cursor to pointer position
- Middle Mouse - clear the entire field
- Up Arrow - move to next text field
- Down Arrow - move to previous text field
- Tab - move to next text field
- Shift-Tab - move to previous text field
- Clr - clear all text fields

Option Menus

Option menus are used for input items that have a defined set of legal values. An option menu consists of the field name and the currently selected item. To present the list of alternatives, move the pointer to the selected item and press and hold the left mouse button. To select a new item, move the pointer over the desired item and release the left mouse button.

Scrolled Lists

Scrolled lists are used to display record oriented data. The vertical scroll bar on the right indicates the relative location of the viewed items within the entire list. The length of the slider indicates the percentage of the entire list that is visible.

Viewing a Scrolled List

The portion of the list that is visible is controlled by scroll bars. If the entire list fits into the scrolled area, no scroll bars will appear. If the list exceeds the size of the scrolled area, horizontal and/or vertical scroll bar appear automatically. The mouse is used to manipulate the scroll bar:

1. To move the scrolled list one line (or character), position the pointer over the desired scroll bar arrow head and press the left mouse button.
2. To scroll the list, position the pointer over the desired scroll bar arrow head and press and hold the left mouse button. Alternatively, position the pointer over the slider, press and hold the left mouse button and drag the slider in the desired direction.
3. To move the scrolled list one page, position the pointer on the desired side of the slider bar and press the left mouse button.

Selecting/Editing a Scrolled List

Standard scrolled list operations include inserting, modifying and deleting records and selecting records for a program action.

The selected records in a scrolled list are displayed in reverse video. There are several ways to select records:

1. To select a single record, position the pointer over the record and press the left mouse button.
2. To select a single for EDIT, position the pointer over the record and double click the left mouse button.
3. To select multiple records, select the first record and then press and hold the CTRL key while selecting subsequent records.
4. To select a contiguous range of records, position the pointer over the first record, press and hold the left mouse button and drag the pointer to the last record.
5. To deselect a record, select a different record. To deselect the last selected record, press and hold the CTRL key and select the record with the left mouse button.

C. MENU BAR

1. The Menu Bar is displayed at the top of the screen.

File option

The File option in the menu bar can be selected with the left mouse button or with a Meta-F key. (Meta is the Alt Function key on the workstation). The File option can also be selected by pressing F10. From this point the arrow keys can be used to traverse the menus.

1. Initialize

The Initialize option (selected via the left mouse button or Meta-Z) displays a popup window with initial information needed for each database. For new flights this will be the first option performed. The user enters flight, vehicle, starting DSM, serial #'s, and the initial Bias information. When the user selects OK the initial Bias record is added to the database.

2. Save

The Save option when selected will display a popup window with a list of existing files and the currently selected file. The user can select the 'Write' button to write to the default file or change the name of the default file or select any file to write to. Most instances the user will simply select the 'Write' button using the default name (i.e. stsxxx).

3. Load

The Load option presents the user with a popup window with a listing of available files to read. The user selects the file (with left mouse button) and then selects the 'Read' button. The data will be read and displayed in the database area.

The previous information in the database area will be lost. If the database is currently being used by another person then a message is displayed indicating that the database is in view mode and that no changes can take place.

4. Print

The Print option presents to the user an option popup. The user can select from a Full Report or Last Page Report. The last page report will, of course, only print the last page of data to the printer. Once the option is selected the user is presented another popup querying the output device. By default the output device is the laser printer so simply select the OK button. Cancel will terminate the print. The printed output will be of the database records (but only those records that have been selected by the View option, see section C.2)

5. Exit

When Exit is selected the user is questioned if they really wish to Quit. If OK, the application exits; if Cancel, the user remains where they were.

Edit

The Edit pulldown menu can be selected via the left mouse button or the Meta-E key. The pulldown has options for manipulating items in the Database area.

1. Insert

The Insert option displays a popup window that will allow the user to enter records into the database manually.

2. Delete

The Delete option will prompt the user to be sure they wish to delete the selected records. If yes, the selected records will be deleted from the database. If no records are selected, the user is informed of such.

3. Modify

The Modify option pops up the 'insert form' and displays currently selected record so that modifications can be performed. If more than one record is selected the user is presented with a message indicating only one record can be modified. Once the user has done their modifications and the OK button is selected, the record is updated in the database. Note, the MET time cannot be changed. To change the MET time of a record, that record must be deleted and then re-inserted manually. With the modify window displayed the user can select other records to be displayed for modification by double clicking on the records of interest.

4. Auto Drift Calc

This toggle button provides for automatic calculation of a drift record when any record is accepted from the realtime list. So when the user selects a realtime torque record and accepts it into the database the drift record is automatically calculated and inserted into the database as well. If "Auto Drift Calc" is not active, no drift records will be calculated and the user must select the Calc-Drift button to calculate the drifts.

View

The View pulldown menu contains items that will manipulate what is displayed in the database area of the screen. These options can be selected with the left mouse button or the meta keys that have been defined for each item. By default, all items are viewable.

1. Torque

The Torque toggle button is used to toggle the display of torque records in the database area. When the toggle is off, no torque records will be displayed in the database area.

2. Align

The Align toggle button is used to toggle the display of align records in the database area. When the toggle is off, no align records will be displayed in the database area.

3. Drift

The Drift toggle button is used to toggle the display of drift records in the database area. When the toggle is off, no drift records will be displayed in the database area.

4. Bias

The Bias toggle button is used to toggle the display of bias records in the database area. When the toggle is off, no bias records will be displayed in the database area.

Plot

When the user selects the plot option the plot popup is displayed showing the three IMU plots. These plots show align, drift, and bias data. By selecting a window with the left mouse button the user can bring that plot to the front. By selecting one axis, the user can enlarge the selected item. By reselecting the enlarged plot, the plot will be reduced to normal size. Selecting other IMU boxes will bring those windows to the front.

1. Hardcopy

The hardcopy option on the plot window will allow the user to hardcopy the topmost window. If the top window is an enlarged window, that window will be dumped. If the top window is one of the IMU windows, that IMU window will be dumped.

Calc Drift

The Calc Drift button will calculate the drift for the three IMUs and display that calculation in the 'insert form' popup window. The user then has to option to accept the drift record. The calculations are performed using the records in the database area.

Accept

The Accept button will move any selected realtime records into the database area and out of the realtime area. If no records are selected, a message is displayed indicating so.

Reject

The Reject button will delete any selected record in the realtime area. If no records are selected, a message is displayed indicating so.

D. DATABASE

The database area contains all the records that are to be saved and used for calculations and plotting. The database records are automatically saved every five minutes to the defined filename (displayed at top of window). The header at the top of the database area defines the items that are displayed in a column fashion.

Scroll bars are used to scroll the data up/down and left/right.

Most columns are divided by the '|' character as well as spaces. The Align record is unique in that it will use the '#' character to delimit the items for the IMUs that were aligned during that alignment. For those IMUs not aligned during that alignment, the default '|' character is used.

E. REALTIME

The realtime area shows the records that have been retrieved from the realtime LAN. When new stars are selected in the star table and new torquing angles are acquired, a new record is added to the realtime list. If an alignment does occur, the last torque record in the realtime list is changed to an alignment record with the correct IMUs flagged as aligned.

If a new bias record is received, a bias record is added to the realtime list.

The user can activate or deactivate the realtime portion of IMUDRIFT by toggling the Inactive/Active toggle button. When active, data is retrieved every 2 seconds to track onboard star table updates.

REFERENCES

1. Space Shuttle Program, Orbiter Project, Computer Program Development Specifications (CPDS), vol. 1, book 4, Downlist/Uplink Software Requirements, Section 6.3.17, July 1984
2. Functional Subsystem Software Requirements (FSSR); Guidance, Navigation, and Control; Part E: IMU SOP, STS 83-0013, June 1989, section 4.5.2.11.
3. GNC offline program IMUDRIFT documentation folder.

TITLE

IMU ACCELEROMETER BIAS CORRECTION

PURPOSE

To describe the procedures necessary to uplink a compensation to correct for an inertial measurement unit (IMU) accelerometer bias.

GENERAL

WARNING: This procedure is governed by FCOH SOP 3.1, COMMAND POLICY FOR MOD, and cannot be modified without prior approval of the FOIG or the Flight Director (during real-time operations). Safety critical steps are marked by a box.

The general purpose computers (GPC's) store the current IMU accelerometer biases for all nine accelerometers (three per IMU). These values are used to determine the actual IMU platform accelerations by differencing the sensed accelerations and the onboard bias. Shifts in individual accelerometer biases can be corrected by altering the corresponding onboard bias via an uplinked compensation.

Restrictions:

OI Load: all

OPS Mode: PASS (OPS 2 and MM 301 of OPS 3) BFS (MM 301 of OPS 3)

Major Function: GNC

Vehicles: all

Crew/MCC coordination: information only

Time Constraints: none

Hazardous: This load replaces the values of KOX, KOY, and KOZ for each IMU (V99G2530C through 2538C) which are stored in the GPC. If the uplink causes erroneous onboard biases, the vehicle state vector may be polluted.

Require safing: no

BACKGROUND

Accelerometer bias is the fixed difference between sensed and actual acceleration. It is a number in the range of $\pm 39545 \mu\text{g}$ determined during manufacture. Over a period of hours, the bias can vary about this factory-determined bias. Periodic calibration will decrease accelerometer uncertainty and will correct for a major shift in the factory-determined bias.

Bias is measured by differencing two velocity readings for each axis of each IMU separated by at least 5 minutes 20 seconds, dividing by the time between the readings, and converting to μg according to the following equation.

$$\text{BIAS } (\mu\text{g}) = \left[\frac{({}^V\text{FINAL} - {}^V\text{INITIAL})\text{ft} / \text{sec}}{({}^T\text{FINAL} - {}^T\text{INITIAL})\text{sec}} \right] \left[\frac{10^6 \mu\text{g} / \text{g}}{32.17 \text{ft} / \text{sec}^2 / \text{g}} \right]$$

where: $(T_{\text{Final}} - T_{\text{Initial}}) \geq 320 \text{ sec} = 5 \text{ minutes } 20 \text{ seconds}$ for acceptable accuracy

Additionally, an MCC comp, NULL ACC, exists on the GNC Orbit and IMU Summary displays which output the bias value directly for each IMU axis. The comp is the primary method to determine the bias.

PROCEDURES

A. BUILDING THE COMMAND

1. Accelerometer bias determination using the null bias comps

- a. For STS-2 and subsequent flights, a computation was established which directly computes accelerometer bias. The comp is started by executing a DELTA V TLM reset on the PBI application. The values from the comp, NULL ACC 1(2,3), are output in the IMU 1(2,3) coordinate system and are therefore independent of which IMU is chosen as a reference. (NULL ACC 1 is IMU 1 coordinates, NULL ACC 2 is IMU 2 coordinates, etc.)
- b. Using the NULL ACC 1(2,3) values on the GNC Orbit display and the current onboard biases from the IMU Summary display, compute the new bias as follows:

$$\text{New bias} = \text{Current bias} + \text{NULL ACC 1(2,3)}$$

Regardless of whether the NULL ACC 1(2,3) values are positive or negative, the values should be added to the current bias. The comp outputs the biases in the proper polarity.

Example:	NULL ACC 1X	=	-75
	Current bias	=	3575
	New bias	=	3575 + (-75)
		=	3500

- c. Due to IMU quantization errors, the comp should be allowed to run at least 15 to 20 minutes prior to using the data. The best results are obtained by allowing the comp to run for one rev.

B. LOADING THE COMMAND INTO THE COMMAND SERVER

The following steps describe how to prepare an accelerometer bias uplink load. The decision to uplink new biases is generally based on the identification of a trend in the uncompensated accelerometer biases observed over a period of time.

NOTE: A Command Manager must be running on any workstation that runs command applications. Start or Stop a Command Manager from the Master DNAV, Global Apps, Command Server menu.

1. Select the IMU Accelerometer Bias Command display from the GNC DNAV. Any previous accelerometer load in the command server should be displayed. If no previous load is on the server, use File retrieve to recall the previous saved accelerometer load

(path: /mcc/rw_remote/common/gnc/SSPXXX/MEDS). The IMU Accelerometer Bias Command display is shown in figure 2.5-1. See the IMU log for the current onboard bias, identified by DSM 432XX.

NOTE: Command Display inputs are not allowed when the Command Server is in checkpoint.

2. Create DSM 432XY (thus retaining current load in buffer) and add the measured accelerometer biases to the current accelerometer biases for the applicable IMU axes.
3. Select STORE to send the load to the Command Server.
4. Obtain a hardcopy of the new load.

File																																											
IMU Accelerometer Bias																																											
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<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 15%;"></th> <th style="width: 15%; text-align: center;">hex</th> <th style="width: 20%; text-align: center;">micro-g</th> <th style="width: 50%; text-align: center;">micro-g</th> </tr> </thead> <tbody> <tr> <td>IMU 1 X</td> <td style="text-align: center;">c27c0000</td> <td style="text-align: center;">-124.00000000</td> <td style="text-align: center;"><input type="text" value="-124.00000000"/></td> </tr> <tr> <td style="padding-left: 20px;">Y</td> <td style="text-align: center;">c2250000</td> <td style="text-align: center;">-37.00000000</td> <td style="text-align: center;"><input type="text" value="-37.00000000"/></td> </tr> <tr> <td style="padding-left: 20px;">Z</td> <td style="text-align: center;">428d0000</td> <td style="text-align: center;">141.00000000</td> <td style="text-align: center;"><input type="text" value="141.00000000"/></td> </tr> <tr> <td>IMU 2 X</td> <td style="text-align: center;">c22f0000</td> <td style="text-align: center;">-47.00000000</td> <td style="text-align: center;"><input type="text" value="-47.00000000"/></td> </tr> <tr> <td style="padding-left: 20px;">Y</td> <td style="text-align: center;">c2500000</td> <td style="text-align: center;">-80.00000000</td> <td style="text-align: center;"><input type="text" value="-80.00000000"/></td> </tr> <tr> <td style="padding-left: 20px;">Z</td> <td style="text-align: center;">42740000</td> <td style="text-align: center;">116.00000000</td> <td style="text-align: center;"><input type="text" value="116.00000000"/></td> </tr> <tr> <td>IMU 3 X</td> <td style="text-align: center;">423f0000</td> <td style="text-align: center;">63.00000000</td> <td style="text-align: center;"><input type="text" value="63.00000000"/></td> </tr> <tr> <td style="padding-left: 20px;">Y</td> <td style="text-align: center;">c2640000</td> <td style="text-align: center;">-100.00000000</td> <td style="text-align: center;"><input type="text" value="-100.00000000"/></td> </tr> <tr> <td style="padding-left: 20px;">Z</td> <td style="text-align: center;">421d0000</td> <td style="text-align: center;">29.00000000</td> <td style="text-align: center;"><input type="text" value="29.00000000"/></td> </tr> </tbody> </table>					hex	micro-g	micro-g	IMU 1 X	c27c0000	-124.00000000	<input type="text" value="-124.00000000"/>	Y	c2250000	-37.00000000	<input type="text" value="-37.00000000"/>	Z	428d0000	141.00000000	<input type="text" value="141.00000000"/>	IMU 2 X	c22f0000	-47.00000000	<input type="text" value="-47.00000000"/>	Y	c2500000	-80.00000000	<input type="text" value="-80.00000000"/>	Z	42740000	116.00000000	<input type="text" value="116.00000000"/>	IMU 3 X	423f0000	63.00000000	<input type="text" value="63.00000000"/>	Y	c2640000	-100.00000000	<input type="text" value="-100.00000000"/>	Z	421d0000	29.00000000	<input type="text" value="29.00000000"/>
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Figure 2.5-1. - IMU accelerometer bias Command Display.

C. VERIFICATION OF GCS LOAD

1. Verify the correct command has been loaded in the Command Server by comparing the Server feedback on the IMU Accelerometer Bias display with the load built in step B2.
2. Record new accelerometer biases into the IMU Log.

D. NOTIFICATION AND APPROVAL

1. Advise the GNC FCR by DSM number that the load has been built, verified, and ready for uplink.
2. The GNC FCR will verify that the load is correct.
3. The GNC FCR will receive Flight Director approval to perform the uplink. The GNC FCR request to INCO for the uplink command will include a confirmation of Flight Director approval for uplink, the GPC major function destination, and the DSM number of the command.
4. The GNC FCR will monitor the loop until all command actions are completed. INCO will notify the GNC FCR when the actions are completed. The GNC FCR will monitor the COMMAND TRACKING display to verify that the correct commands have been executed.

E. VERIFICATION OF UPLINK ONBOARD

1. When uplink is complete, verify the new onboard values on IMU Summary (record uplink time in the IMU Log).

NOTE: If uplink causes erroneous onboard biases, request the previous DSM number to be uplinked "immediately".
2. Restart accel comps to verify results of new compensation updates.

F. TRACKING OF LOADS BUILT

1. Once the load has been uplinked and IMU performance has been verified, the previous accelerometer load should be deleted from the Command Server.
2. Since the backup flight system (BFS) is not active on orbit, it has not tracked the compensations made to the onboard accelerometer biases in the GNC GPC's. It is therefore necessary to update these biases. This is planned to occur in MM 301 of OPS 3 at deorbit burn minus 46 minutes (per Entry Checklist). The uplink is performed as described above by uplinking the most recent compensations to the BFS GPC. There is no method of verifying that the compensation has been received correctly.

REFERENCES

1. Space Shuttle Program, Orbiter Project, Computer Program Development Specifications (CPDS), vol. 1, book 4, Downlist/Uplink Software Reqmnts, sec. 6.3.18, July, 1984.
2. Functional Subsystem Software Requirements (FSSR); Guidance, Navigation, and Control; Part E: IMU SOP, STS 83-0013B, section 4.5.2.11, June 1989.

TITLE

IMU SWITCHING RESOLUTION

PURPOSE

It is important to be aware of the propellant and controllability problems that can result from frequent IMU switching and use the following guidelines for an interim procedural workaround to eliminate or at least reduce IMU switching.

BACKGROUND

It has been noted, in previous flights, that as result of IMU switching (at the three level), propellant usage can be significantly higher than expected. With each switch of the reference inertial measurement unit (IMU), the attitude supplied to the digital auto pilot (DAP) changes. If this attitude change causes current attitude deltas to exceed the attitude deadband, jet firings based on attitude or rate error will occur. As switching frequency and IMU misalignments increase, propellant usage increases dramatically. Specifically, the switching of the selected IMU produces transients (noise) in the measured vehicle attitude by an amount equal to the attitude difference between the selected IMU's. This can result in:

A. Degraded navigation filter performance

Noise is reflected into rendezvous navigation during star tracker passes resulting in degraded NAV filter performance. The present solution is to deselect an IMU prior to rendezvous (star tracker pass) since switching cannot occur at the two level.

B. Transients in DAP attitude and rate errors

Noise in vehicle attitude is projected into the DAP phase plane causing instantaneous jumps in the DAP attitude and rate errors resulting in increased RCS jet firings that become more excessive as the attitude and rate deadbands are decreased.

The IMU switching phenomenon occurs when the two greatest IMU attitude deltas are equal within resolver noise. Because of resolver non-linearity and relative IMU drift, great care must be exercised in concluding that switching cannot occur (particularly during LOS periods). A conservative approach to this problem is to assume that switching can occur and to take action to preclude its causing excessive jet firings.

In the present software, the three level IMU attitude selection filter operates by:

A. Calculating the squared attitude errors among the three IMUs (RSS each of attitude deltas $1/2$, $1/3$, $2/3$). These squared errors are a measure of the delta between the ideal and the actual skewed geometry existing at that point in time.

B. Finding the ID number of the middle value IMU by identifying the maximum squared attitude error and set the selected IMU ID flag equal to the excluded index.

PROCEDURES

A. ACTION - deselect an IMU

This downmodes IMU RM to the two level and causes the selection filter to remain on a single IMU until reaching the RM limit. This is a somewhat simple solution, but the cost is in IMU redundancy.

B. GUIDELINES - for deselection (at the IMU three level)*

1. Orbiter mated to ISS operations

IMU switching should be avoided anytime the orbiter is providing attitude control while mated to the International Space Station. Experience during the STS-84 mission found a significant increase in propellant usage with IMU switching while docked to MIR.

Attitude Deadband Range (Attitude Deadband = x)	Action Required
$x \geq 1^\circ$	No action required**
$0.1^\circ < x < 1^\circ$	Evaluate deselection of an IMU based on attitude deltas. (Recommend deselection if DB two times smallest delta.)
$x \leq 0.1^\circ$	Deselect an IMU***

2. Orbiter alone operations

* For orbit operations, be aware of MDM stringing when choosing an IMU for deselection (i.e., if in normal orbit stringing configuration, NBAT = 1212, deselect IMU 1 or 3 to keep the remaining units separated).

** If flight is extended and/or available propellant is low, deselect an IMU to insure no unnecessary switching occurs costing propellant.

*** Exception: COAS /HUD calibrations are scheduled immediately after IMU alignments. At this point, IMU attitude deltas are near zero and IMU switching is common, yet has minimal effect (DAP not sensitive to change).

NOTE: The limits set above are based on engineering judgment. In the case where the DB is as large or larger than 1° , IMU switching, if it does occur, will have little effect on jet firing/propulsion usage because the

smallest IMU delta will be small in comparison to the attitude deadband. The shift in plane boundary location will not cause a maneuver. For DB 0.1° , IMU switching will most probably continuously force jets to fire as the DAP boundaries are exceeded on each oscillation. Action in the zone between these two points is based on evaluation of each case. As a rule of thumb, IMU switching could cause the boundary error to be over twice the DB and, as such, force a maneuver rather than just a single jet firing. This maneuver would call for a jet response that would likely force a boundary overshoot and only worsen the issue.

REFERENCE

1. Engineering judgment and experience from flights and simulations (51-G, OEX tests, IMU switching experiment.).
2. GNC Post Flight report for STS-84.

TITLE

IMU ROLL-TO-ROLL MATRIX DETERMINATION

PURPOSE

To describe the procedures necessary to generate the Inertial Measurement Unit (IMU) roll-to-roll matrices and to transmit them to the GNC Information Sharing Protocol (ISP) server and the Orbiter Data Reduction Complex (ODRC).

BACKGROUND

The IMU roll-to-roll matrices describe the relationships between the outer roll axes of the three IMU's. Small differences in the mounting hardware for each IMU require the use of the roll-to-roll transformation matrices in the IMU computations. The matrices are used by the GNC ISP server and the ODRC host computer to calculate the relative differences between each IMU's velocity and attitude data.

The roll-to-roll matrices for each vehicle must be loaded prior to each flight or test which involves real IMU hardware. The roll-to-roll matrices for HAINS IMUs are only vehicle dependent since HAINS IMUs are internally calibrated. The roll-to-roll file for each vehicle has been calculated and stored on the GNC read/write (R/W) server. As long as the NAV base-to-case I-LOAD matrices have not been modified, these roll-to-rolls can be used. If a change is made to the vehicle nav base, these data files should be corrected (see accompanying backup procedure).

For simulations, the Shuttle Mission Simulator (SMS) IMU model assumes a perfect NAV base such that each IMU's NAV base to case transformation matrix is identity. As a result, all of the roll-to-roll matrices are identity. The ODRC computations assume the roll-to-roll matrices are identity at computation start and therefore only need to be updated during flights. However, the workstation computations do not assume the roll-to-rolls are identity at computation start and therefore the correct IMU roll-to-roll matrices must be sent to the ISP server for both simulations and flights.

ODRC inputs are made by sending the ODRC Help Desk a copy of the roll-to-roll med values.

PROCEDURE

A. SEND THE ROLL-TO-ROLLS TO THE ISP SERVER

1. From the GNC DNAV menu, select *ISP > Value Manager* to open the Value Manager application.
2. In Value Manager, select *File > Open*. This will bring up the Open Value File selection window.

3. Select the desired roll-to-roll file. The files are located in the /amd/df6/gnc/rw_common/isp/ispvalue directory (the filter should default to the correct directory) and will be labeled 'XXX_rollroll.val" where XXX is the vehicle number. Compare the file to the values listed in Table 2.7-I.
4. After selecting the file, select *Transmit > All* from the Value Manager window to send the file to the ISP server.

TABLE 2.7-I. - GENERIC ROLL-TO-ROLLS TO ISP SERVER

MSID	OV-103	OV-104	OV-105
W11G0300M	+0.9999997735	+0.9999999985	+0.9999999993
W12G0300M	-0.0006730917	+0.0000529210	+0.0000262293
W13G0300M	+0.0000028514	-0.0000145448	-0.0000258256
W21G0300M	+0.0006730916	-0.0000529211	-0.0000262292
W22G0300M	+0.9999997731	+0.9999999986	+0.9999999996
W23G0300M	+0.0000254580	-0.0000034126	+0.0000046811
W31G0300M	-0.0000028686	+0.0000145447	+0.0000258258
W32G0300M	-0.0000254561	+0.0000034133	-0.0000046804
W33G0300M	+0.9999999997	+0.9999999999	+0.9999999997
W11G0301M	+0.9999997989	+0.9999999995	+0.9999999998
W12G0301M	-0.0006338288	+0.0000164948	+0.0000182984
W13G0301M	-0.0000194062	-0.0000266650	-0.0000126244
W21G0301M	+0.0006338281	-0.0000164951	-0.0000182985
W22G0301M	+0.9999997985	+0.9999999998	+0.9999999998
W23G0301M	-0.0000367539	-0.0000117096	-0.0000074085
W31G0301M	+0.0000194295	+0.0000266648	+0.0000126243
W32G0301M	+0.0000367416	+0.0000117100	+0.0000074087
W33G0301M	+0.9999999991	+0.9999999996	+0.9999999999
W11G0302M	+0.9999999990	+0.9999999993	+0.9999999999
W12G0302M	+0.0000392623	-0.0000364262	-0.0000079308
W13G0302M	-0.0000222587	-0.0000121202	+0.0000132012
W21G0302M	-0.0000392637	+0.0000364261	+0.0000079310
W22G0302M	+0.9999999973	+0.9999999993	+0.9999999999
W23G0302M	-0.0000622118	-0.0000082965	-0.0000120893
W31G0302M	+0.0000222562	+0.0000121205	-0.0000132011
W32G0302M	+0.0000622126	+0.0000082960	+0.0000120894
W33G0302M	+0.9999999978	+0.9999999999	+0.9999999998

B. VERIFY THE ROLL-TO-ROLLS ARE LOADED

From the GNC DNAV menu, select *Displays > REFS, Rolls & Quats*. A window should appear which displays the currently loaded roll-to-rolls values.

C. SUBMIT ROLL-TO-ROLLS TO THE ODRC HOST

Call the ODRC Help Desk (483-6372) to verify their fax number (483-6972). Notify the Help Desk that you will be sending them a fax with global med changes. Since the ODRC Help Desk is located in room 116 of 30M, a copy of the roll-to-roll file can be hand delivered. When submitting the roll-to-rolls file, make a copy of Table 2.7-II and note the appropriate column to be entered into ODRC (or simply mark out the two unnecessary columns). Verification that the values have been entered should be received from the help desk within a few hours.

TABLE 2.7-II. - GENERIC ROLL-TO-ROLLS TO ODRC

MSID	OV-103	OV-104	OV-105
M11G0300M	+0.9999997735	+0.9999999985	+0.9999999993
M12G0300M	-0.0006730917	+0.0000529210	+0.0000262293
M13G0300M	+0.0000028514	-0.0000145448	-0.0000258256
M21G0300M	+0.0006730916	-0.0000529211	-0.0000262292
M22G0300M	+0.9999997731	+0.9999999986	+0.9999999996
M23G0300M	+0.0000254580	-0.0000034126	+0.0000046811
M31G0300M	-0.0000028686	+0.0000145447	+0.0000258258
M32G0300M	-0.0000254561	+0.0000034133	-0.0000046804
M33G0300M	+0.9999999997	+0.9999999999	+0.9999999997
M11G0301M	+0.9999997989	+0.9999999995	+0.9999999998
M12G0301M	-0.0006338288	+0.0000164948	+0.0000182984
M13G0301M	-0.0000194062	-0.0000266650	-0.0000126244
M21G0301M	+0.0006338281	-0.0000164951	-0.0000182985
M22G0301M	+0.9999997985	+0.9999999998	+0.9999999998
M23G0301M	-0.0000367539	-0.0000117096	-0.0000074085
M31G0301M	+0.0000194295	+0.0000266648	+0.0000126243
M32G0301M	+0.0000367416	+0.0000117100	+0.0000074087
M33G0301M	+0.9999999991	+0.9999999996	+0.9999999999
M11G0302M	+0.9999999990	+0.9999999993	+0.9999999999
M12G0302M	+0.0000392623	-0.0000364262	-0.0000079308
M13G0302M	-0.0000222587	-0.0000121202	+0.0000132012
M21G0302M	-0.0000392637	+0.0000364261	+0.0000079310
M22G0302M	+0.9999999973	+0.9999999993	+0.9999999999
M23G0302M	-0.0000622118	-0.0000082965	-0.0000120893
M31G0302M	+0.0000222562	+0.0000121205	-0.0000132011
M32G0302M	+0.0000622126	+0.0000082960	+0.0000120894
M33G0302M	+0.9999999978	+0.9999999999	+0.9999999998

D. VERIFY THE ROLL-TO-ROLLS ARE LOADED CORRECTLY IN ODRC

After receiving confirmation that values have been loaded in ODRC, check the values by issuing a data request to the ODRC host, which is done by running the Mews ODRC Request application. The user must specify the MSIDs from Table 2.7-II along with MSIDs of Workstation Comps that utilize the roll-to-roll matrices. Since each request file

is limited to 25 MSIDs, two files need to be issued together in order to include all roll-to-roll and Comp MSIDs. Examples of two files created to submit an ODRC data request to verify the roll-to-rolls values are shown in Figure 2.7-1 and Figure 2.7-2.

Flight/Test: STS-101			
Title: IMU ROLL TO ROLL CHECK			TDF: ROL_ROL_CHK1
			Data: IMUROL_CHK
Col No.	MSID	Nomenclature	Prt Interpretation of Replacement States Fmt
1	M11G0300M	MED VALUE	G12.7
2	M12G0300M	MED VALUE	G12.7
3	M13G0300M	MED VALUE	G12.7
4	M21G0300M	MED VALUE	G12.7
5	M22G0300M	MED VALUE	G12.7
6	M23G0300M	MED VALUE	G12.7
7	M31G0300M	MED VALUE	G12.7
8	M32G0300M	MED VALUE	G12.7
9	M33G0300M	MED VALUE	G12.7
10	M11G0301M	MED VALUE	G12.7
11	M12G0301M	MED VALUE	G12.7
12	M13G0301M	MED VALUE	G12.7
13	M21G0301M	MED VALUE	G12.7
14	M22G0301M	MED VALUE	G12.7
15	M23G0301M	MED VALUE	G12.7
16	M31G0301M	MED VALUE	G12.7
17	M32G0301M	MED VALUE	G12.7
18	M33G0301M	MED VALUE	G12.7

FIGURE 2.7-1 – ROLL-TO-ROLLS CHECK 1

Flight/Test: STS-101			
Title: IMU ROLL TO ROLL CHECK FOR IMU3			TDF: ROL_ROL_CHK2
			Data: IMUROL_CHK
Col No.	MSID	Nomenclature	Prt Interpretation of Replacement States Fmt
1	M11G0302M	MED VALUE	G12.7
2	M12G0302M	MED VALUE	G12.7
3	M13G0302M	MED VALUE	G12.7
4	M21G0302M	MED VALUE	G12.7
5	M22G0302M	MED VALUE	G12.7
6	M23G0302M	MED VALUE	G12.7
7	M31G0302M	MED VALUE	G12.7
8	M32G0302M	MED VALUE	G12.7
9	M33G0302M	MED VALUE	G12.7
10	M01G0300C	REF CL ANG1 ROLL	G10.3
11	M02G0300C	REF CL ANG1 PITCH	G10.3
12	M03G0300C	REF CL ANG1 YAW	G10.3
13	M04G0300C	REF CL ANG2 ROLL	G10.3
14	M05G0300C	REF CL ANG2 PITCH	G10.3
15	M06G0300C	REF CL ANG2 YAW	G10.3
16	M07G0300C	REF CL ANG3 ROLL	G10.3
17	M08G0300C	REF CL ANG3 PITCH	G10.3
18	M09G0300C	REF CL ANG3 YAW	G10.3

FIGURE 2.7-2 – ROLL-TO-ROLLS CHECK 2

BACKUP PROCEDURES

Contained in this section are the procedures used to:

1. Compute the roll-to-roll matrices using the MQEUT program
2. Store the roll-to-roll file on the workstation

This procedure should be run anytime a change has been made to the vehicle nav base. See the following section for actual I-Load values used in the calculations of the Generic Roll-to-Rolls found in Tables 2.7-I and 2.7-II above.

A. OBTAIN RGAO AND RGPO

The roll-to-roll matrices are calculated from the Roll Gimbal Azimuth Offset (RGAO) and the Roll Gimbal Pitch Offset (RGPO) parameters. For HAINS IMU's, these terms are internally calibrated by the IMU. The GPC values are therefore zero (0.0 radians). This should always be verified using either the Flight Software I-Load Map or the Preflight IMU Reports published by the Inertial Systems Lab. The Preflight IMU Report is documented in units of arc seconds with less accuracy than the flight software values.

TABLE 2.7-III. - RGAO AND RGPO MSID'S, HAL NAMES, AND FSSR NAMES

		MSID	HAL NAME	FSSR NAME
IMU 1	RGAO	V99U9559C	CGMS_RGAO\$(O1)	RGAO (1)
	RGPO	V99U9562C	CGMS_RGPO\$(O1)	RGPO (1)
IMU 2	RGAO	V99U9560C	CGMS_RGAO\$(O2)	RGAO (2)
	RGPO	V99U9563C	CGMS_RGPO\$(O2)	RGPO (2)
IMU 3	RGAO	V99U9561C	CGMS_RGAO\$(O3)	RGAO (3)
	RGPO	V99U9564C	CGMS_RGPO\$(O3)	RGPO (3)

B. COMPUTE THE ROLL-TO-ROLL MATRICES USING THE MQEUT PROGRAM.

1. From the GNC DNAV menu, select *Apps > MQEUT*.
2. In response to the prompt "Enter Operation", type Y(RGAO)P(RGPO)R0>M1/CASE1_RL1 and press RETURN (where RGAO and RGPO are the actual values for IMU 1).

Note: The RGAO and RGPO must be in the units of degrees.

3. Type Y(RGAO)P(RGPO)R0>M2/CASE2_RL2 and press RETURN (where RGAO and RGPO are the actual values for IMU 2).
4. Type Y(RGAO)P(RGPO)R0>M3/CASE3_RL3 and press RETURN (where RGAO and RGPO are the actual values for IMU 3).

5. From the I-loads documentation, obtain the values of the nav base-to-case transformations for each IMU. The MSID's are listed in Table 2.7-IV.

TABLE 2.7-IV. - NAV BASE-TO-CASE TRANSFORMATIONS

CASE 1 T NB	V96U7132C	V96U7135C	V96U7138C
	V96U7141C	V96U7144C	V96U7147C
	V96U7150C	V96U7153C	V96U7156C
CASE 2 T NB	V96U7133C	V96U7136C	V96U7139C
	V96U7142C	V96U7145C	V96U7148C
	V96U7151C	V96U7154C	V96U7157C
CASE 3 T NB	V96U7134C	V96U7137C	V96U7140C
	V96U7143C	V96U7146C	V96U7149C
	V96U7152C	V96U7155C	V96U7158C

6. Enter the nav base-to-case matrix for IMU 1 by typing ENTERM4/NB_CASE1 followed by RETURN.
7. Enter the nav base-to-case matrix for IMU 2 by typing ENTERM5/NB_CASE2 followed by RETURN.
8. Enter the nav base-to-case matrix for IMU 3 by typing ENTERM6/NB_CASE3 followed by RETURN.
9. Multiply the TCASE1_RL1 and the TNB_CASE1 matrices to generate the TNB_RL1 transformation; type M1*M4>M7 and press RETURN.
10. Multiply the TCASE2_RL2 and the TNB_CASE2 matrices to generate the TNB_RL2 transformation; type M2*M5>M8 and press RETURN.
11. Multiply the TCASE3_RL3 and the TNB_CASE3 matrices to generate the TNB_RL3 transformation; type M3*M6>M9 and press RETURN.
12. To generate the roll-to-roll matrices, the nav base-to-roll matrices must be multiplied together. The first step is to transpose the IMU 1 matrix; type TNB_RL1 and press RETURN.
13. Multiply the matrices for IMU 1 and IMU 2 to get the roll-to-roll relationship between IMU's 1 and 2; type M8*M7>M10 and press RETURN.
14. Orthogonalize the result, type ORTHM10 and press RETURN.
15. Multiply the matrices for IMU 1 and IMU 3 to get the roll-to-roll relationship between IMU's 1 and 3; type M9*M7>M11 and press RETURN.
16. Orthogonalize the result; type ORTHM11 and press RETURN.
17. Transpose the nav base-to-roll matrix for IMU 2; type TNB_RL2 and press RETURN.

18. Multiply the matrices for IMU 2 and IMU 3 to get the roll-to-roll relationship between IMU's 2 and 3; type M9*M8>M12 and press RETURN
19. Orthogonalize the result; type ORTHM12 and press RETURN.
20. To get a printout of the roll-to-roll matrices, type ONPRINT and press RETURN. Now type M10 followed by RETURN, M11 followed by RETURN, M12 followed by RETURN, and finally, OFFPRINT followed by RETURN

C. STORE THE ROLL-TO-ROLL MATRICES ON THE WORKSTATION USING VALUE MANAGER.

1. From the GNC DNAV menu, select *ISP > Value Manager* to open the Value Manager application.
2. IN VALUE MANAGER, SELECT *FILE > OPEN*. THIS WILL BRING UP THE OPEN VALUE FILE SELECTION WINDOW. TABLE 2.7-V. - WORKSTATION COMP MSID'S

T	RL2	=	W11G0300M	W12G0300M	W13G0300M
			W21G0300M	W22G0300M	W23G0300M
	RL1		W31G0300M	W32G0300M	W33G0300M

T	RL3	=	W11G0301M	W12G0301M	W13G0301M
			W21G0301M	W22G0301M	W23G0301M
	RL1		W31G0301M	W32G0301M	W33G0301M

T	RL3	=	W11G0302M	W12G0302M	W13G0302M
			W21G0302M	W22G0302M	W23G0302M
	RL2		W31G0302M	W32G0302M	W33G0302M

3. Select the desired roll-to-roll file. The files are located in the /amd/user2/gnc/DATA/isp/ispvalue directory (the filter should default to the correct directory) and will be labeled 'XXX_rollroll.val" where XXX is the vehicle number.
4. Enter the MSID's and the values for the roll1-to-roll2, roll1-to-roll3, and roll2-to-roll3 matrices in the Value column. The MSID's correspond to the values as shown in Table 2.7-V. When all the values have been updated, select *File > Save*.
5. Run the nominal procedures for sending the file to the ISP server and the ODRC host.

NOTES

Table 2.7-VI lists the I-Load values of the vehicle-specific nav base-to-case transformations for each IMU used in the calculations of the Generic Roll-to-Rolls found in Tables 2.7-I and 2.7-II above. The I-Load values for the RGAO and RGPO parameters used in the roll-to-roll calculations were 0.0 for all IMU's in each vehicle. The I-Load values are documented here for reference.

TABLE 2.7-VI. - NAV BASE-TO-CASE I-LOAD VAULES

	MSID	OV-103	OV-104	OV-105
CASE 1 T NB	V96U7132C	+1.000000E+00	+1.000000E+00	+1.000000E+00
	V96U7135C	0.000000E+00	0.000000E+00	0.000000E+00
	V96U7138C	0.000000E+00	0.000000E+00	0.000000E+00
	V96U7141C	0.000000E+00	0.000000E+00	0.000000E+00
	V96U7144C	+1.000000E+00	+1.000000E+00	+1.000000E+00
	V96U7147C	0.000000E+00	0.000000E+00	0.000000E+00
	V96U7150C	0.000000E+00	0.000000E+00	0.000000E+00
	V96U7153C	0.000000E+00	0.000000E+00	0.000000E+00
	V96U7156C	+1.000000E+00	+1.000000E+00	+1.000000E+00
CASE 2 T NB	V96U7133C	+9.9999977E-01	+1.000000E+00	+1.000000E+00
	V96U7136C	-6.730916E-04	+5.2921023E-05	+2.6229324E-05
	V96U7139C	+2.814276E-06	-1.4544837E-05	-2.5825638E-05
	V96U7142C	+6.730916E-04	-5.2921072E-05	-2.6229203E-05
	V96U7145C	+9.9999977E-01	+1.000000E+00	+1.000000E+00
	V96U7148C	+2.5458002E-05	-3.4125531E-06	+4.6810743E-06
	V96U7151C	-2.8685627E-06	+1.4544656E-05	+2.5825761E-05
	V96U7154C	-2.5456076E-05	+3.4133228E-06	-4.6803969E-06
	V96U7157C	+1.000000E+00	+1.000000E+00	+1.000000E+00
CASE 3 T NB	V96U7134C	+9.999998E-01	+1.000000E+00	+1.000000E+00
	V96U7137C	-6.3382877E-04	+1.6494757E-05	+1.8298441E-05
	V96U7140C	-1.940624E-05	-2.6664951E-05	-1.2624440E-05
	V96U7143C	+6.3382806E-04	-1.6495069E-05	-1.8298534E-05
	V96U7146C	+9.999999E-01	+1.000000E+00	+1.000000E+00
	V96U7149C	-3.6753878E-05	-1.1709564E-05	-7.4084637E-06
	V96U7152C	+1.9429532E-05	+2.6664758E-05	+1.2624304E-05
	V96U7155C	+3.674157E-05	+1.1710004E-05	+7.4086947E-06
	V96U7158C	+1.000000E+00	+1.000000E+00	+1.000000E+00

REFERENCES

1. GNC SCP 10.5 MQEUT

TITLE

IMU MATRIX ALIGNMENT USING IMU DATA

PURPOSE

This SCP provides an explanation of how a matrix alignment using IMU data works and its uses during flight for OI-32 and subsequent software loads. It should be noted that, as with a matrix alignment using star data, this procedure does not maintain optimal IMU/IMU skew angles. To return the IMUs to the optimal skewed REFSMMATs, reference GNC SCP 2.9 "Platform Skew Recovery."

For reference, a way of manually calculating REFSMMATS to perform a matrix alignment using IMU data exists in the GNC SCP archives, but is obsolete post OI-32.

DEFINITIONS

DESIRED REFSMMAT:

An onboard software term which defines the position at which it is desired to align a platform.

CURRENT REFSMMAT:

An onboard software term which defines the position at which onboard software assumes each IMU platform is located. Normally (not always), the current REFSMMAT is equal to the desired REFSMMAT.

PRESENT REFSMMAT:

An onboard software term which defines the position of the IMU platform as determined by an external reference, either another IMU during an IMU to IMU alignment, or star vectors during a star align.

TRUE REFSMMAT:

An MCC term which defines the actual position at which each IMU platform is located.

OPERATION

There are two ways, described below, to recover IMU attitude reference using the IMU matrix alignment option.

MATRIX ALIGNING ONE IMU USING ANOTHER IMU AS REFERENCE

A matrix alignment using IMU data requires that at least one other IMU is available and well aligned. This IMU will be used as the "reference IMU" to which the misaligned or "recovery IMU" is aligned. (Note: The reference IMU is assumed to be perfectly aligned to the position represented by its current REFSMMAT. Any misalignment of the reference IMU will be mirrored in the initial misalignment of the recovery IMU.) Utilizing the reference IMU's current REFSMMAT and gimbal resolver angles, the M50 inertial position of the recovery IMU may be defined; this is the recovery IMU's present REFSMMAT. The calculation of the present

REFSMMAT for a matrix align using IMU data is identical to that of an IMU to IMU torquing alignment. However, the remaining alignment steps are performed in the same manner as a matrix alignment using star data. Delta angles are calculated based upon differences between the recovery IMU's present and current REFSMMATs, and are displayed to the crew on SPEC 21. At this point, the platform is not torqued to a new position. Instead, since the platform is known to be at the position represented by the present REFSMMAT, the current REFSMMAT is simply set equal to the calculated present REFSMMAT. The recovery IMU now has a correctly defined current REFSMMAT used in GPC attitude calculations. See Figure 2.8-1 below for a schematic of a matrix align using IMU data.

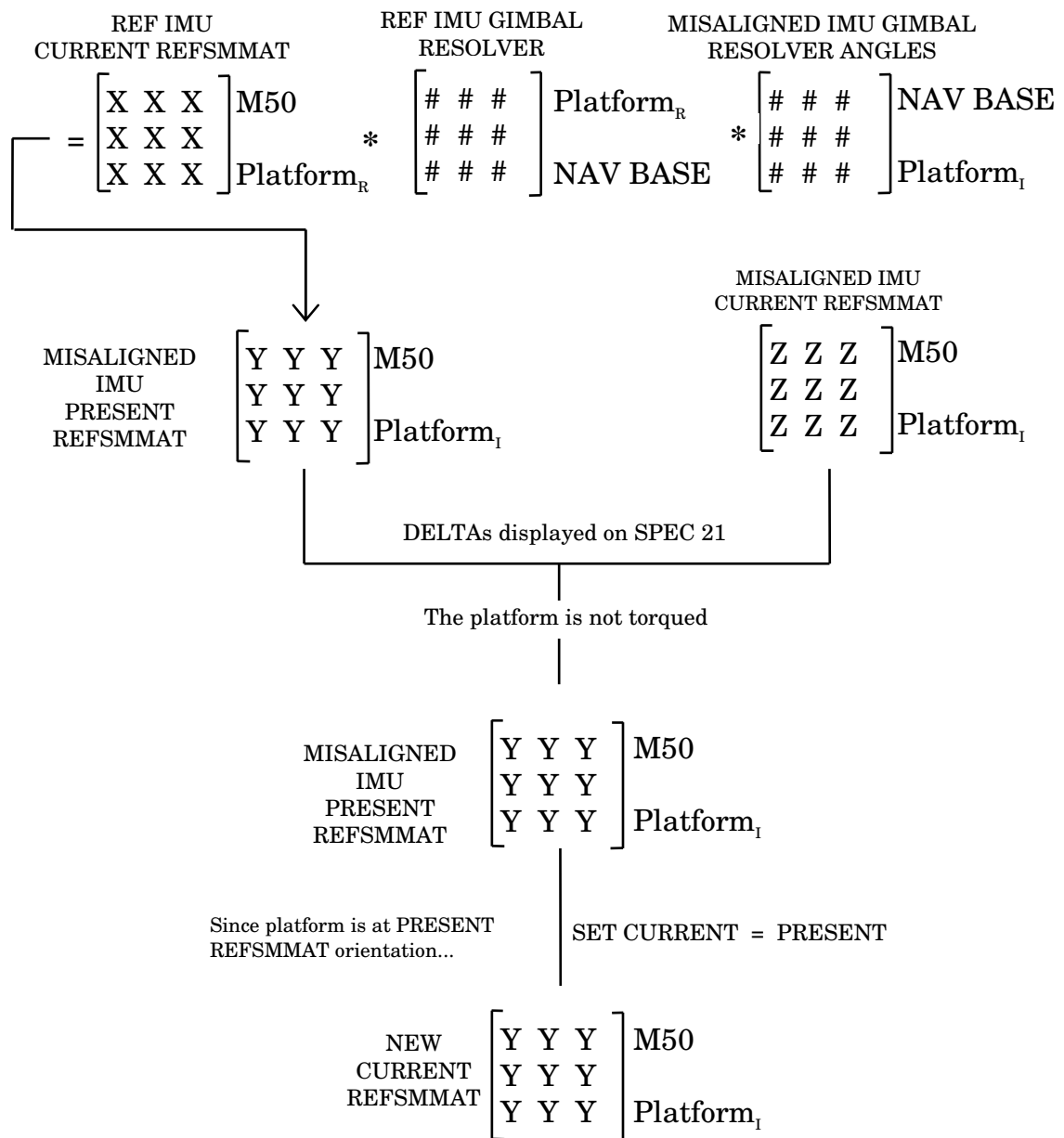


Figure 2.8-1 Schematic of an IMU Matrix Align Using IMU Data

MATRIX ALIGNING AN IMU TO ITSELF

If the designated reference IMU is the only IMU to be aligned with the matrix alignment using IMU data option, the matrix update will consist of copying the desired REFSMMAT to the current REFSMMAT. If the reference IMU is selected for alignment in addition to at least one other IMU, the reference IMU's current cluster orientation after alignment will reflect the current cluster orientation prior to alignment (in effect, a null operation).

USES IN FLIGHT

The ability to matrix align an IMU using another IMU as a reference provides an effective way of recovering IMU attitude reference where previously complicated procedures were required, star data was required, or it was simply impractical to pursue the recovery of a misaligned IMU. It is always preferable to perform a torquing alignment using either star or IMU data rather than a matrix alignment in order to preserve optimal IMU skewing. It is also preferable to perform a matrix alignment using star tracker star data rather than IMU data to avoid the initial misalignment associated with drift of the reference IMU platform. That being said, it should be noted that a matrix alignment using IMU data is NOT a nominal procedure. All procedural uses of this function are contained within the FDF Malfunction Procedures book. There are three distinct situations where a matrix alignment using IMU data becomes useful:

1. In place of a matrix alignment using star data when stars are not readily available
2. Rolling in REFSMMATs for a known IMU platform position when the current REFSMMAT does not correctly define the IMU platform position
3. Quick Recovery of an IMU when other IMU alignment methods are not available on orbit or during entry.

The benefits of a matrix alignment using IMU data are two-fold. Like a matrix alignment using star data, the alignment is an instantaneous, purely mathematical alignment; and like an IMU to IMU torquing alignment, no external references are required, only another well aligned IMU. The drawbacks to a matrix alignment using IMU data are that the initial misalignment of the recovery IMU is dependent on the misalignment of the reference IMU at the time of alignment, optimal two level skew is not preserved, and REFSMMAT configurations in the PASS and BFS become complicated for entry operations (these will be discussed later).

OPS 2 PROCEDURES

After matrix aligning one IMU using another IMU as reference, the current REFSMMAT should be retrieved from telemetry and uplinked to the desired REFSMMAT slot. Retrieve the new REFSMMAT from telemetry by following GNC SCP 10.12 ENTREF, and uplink to the DESIRED REFSMMAT by following GNC SCP 10.11 REFSLOAD USER'S GUIDE. This is done to provide the crew/MCC with correct torquing angles for drift calculations and subsequent alignments, if required.

Note: If the matrix align was performed for loss of slew capability, consideration should be given to performing GNC SCP 2.9 "Platform Skew Recovery" in order to re-establish optimal two-level skew.

OPS 3 ALIGNMENT ISSUES

During entry, it is highly desirable to maintain IMU redundancy. However, when an IMU has been caged and is recovered during entry, special attention should be paid to redundancy management (RM) reset limits and REFSMMAT configurations in the PASS and BFS.

RM limits are reset every time an IMU alignment is performed. This is important for the GNC Sensors operator to keep in mind while performing alignments during entry to recover an IMU. This issue applies to both matrix alignments using IMU data as well as IMU to IMU torquing alignments. For the following example, we will call IMU 1 the "best IMU/reference IMU," IMU 2 the "other good IMU," and IMU 3 the "recovery IMU/caged IMU".

Example: It would be undesirable to recover IMU 3 by matrix aligning it to IMU 1 if IMU 1 and 2 disagree by an RSS value greater than 0.14 degrees (the RM reset value for 3 level IMU operation). This would cause RM to vote out IMU 2, thus trading two reliable IMUs (1 and 2) for one good IMU and a previously failed IMU (1 and 3). The IMUs would again be at the two level, but in a less desirable configuration and not optimally skewed. To avoid this scenario, IMU 2 could be matrix aligned to IMU 1 along with IMU 3. This would eliminate the possibility of voting out IMU 2 after RM is reset. The current REFSMMAT for IMU 2 will be altered, but only by a small amount, and IMU 2 will still be usable in the BFS, which will use the unaltered REFSMMAT. The recovery IMU (IMU 3) will not be usable in the BFS because of the large difference between the BFS and PASS current REFSMMATs. This will be discussed in detail later.

With the addition of an IMU to IMU matrix align capability in OI-32, there are now two ways of recovering an IMU after it has been caged by temporary loss of power or operate discrete. A caged IMU may be recovered by an IMU to IMU torquing align. The benefits of this method are that the caged IMU's platform is placed back in its optimally skewed position, and it maintains the current PASS REFSMMATs equal to the PASS desired and BFS current REFSMMATs. However, an IMU to IMU torquing alignment will take up to 6 minutes to complete, and during this time IMU RM does not function, leaving the orbiter subject to resolver shifts and acceleration errors in the currently selected IMUs. The other method, a matrix alignment using IMU data, will quickly redefine a caged IMU's current REFSMMAT without risking time and RM operation during the dynamic entry timeframe. Drawbacks to this method are the IMUs will no longer be optimally skewed, and the PASS current REFSMMAT is no longer equal to that of the PASS desired or BFS current REFSMMATs. IMU skew is only an issue at the two level and is used to enhance failure identification. Flying with non-optimally skewed IMUs is acceptable; however, the difference in current REFSMMATs between the PASS and BFS causes issues with BFS IMU availability. These issues are discussed below.

OPS 3 BFS ISSUES

During OPS 3, close attention must be paid to the configuration of the BFS REFSMMATs when performing matrix alignments using IMU data. If an IMU is recovered during OPS 3 by a matrix align using IMU data, the PASS current REFSMMAT will correctly define the IMU platform position. However, the BFS current REFSMMAT will not be updated and is no longer correct. If the BFS was engaged and used the IMU with the incorrect REFSMMAT, the vehicle attitude would be incorrect, possibly causing the loss of vehicle and crew during the critical deorbit/entry phase.

There are two ways to update REFSMMATs in the BFS. One way is to uplink the REFSMMATs to the BFS during MM 301. It should be noted that the uplink may ONLY be performed during MM 301 and that the uplink changes the current REFSMMAT in the BFS and NOT the desired (there are no present or desired REFSMMATs in the BFS). The second way to update the REFSMMATs in the BFS is to mode the BFS through OPS 0 and back to OPS 3. This will re-initialize the T_CLUSTERM50 matrices with transfer data from PASS representing the current IMU alignment matrices.

OPS 3 PROCEDURES

During major modes 301 to 304 there are a few options to maintain the BFS in a good configuration after an IMU has been recovered by a matrix align using IMU data. These options are discussed below for each entry major mode of flight. In every phase of entry, there is the option to recover the IMU in PASS with a matrix align using IMU data and leave the IMU deselected in the BFS.

MM 301: Time permitting, an uplink may be performed to the PASS desired and BFS current REFSMMAT slots. Moding the BFS through OPS 0 and back to OPS 3 is also acceptable. However, this should be coordinated with DPS, and will not set the PASS desired REFSMMAT. Either method will result in good attitude reference for the recovered IMU in the BFS. For a second IMU fail, consideration should be given to waving off and performing GNC SCP 2.9 "Platform Skew Recovery" to re-establish optimal two level skew. This will also allow time to ensure a good REFSMMAT configuration in PASS and BFS.

MM 302 or MM 303: If time allows it may be feasible to mode the BFS back to MM 301 and uplink REFSMMATs to the BFS, or after moding the BFS back to MM 301, a transition from OPS 3 to OPS 0 and back would also put the BFS in a good configuration. Both options should be coordinated with DPS.

MM 304: The transition back to MM 301 is no longer legal, and as of OI-32, if the BFS is taken to STBY/HALT and back to OPER it will re-initialize in the same MM as before, not in OPS 0. Therefore, once in MM 304 there is no feasible way to get a good current REFSMMAT to the BFS for an IMU that has been matrix aligned using IMU data. Deselect the IMU in the BFS (not usable as a last) and continue to the ground.

TITLE

PLATFORM SKEW RECOVERY

PURPOSE

To recover desired platform skew with loss of slew capability. (A procedure to recover platform skew from loss of pulse torquing is not necessary, and does not exist.)

BACKGROUND

There is not a requirement for any skew between the platforms at the three level. However, platform skew is required for 2-level RM to be effective (*FSSR 83-0010-32 para. 4.2*). To protect against the case where one IMU has failed, it is highly desirable to recover optimal ($+\sqrt{6}$) skew. Also, it is desired that the IMU's be skewed about a line of ambiguity that optimizes performance during entry ops.

PROCEDURE

The following procedures were developed for either orbit ops, or in preparation for deorbit. **These procedures are not intended to be used for recovering an IMU with a resolver shift.** It is recommended that one of the following 4 options be used to recover an additional IMU for entry.

OPTION 1: Maneuver to Attitude and Cage IMU

This procedure requires maneuvering the orbiter to the inertial attitude which will place the caged IMU platform at the desired REFSMMAT. The one disadvantage of this option is the requirement of maneuvering the vehicle which may not be practical during mated operations with ISS.

OPTION 2: Using IMU/IMU Align to Torque Good IMU's

This procedure will calculate new $\sqrt{6}$ REFSMMATs, rotating the two good IMU's 120 degrees from the IMU that has lost slew. The IMU with loss of slew must be aligned by a matrix alignment before this procedure can be performed. The procedure will result in placing the line of ambiguity of the X-Y plane of the IMU's in an arbitrary direction. There is no documented requirement for where this line of ambiguity should be placed.

OPTION 3: Using Gyro Comp Uplink to Align IMU

This procedure will use uplinked gyro compensation to pulse torque the IMU platform to the desired REFSMMAT. Typically this will take a long time to complete, in the order of 12 to 18 hours. Communication must be maintained near the end of the torquing period in order to stop the align process by uplinking the original gyro compensations. You can expect to get a Redundant Rate BITE during this procedure.

OPTION 4: Using Star Align to Recover Skew

This procedure simply uses the normal star align to pulse torque the IMU platform to the desired REFSMMAT. Normally this will take a long time to complete, although on the

order of half as long as option 3. RM will be disabled for all IMU's while the align is in progress.

OPTION 1: MNVR TO ATT AND CAGE IMU

The objective of this procedure is to determine the Orbiter inertial attitude, which will place the IMU platform at the desired REFSMMAT orientation at the time of caging the IMU. This procedure calculates an attitude that the crew will maneuver to that will place the platform of the target IMU near its optimal 2-level RM skew. The crew has to maneuver to the platform release attitude and cage the platform (mode from STBY to OPER). Then platform skew can be re-established with a star tracker align. This procedure can be repeated as needed to recover platform skew if more than one IMU has experienced loss of slew.

It is assumed that the target IMU can cage the gimbals, and that only slew capability as used during IMU/IMU aligns has been lost. It is also assumed that the onboard Desired REFSMMAT is the launch or normalized REFSMMAT. If not, it is recommended that the correct Desired REFSMMAT be uplinked.

1. Start MQEUT (Matrix, Quaternion, and Euler Angle Sequence) program per GNC SCP 10.5. All operations used here are identified and explained in the MQEUT program. *IMU 1 is used here as an example.*
2. Enter "ONPRINT"
This will provide a printout of the MQEUT operations for verification and log documentation.
3. Load the Desired REFSMMAT file using the LDREFS command. This example assumes the initial launch REFSMMAT file.
Enter "LDREFS".
When prompted for file name enter "initial".
When prompted for matrix numbers enter "1,2,3".
Print the appropriate IMU REFSMMAT, in this example enter "M1".

4. Convert IMU 1 REFSMMAT to Quaternion:

```
Enter: M1>Q1          | .5347600 .1990850 .8212170 | CL1      | -.579007641 |
                    | -.7895130 -.2286600 .5695480 |          | .657366070 |
                    | .3011670 -.9529320 .0349020 | M50     | -.224544318 |
                    | .426848742 | CL1_M50
```

5. Conjugate the Quaternion and store it:

```
Enter: CONJQ1>Q2     | -.5790076418 |
                    | -.6573660706 |
                    | .2245443181  |
                    | -.4268487428 | M50_CL1
```

6. We will assume the angle between the IMU Cluster (Platform) and the Nav Base is negligible and the angle between the Nav Base and Body is a pitch of 10.6 degrees. Generate the CL_i_BDY quaternion using the Euler Sequence to Quaternion transformation.

```
Enter: P10.6Y0R0>Q3/CLi_BDY  P  10.60      | 0.9957246 |
                               Y   0.00      > | 0.0000000 |
                               R   0.00      | 0.0923705 |
                               | 0.0000000 | CL1_BDY
```

7. Multiply two Quaternions and store the product by entering:

```

Q2 * Q3 > Q4   |-.5790076 |           |.9957246 |           |-.5972735 |
                  |-.6573666 |           |.0000000 | >         |-.6151274 |
                  |.2245443  |           |.0923705 |           |.1701010 |
                  |-.4268487 |M50_CL1  ||.0000000 |CL1_BDY  |-.4857451 |M50_BDY
    
```

8. Convert Quaternion to a P,Y,R Euler sequence by entering:

```

Q4>PYR  |-.5972734999 |           P | 300.42 |
            |-.6151273631 |           > Y | 21.77 |
            |.1701010473 |           R | 104.25 |
            |-.4857451257 |M50_BDY
    
```

NOTE: The Result is the R,P,Y inertial attitude required for caging the IMU at its desired REFSMMAT orientation.

9. Enter "OFFPRINT".

10. Perform a Star Align as required to recover IMU.

CREW PROCEDURE

1. Maneuver to the R,P,Y inertial attitude as determined in step 8 of the Ground Procedure. Once in attitude, check that the attitude deadband is ≤ 1 deg. This will help ensure IMU misalignment will be within the 1.4 deg constraint of performing star tracker aligns.
2. On SPEC-21, verify the IMU (that has lost slew capability) has been deselected and is in standby. Transition to standby will cause a BCE STRG IMU fault message.
3. When at correct attitude and in standby, select operate and wait for operate mode on SPEC-21 (≈ 85 sec). When the IMU is in operate mode, perform an I/O RESET EXEC.
4. Crew can now maneuver and perform a nominal STAR TRKR IMU alignment as required.

For reference only. The following operations reflect assumptions made, and carries through the correct sequencing of operational labels:

```

Q M50_CLi ----- M50 to Cluster i quaternion (IMU 1 REFSMMAT converted to
                    quat).

Q M50_CLi = Q M50_RL1 ----- IMU i Standby to Operate: gimbal angles equal to zero.
                               Transformation between Platform(CL) and IMU Case(RL) is zero

Q M50_RLi = Q M50_NB ----- Assume RL (Roll or IMU Case) to NB (Nav Base) transformation
                               equal to zero or negligible.

Q1 M50_CLi = Q1 M50_NB --- Thus, IMU i M50 to Cluster quaternion equals the M50 to Nav
                               base quaternion.
    
```

OPTION 2: USING IMU/IMU ALIGN TO TORQUE GOOD IMU'S

This procedure uses the current REFSMMAT of the IMU that has lost the ability to slew, and calculates a new desired REFSMMAT for the other two IMUs. An IMU/IMU align has to be performed afterwards to re-obtain platform skew. Skew about the optimal line of ambiguity will not be obtained using this procedure. This option requires the attitude reference of IMU with loss of slew to have been recovered. To recover attitude reference of the IMU with loss of slew, a matrix alignment using star data may be performed. Also available, as of OI-32, a matrix alignment using IMU data may be performed to regain attitude reference when star data is not readily available, such as during docked ops.

The following procedure will use the MQEUT program to calculate the new REFSMMAT. The current REFSMMAT will be loaded into matrixes M11, M12, and M13 for IMU's 1, 2, and 3, respectively. The $\sqrt{6}$ rotation matrix will entered into M15. The new REFSMMAT will end up in matrixes M1, M2, and M3 for IMU's 1, 2, and 3, respectively.

MQEUT- Summary of Commands Used	
LDREFS	-Prompts for a REFSMMAT file name and three matrix numbers and loads the matrices from standard REFSMMAT files in the refs directory.
ENTERMn	-Enter matrix n. Will prompt to make inputs by row and elements of that row. Ex, will prompt: <i>Enter row 1, Elements 11,12, & 13 -></i>
Qn>Mn	-Convert quaternion n to matrix n
Mn>Qn	-Convert matrix n to quaternion n
Ma*Mb>Mc	-Multiply matrix a by matrix b and write results to matrix c
TNSP	-Transpose matrix
Mn/CLi_CLj	-Labels the matrix. In this case the matrix would be a transformation from i to j (or a rotation from j to i). Labeling is an extension that can be used on most arguments.

1. If not already done, retrieve the Current REFSMMAT from telemetry using ENTREF (SCP 10.12).
2. Start MQEUT per GNC SCP 10.5. All operations used here are identified and explained in the MQEUT program.
3. Enter "ONPRINT"
This will provide a printout of the MQEUT operations for verification and log documentation.
4. Load the Current REFSMMAT file from step 1 using the LDREFS command.
Enter "LDREFS".
When prompted for file name, enter file name from step 1.
When prompted for matrix numbers, enter "11,12,13".
5. Enter the $\sqrt{6}$ rotation matrix. This matrix will rotate the REFSMMAT 120 degrees about a line of ambiguity in the X-Y plane. i will be the REFSMMAT being rotated to the j position. The REFSMMAT's are rotated in the sequence of IMU 1 to 2 to 3 to 1. Enter the matrix shown below.

```

ENTERM15/CL(j)_CL(i) | .25          .75          -.6123724357 |CLi
                      | .75          .25          .6123724357 |
using this data -----> | .6123724357  -.6123724357  -.5          |CLj
    
```

6. Move the loss of slew IMU(i) REFSMMAT to the appropriate matrix M(i). In this example using IMU 1 move M11 to M1.

Enter **M11>M1**

7. Calculate the two new REFSMMATs:

Transpose M1:

TNSPM1 | -.5283921764 .2844397711 -.79993482513 | M50
 | -.5400031572 .6144587863 .57518430959 |
 | .6551322752 .7358902203 -.17107684101 | CL1

Multiply M1 by rotation matrix (M15) to rotate it 120 degrees, storing the result to M2:

M1*M15>M2 | M1 | M50 * | M15 | CL1 = | M2 | M50
 | | CL1 | | CL2 | | CL2

Re-title the rotation matrix for the calculation of the second REFSMMAT:

M15/CL(k)_CL(j) = | | CL2
 | M15 |
 | | CL3

Multiply M2 by rotation matrix (M15) to get the second REFSMMAT, storing it to M3:

M2*M15>M3 | M2 | M50 * | M15 | CL2 = | M3 | M50
 | | CL2 | | CL3 | | CL3

Note: Multiplying M3 by the rotation matrix (M15) will produce a matrix identical to M1 for verification purposes. Each time the result is multiplied by the M15, it is being rotated 120 degrees about the same axis of ambiguity (3x120° = 360°).

Transposing M1, M2 and M3 will produce the REFSMMAT's to be uplinked:

TNSPM1 = | | CL1
 | M1^{-T} |
 | | M50

TNSPM2 = | | CL2
 | M2^{-T} |
 | | M50

TNSPM3 = | | CL3
 | M3^{-T} |
 | | M50

Now, uplinking M1, M2, and M3 will produce the correct torquing angles for torquing two of the platforms to desired skew with the IMU that has lost slew capability

8. Save the new REFSMMAT file for building the uplink using the RCDREF command. Choose an appropriate name for the file such as "newsqrt6". Enter "RCDREF". When prompted enter file name such as "newsqrt6". When prompted for matrices enter "1,2,3".
9. Enter "OFFPRINT"

10. Use program NREF and SCP 2.10 to build and uplink the new REFSMMAT using the file name from step 8 as input to NREF.
11. Perform an IMU/IMU align with the non-slewing IMU as reference to recover optimal skew between IMU's.

OPTION 3: USING GYRO COMP UPLINK TO ALIGN IMU

This procedure uses gyro pulse-torquing compensation to move the platform. Due to the high rate pulse torquing that will occur with this uplink, expect to get a Redundant Rate BITE.

1. Determine the amount of open loop torquing that is required to recover the IMU:

Hardcopy the GNC ORBIT display such that there is a record of torquing angles used to calculate the gyro compensation. Torquing angles from star data or an IMU/IMU align can be used. Make sure the torquing angle data is valid for the IMU being aligned.

GNC ORBIT				
TRQ	1	-0.006	0.001	0.003
ANG	2	125.764	-93.205	178.026
	3	0.000	0.001	-0.002

As can be seen above, the torquing angles for IMU 2 are: 125.764 X, -93.205 Y, and 178.026 Z. Use the largest torquing angle for the next step.

2. Calculate duration of align:

Determine the axis with the largest torquing angle (Z is the largest in the example at 178.026 deg). Calculate the net drift for this axis using the onboard drift for that axis, (GNC DNAV-APPS>IMU Summary), and the max uplink compensation rate (± 10 deg/hr) by the following equation. The sign of the max uplink should be opposite the sign of the torquing angle.

$$\text{Net Drift} = \text{Onboard bias} - (\pm \text{Max uplink})$$

Divide the biggest torquing angle by the result to determine the duration of the align.

IMU SUMMARY				
		X	Y	Z
O/B DRIFT	1	-0.001	0.011	0.023
	2	-0.012	0.005	0.015
	3	0.000	0.001	-0.002

<p>Ex.</p> <p>Onboard bias: 0.015</p> <p>Max uplink: - (-10.000)</p> <p>Net drift: 10.015 deg/hr</p>	<p>Biggest torque angle (from step 1) : 178.026 deg</p> <p>Net drift: 10.015 deg/hr</p> <p>Duration of align: 17.776 hrs</p>
--	--

Note: In the example above, arrows indicate that the '0.015' from the IMU Summary table is used for the 'Onboard bias' in the calculation, and the '178.026 deg' is used for the 'Biggest torque angle'. The result of the division is shown as '=17.776'.

3. Compute the gyro compensation load to be used to align the IMU.

Calculate the net drift for the other two axes by dividing their torquing angles by the time derived in step 2. Using this net drift and the onboard bias for each axis calculate the uplink using the following equation.

New Uplink = Onboard bias – Net drift

GNC ORBIT			
	X	Y	Z
TRQ 1	-0.006	0.001	0.003
ANG 2	125.764	-93.205	178.026
3	0.000	0.001	-0.002

Net drift: 125.764deg / 17.776hrs = 7.075 deg/hr

Uplink: (-0.012) – 7.075 = **-7.087deg/hr**

IMU SUMMARY			
	X	Y	Z
O/B DRIFT 1	-0.001	0.011	0.023
2	-0.012	0.005	0.015
3	0.000	0.001	-0.002

Net drift: -93.205deg / 17.776hrs = -5.243 deg/hr

Uplink: +.005 – (-5.243) = **5.248deg/hr**

4. Build and uplink the gyro compensation that will be used to establish the skew using SCP 2.4 steps C thru F. In this case, the uplink would be:
X = (-7.087) Y = 5.248 Z = (-10.000)
5. Start timing at the time of buffer execute on the Command Track display. When within 1 minute of the duration time calculated in step 2 uplink the original bias using SCP 2.4 steps C thru F.

OPTION 4: USING STAR TRACKER ALIGN TO RECOVER SKEW

1. Calculate align time by dividing the RSS of the torquing angles by the maximum torque rate of 25 degrees/hour. Using the example from option 3, the align time would be 9.5 hours.
2. This option must have the correct Desired REFSMMAT onboard. Perform a nominal star align to recover the IMU.

Note: Any star align is an open loop align, so the IMU's will continue to drift the entire duration of the align. As an example, an IMU drifting at 0.006 deg/hr will drift 0.10 degrees in 16 hours. So, an align taking 16 hours will show about a 0.10 deg error from drift after the align completes. **Also, RM(FDIR) will be disabled while the align_in_progress flag is set (if any number of IMUs are being aligned, the flag is set).** Thus, MCC will have to provide fault detection while the align is in progress.

TITLE

IMU REFSMMAT NORMALIZATION

PURPOSE

To describe the use of the GNC offline program NREF. The GNC flight controller will use NREF to create a set of normalized REFSMMAT's for uplink to the Orbiter IMU's.

GENERAL

WARNING: This procedure is governed by FCOH SOP 3.1, COMMAND POLICY FOR MOD, and cannot be modified without prior approval of the FOIG or the Flight Director (during real time operations). Safety critical steps are marked by a box.

Restrictions:

OI Load: all

OPS mode: PASS (OPS 2 and MM 301 of OPS 3) BFS (MM301 of OPS 3)

Major Function: GNC

Vehicles: all

Crew/MCC coordination: information only

Time Constraints: none

Hazardous: This load replaces the desired REFSMMAT values for each IMU (V96U7185C through V96U7211C) with the appropriate uplinked values if an IMU alignment is not in progress. If an IMU alignment is in progress, the uplink is ignored. If the uplink causes erroneous desired REFSMMAT values, the IMUs may be skewed to an undesired location during a subsequent IMU alignment.

Require safing: no

BACKGROUND

Each IMU is associated with a REFSMMAT, a matrix in software which describes the orientation of the IMU stable platform with respect to the M50 inertial coordinate system. The IMU platforms are skewed with respect to M50, to optimize IMU redundancy management. The REFSMMATs are calculated at Platform Release during the prelaunch sequence.

These REFSMMAT's are not perfectly orthogonal (i.e., the row and column vectors are not exactly equal to 1 and the angles between them are not exactly 90°. This non-orthogonality is only noticeable during the calibration of the Head Up Display (HUD) or crew optical alignment sight (COAS).

When the crew takes a mark during a HUD/COAS calibration, the software generates a HUD/COAS line-of-sight (LOS) vector. This is supposed to be a unit vector; however, since the REFSMMAT's are used in the calculation, the HUD/COAS LOS vector ends up being slightly smaller than unity.

After the new LOS vector has been generated, the software compares it to the old LOS vector and displays the angle between them for a reasonableness check. The software calculates the separation angle using the dot product formula:

$$A \cdot B = AB \cos \alpha$$

The algorithm is written assuming that the two LOS vectors are unit vectors (so that $AB = 1$). Therefore, the separation angle is actually calculated with the following equation:

$$\alpha = \arccos (A \cdot B)$$

Since the two vectors are slightly shorter than unity, the dot product (scalar) of the two vectors is smaller than it should be, and the arc cosine function returns a greater angle than actually exists between the two vectors. This angle is displayed to the crew, indicating a larger than actual error in every HUD/COAS mark. The error can be as large as 0.1. This is the most obvious result of the slightly inaccurate REFSMMAT's; the effects on navigation and attitude control are very small.

To eliminate this source of error, the GNC flight controllers have developed a procedure to "normalize" the launch REFSMMAT's. A UNIX shell script called NREF was then built to automate this procedure using the workstations. NREF can read the REFSMMAT's from a prebuilt file, directly from the flight controller inputs or directly from telemetry. It will then normalize them, setting all of the vectors to unity, and prepare a command load for uplink to the Orbiter.

PROCEDURE

The following procedure describes the use of the workstation program NREF.

A. BUILDING THE COMMAND

1. Collect the data

NREF requires the existing launch REFSMMAT's as input. It will accept the REFSMMAT's in three forms: (1) input manually, (2) read from an existing file, or (3) read from telemetry.

2. Run the NREF program

The program NREF is included on the GNC DNAV MENU. To execute the NREF program, use the left mouse button and select the "Apps" menu option, then select "NREF".

At the start of the program, NREF will search your current directory for a subdirectory named "refs". If it does not find one, it will create one, and print out the message

```
creating "refs" directory . . .
```

to let you know what it did. This should not happen during a flight, provided that NREF has been used during simulations for that flight.

NREF then displays the REFSMMAT entry options. Select the appropriate option and follow the prompts. If you select option 1 or 3, you must supply NREF with the name of the file you wish to create. Once you have entered all elements, the three files (one for each IMU) will be stored in the refs subdirectory of the current working directory (path: /users/gnc/Data/SSPxxx). Option 2 will display the current REFSMMAT files stored in the refs directory. Select one and NREF will continue. A good name to use for these REFSMMAT files is "launch". That way, there will be no confusion as to which file contains the prelaunch generated REFSMMATs.

The next two questions ask what names you want to give to the processed REFSMMAT files which the program creates as it executes. NREF supplies default names, which will be used if you hit RETURN without typing a name of your own. In almost all cases, you should use the default names. If you want to use the defaults, simply hit RETURN three times.

What name shall I use to store the intermediate, orthogonal REFSMMATs?
(default "inter")

What name shall I use to store the final, uplink REFSMMAT's? (default "flight")

The next question asks for the DSM number to use for the uplink load containing the normalized REFSMMAT's. The DSM numbers for a REFSMMAT uplink load range from 43001 to 43010. NREF only requires that the last two digits be typed. Generally, you will store the launch REFSMMAT's in DSM 43001 (using another technique, see SCP 2.18) and the normalized REFSMMAT's in DSM 43002. The default answer to this question is "2", so normally you will just hit RETURN again.

I'm building a load from the new, orthogonalized REFSMMAT's. What DSM number (1 to 10) should I use for this load? (default "2")

Other information that may be asked for is the vehicle number and the flight number. Enter the numeric number only in both cases. As an example for OV102 and STS-090, you would enter 102 and 90 or 090.

NREF now has all the information that it needs. It runs through the operations necessary to generate the working REFSMMAT files, normalizes them, and builds an uplink MED with the new REFSMMAT's. This process takes about 10 seconds and is invisible to you. When it is complete, NREF prints out a message to inform you of success:

NREF processing complete

Original REFSMMAT's stored under the name: launch

Orthogonalized REFSMMAT's stored under the name: inter

Uplink REFSMMAT's stored under the name: flight

The new REFSMMAT command load file name: flight.gcs

Report file stored in the current directory as nref.out

If you used REFSMMAT names other than the defaults, you will see them here in place of "launch", "inter", and "flight".

Finally, NREF will give you the option of printing a copy of the report file. This copy should be put in the flight controller's IMU log book.

3. Check the NREF output

The NREF report file is five pages long. The first three pages are orthogonality checks. Each page shows the checks for one set of three REFSMMAT's (one REFSMMAT per IMU). The checks are done independently for each REFSMMAT. The orthogonality check prints out the length of each row vector and column vector in the matrix. Ideally, these lengths should all be unity (1.0). The variations in these lengths are what the NREF program is intended to remove. The orthogonality check also prints the angles between each pair of row vectors and each pair of column vectors. These angles should all be 90° (90.0).

The first page shows the orthogonality of the input REFSMMAT's, the ones the Orbiter launched with. The vector lengths are expected to be slightly less than unity (all nines except for the last four or five digits).

The second page shows the orthogonality of the intermediate normalized REFSMMAT's. These matrices are normalized to the numerical accuracy limits of the workstation computer. The vector lengths on this page should all be exactly unity (1.0).

The third page shows the normalized REFSMMAT's from the previous page, after rounding to the numerical accuracy of the Flight Software (FSW). The vector lengths on this page should all be either unity (1.0) or very slightly less (all nines except for the last one or two digits).

While you are checking the detailed numerical accuracy of the REFSMMAT's, you should also check that the overall orientation of each REFSMMAT has not changed through the NREF process. To do this, check that the sign and the first couple of digits of each matrix element are the same across all three pages.

B. LOADING THE COMMAND INTO THE COMMAND SERVER

NOTE: A Command Manager must be running on any workstation that runs command applications. Start or Stop a Command Manager from the Master DNAV, Global Apps, Command Server menu.

The NREF program creates a command display file containing the normalized REFSMMAT's. If you used the default names, this file will be named "flight.gcs". Retrieve this file using the REFSMMAT Command display from GNC DNAV. Use the STORE button on this display to send the load to the Command Server.

NOTE: Command Display inputs are not allowed when the Command Server is in checkpoint.

C. VERIFICATION OF COMMAND SERVER LOAD

Once you have stored the normalized REFSMMAT load in the Command Server, feedback from the Command Server is displayed on the REFSMMAT command display.

The fifth page of the NREF report file is a prediction of the stored load on the REFSMMAT command display. Compare this page to the actual load you see on the display. The decimal numbers should all be identical. The hex numbers should also be identical with the following exception.

Exception: When the decimal number is small (less than 0.07), the one or two least significant bits of the second hex halfword may vary between the Command Server and the NREF printout. NREF converts the decimal numbers to hex at full precision, but the command display input only provides for eight decimal digits of precision. This loss of full precision has no impact since the decimal numbers (the "meaning" of the hex words) are still identical to eight digits.

Once you have verified that the load on the Command Server is identical to the load on the NREF printout (subject to the above exception), you should perform one final end-to-end confidence check. Call up REFS/Rolls/Quats on an adjacent display, and confirm that the sign and first four digits of each matrix element are identical between REFS/Rolls/Quats and the Command Display. This check confirms that the general orientation of the normalized REFSMMAT load (on the Command Server) has not changed from the orientation of the original REFSMMAT load (on REFS/Rolls/Quats).

If any of the checks in section 3 or this section fail, do not uplink the load! Check your work, and repeat this procedure if necessary. If the load still fails the checks, refer to the backup procedures of this SCP for an alternate procedure.

D. NOTIFICATION AND APPROVAL

1. Advise the GNC FCR by DSM number that the normalized REFSMMAT load has been built, verified, and is ready for uplink.
2. The GNC FCR will verify that the load is correct.
3. The GNC FCR will receive Flight Director approval to perform the uplink. The GNC FCR request to INCO for the uplink command will include a confirmation of Flight Director approval for uplink, the GPC major function destination, and the DSM number of the command.
4. The GNC FCR will monitor the loop until all command actions are completed. INCO will notify the GNC FCR when the actions are completed. The GNC FCR will monitor the COMMAND TRACKING display to verify that the correct commands have been executed.

E. VERIFICATION OF UPLINK ONBOARD

1. Record the load number and the time of uplink in the console log. Although the new REFSMMAT's are now onboard, they will not actually be used until an IMU alignment is performed. A star alignment or IMU-to-IMU alignment will incorporate the new REFSMMAT's.
2. If the uplink was unsuccessful and erroneous data was received in the desired REFSMMAT slot, the IMU torquing angles generated by a subsequent acceptable star pair would have unusually high values. The GNC should not align the IMUs to such torquing angles and the original REFSMMAT load should be uplinked. If an alignment was performed to erroneous desired REFSMMAT values, the IMU skewing would be undesired and a successful uplink followed by an alignment would be required to achieve the desired entry skewing.
3. After the IMU alignment has been made to update the REFSMMAT's, verify the transition to the new REFSMMATs on REFS/Rolls/Quats. Record the time of the transition in the console log and the IMU update log. Save the NREF report printout in the IMU update log.

F. TRACKING OF LOADS BUILT

REFSMMAT loads are recorded and tracked by GNC. There is no need to save REFSMMAT loads on the Command Server. Assuming no IMU failures, the initial launch $\sqrt{6}$ load and the normalized REFSMMAT load are the only loads planned for each flight.

REFERENCES

1. GNC Offline Program NREF Documentation Folder.

TITLE

RECOVERY FROM LOSS OF IMU GYRO PULSE TORQUING

PURPOSE

Provides procedures to compute and uplink the REFSMMAT required to recover an IMU that has lost gyro pulse torquing capability.

BACKGROUND

The loss of an IMU's gyro torquing capability (due either to the Transmission Word 1 GPC commands or a physical gyro torquer problem) will cause that IMU to drift away from its desired REFSMMAT orientation at a rate equal to the uncompensated drift rate for any given axis. Drift compensation is inhibited with the loss of gyro torquing, since our method of compensation involves adjustment of those same gyro torquing commands. The IMU should still be capable of slewing. IMU-to-IMU alignments could be performed periodically to bring the platform within approximately one degree of its desired orientation. However, this remaining misalignment (between 0.65 degree and 1.05 degree) would still prohibit the use of this IMU for the entire entry phase.

IMU uncompensated drift rates are typically very small and the IMU will remain usable for orbit and entry. Its attitude can be maintained by periodically performing Matrix aligns. This SCP provides three different options for compensating for the misalignment in an IMU which has lost pulse torquing. Option 1 should be satisfactory for IMUs with small uncompensated drift rates that will not violate the entry interface (EI) IMU misalignment constraint (Flight Rule A4-151). However, should the IMU misalignment exceed the EI misalignment constraint, Option 1 can be used by delaying the procedure to later in the deorbit timeline. Option 2 may be necessary if an IMU has a large uncompensated drift rate or if it is desired to optimize the IMU performance during entry. Option 3 utilizes the capability to matrix align an IMU using IMU data in addition to Option 2 to further optimize IMU performance during entry.

PROCEDURE

The following procedures were developed, in accordance with typical deorbit preparation and entry timelines, with minimum impact to crew deorbit preparations. It is recommended that one of the following procedures (Option 1, 2, or 3) be implemented on entry day, in an attempt to recover the IMU for entry.

OPTION 1:

- A. Manually deselect the affected IMU.
- B. Perform an IMU/IMU alignment (if total misalignment greater than 1.0 degree) on affected IMU.
- C. Perform a Matrix alignment. This can be done by using the Deorbit IMU alignment verification stars, or if stars are not available, a matrix alignment using IMU data may

be performed. Note that the Matrix align will change the REFSMMAT for that IMU, but only very slightly (since the total misalignment was only about 1.0 degree) and will not adversely affect the RM coverage.

- D. Retrieve the new REFSMMAT from telemetry by following GNC SCP 10.12 ENTREF, and uplink to the DESIRED REFSMMAT by following GNC SCP 10.11 REFSLOAD USER'S GUIDE. This is done to provide the crew/MCC with correct torquing angles for subsequent alignments, if required.
- E. Reselect the IMU in the PASS and BFS.

Note: Periodic matrix alignments using IMU data may be performed during entry to keep the IMU within limits. However, issues with BFS REFSMMATs and IMU RM should be kept in mind (See GNC SCP 2.8 "IMU Matrix Alignment Using IMU Data").

OPTION 2:

This option is based on computing a new REFSMMAT whose platform orientation represents the anticipated misalignment of the IMU at some convenient time within the entry timeline. This approach should work, as the drift characteristics of the failed gyro axis (or axes) are precisely known, so long as the drift rates in question are not unreasonably high. Typical flight IMU gyro drift rates have been no greater than 0.15 deg/hour for the worst axis; a quick look analysis suggests that drift rates below approximately 2 deg/hour should be candidates for this recovery procedure.

A. DETERMINE THE INITIAL IMU MISALIGNMENT

Prior to the deorbit star alignment (approximately TIG-4.5 hours) we would have the crew perform an IMU-to-IMU alignment on the failed unit, to bring it within one degree of its desired REFSMMAT. During the deorbit star alignment, the crew should not select this IMU for Star Tracker alignment; however, we will read its torquing angles, which accurately represent its misalignment error. This value will be used as the initial IMU misalignment, to which we will add the growing error based upon the drift rate of the axis (or axes) in question.

Note: *Reverse torquing angle polarity to get misalignment error.*

B. COMPUTE THE MISALIGNMENT FOR A FUTURE TIME

As the drift rates are well documented by this point in the mission, we can compute the misalignment error anticipated at any target point in the future, such as EI-5, using the following equation:

$$\text{Total Error} = b + mt$$

where:

- b = initial misalignment error (measured anytime after IMU-to-IMU alignment)
- m = uncompensated drift rate of axis in question
- t = time from "b" to target point

Note: Where more than one axis is involved, each must be computed individually. Also, it might be worthwhile at this time to anticipate possible deorbit burn wave-offs and perform the following calculations for other deorbit opportunities.

This example assumes a problem in IMU 1.

Note: EI-5 can be selected as a nominal target point for zero misalignment as it guarantees an acceptable error at entry interface as well as at Mach 2 (approaching the HAC).

C. BUILD A QUATERNION USING THE PREDICTED ERROR

Using the MQEUT program, build a Quaternion using the total error predicted for the IMU at the target point; use X#Y#Z# >Q1/CL1__FCL1.

X#Y#Z# = Components of the total error calculated in Part B.

CL1 = CLUSTER #1 (Original attitude, defined by Current REFSMMAT of IMU #1)
FCL1 = FINAL CLUSTER #1 (Target Attitude)

D. NORMALIZE THE QUATERNION AND CONVERT IT TO A MATRIX

Use Q1>M4 to normalize Q1. You should now see the Matrix representing the XYZ rotation between the target position of cluster #1 and its original position:

$$M4 = \begin{array}{ccc|cc} X & X & X & CL1 & CL1 \\ X & X & X & & = M \\ X & X & X & FCL1 & FCL1 \end{array}$$

E. TRANSPOSE THE MATRIX

Now transpose M4, using TNSPM4, for later use:

$$M4 = \begin{array}{ccc|cc} X & X & X & FCL1 & FCL1 \\ X & X & X & & = M \\ X & X & X & CL1 & CL1 \end{array}$$

F. LOAD ALL THREE IMUS' REFSMMATS INTO MQEUT

Use the LDREFS command to load the REFSMMATs for the three IMU's into MQEUT matrices M1, M2, & M3. The REFSMMATs should be located in the users/gnc/Data/SSPXXX/refs directory where XXX is the flight number.

G. LABEL THE REFSMMATS

The REFSMMATs in M1, M2, & M3 should be labeled as follows:

$$M_i = \begin{array}{ccc|c} X & X & X & CL_i \\ X & X & X & \\ X & X & X & M_{50} \end{array} = \begin{array}{c} CL_i \\ M \\ M_{50} \end{array}$$

H. ORTHOGONALIZE THE REFSMMATS

Orthogonalize M1, M2 & M3 using ORTHMi.

I. COMPUTE THE REFSMMAT FOR THE TARGET POSITION

Now compute the new REFSMMAT for the target position of CL1:

$$M = \begin{array}{ccc} FCL1 & FCL1 & CL1 \\ M_{50} & CL1 & M_{50} \end{array} = M_{50} * M_{CL1} = M_{50} * M_1 > M_5$$

J. ORTHOGONALIZE THE NEW REFSMMAT

Orthogonalize M5, using ORTHM5

K. CHECK THE FINAL RESULTS

M5 represent the new REFSMMAT for IMU 1, representing the platform orientation at the target point:

$$M_5 = \begin{array}{ccc|c} X & X & X & FCL1 \\ X & X & X & \\ X & X & X & M_{50} \end{array}$$

Note: We can check our results by computing the per axis rotation between the original and final REFSMMAT:

TNSP M5 > M6

$$M_1 * M_6 > M_7 \quad \begin{array}{ccc} CL1 & M_{50} & CL1 \\ M_{50} & FCL1 & FCL1 \end{array} * M = M$$

EIGEN M7 Display $\left. \begin{array}{l} X = \text{-----} \\ Y = \text{-----} \\ Z = \text{-----} \end{array} \right\} = \text{Misalignment Errors}$

L. BUILD THE LOAD FOR UPLINK

Use the RCDREFS command to save the new REFSMMATs. The REFSLOAD program (see SCP 10.11) can be used to build an MCC load for subsequent uplink to the desired REFSMMAT lockers of IMU 1. The uplink of this new desired REFSMMAT can occur anytime before the IMU RM RESET alignment at TIG - 1:10.

NOTE: If new REFSMMATs are uplinked to the PASS while the BFS is already activated and in OPS 301, the same new REFSMMATs must be uplinked to the BFS (in MM 301).

M. ROLL IN THE NEW REFSMMAT

During the IMU RM RESET alignment, the crew should select the failed IMU for alignment. A matrix alignment using IMU data (OI-32 and subs) will be performed aligning the failed IMU to itself. This operation will copy the failed IMU's desired REFSMMAT into the current REFSMMAT slot without torquing the platform. At the completion of the matrix alignment the new desired REFSMMAT will be rolled into the current REFSMMAT and the gyro deltas on the GNC Orbit and A/E Sensors displays will now represent the misalignment of this IMU from the target platform orientation representing the new desired REFSMMAT. From this point on, the gyro deltas should begin to "decrease" at the same drift rate as before, reaching zero misalignment error at our target point.

N. COMPUTE NEW REFSMMAT IF DEORBIT IS DELAYED

If it were necessary to delay deorbit by one (or more) revolutions, we would have to compute a new desired REFSMMAT representing the added misalignment incurred. The faulty IMU would then be matrix aligned to itself during the next IMU RM RESET (see step M) to roll in the new REFSMMAT.

Note: Only the failed axes will show an error. The good axes will show no error between the current and the new desired REFSMMAT).

OPTION 3:

This option is based upon the capability to perform matrix alignments using IMU data, available in GNC software load OI-32 and subs. A failed or drifting IMU may now be mathematically aligned to another IMU at anytime during entry, provided that another IMU with good attitude reference is available. The IMU can now be maintained through periodic matrix alignments using IMU data making it usable with greater accuracy throughout entry. In the event that the IMU with high drift rate becomes the last available IMU (i.e. the other IMUs with good attitude reference become unavailable during entry) this option may be used in conjunction with option 2 in the following manner.

- A. Perform steps A-L of option 2 targeting the earliest time, based upon IMU drift, that will allow the IMU to have a good attitude reference for landing.
- B. Perform a nominal IMU RM RESET during the deorbit timeframe.
- C. At an appropriate time (~EI-5) perform a matrix alignment using IMU data aligning the high drift IMU to a selected best IMU.

- D. Maintain the high drifting IMU within RM limits during entry with periodic matrix alignments using IMU data.

- E. In the event that the high drift rate IMU becomes the last available IMU, the future REFSMMAT calculated and uplinked in step A may be rolled in by matrix aligning the IMU to itself at an appropriate time such that the IMU will provide a usable attitude reference to the ground.

Note: A matrix alignment using IMU data provides a fast and easy way to recover or maintain an IMU during entry, however, issues with BFS REFSMMATs and RM resets should be kept in mind when performing a matrix alignment using IMU data during the entry timeframe (See GNC SCP 2.8 "IMU matrix align using IMU data" for details).

TITLE

IMU GYRO TORQUER SCALE FACTOR DETERMINATION

PURPOSE

To detect, compute, and compensate for a shift in any IMU gyro torquer scale factor.

BACKGROUND

A shift in the gyro torquer H/W scale factor will proportionately reduce the effects of the pulse torquing commands sent by the general purpose computer (GPC) to compensate for known gyro drifts. Thus the gyro will appear to have developed a new drift bias; in reality, the current onboard compensation is no longer adequate to overcome the existing drift characteristics.

The resulting relative platform misalignment will be obvious on the sensors high-density displays. However, only after completion of SCP 2.4, Gyro Drift Compensation, can we distinguish between a gyro drift bias and a gyro torquer scale factor shift. Any noticeable residual drift rate remaining after the gyro bias compensation would suggest a H/W scale factor shift, since the compensation torquing commands will also have been proportionately reduced, as were the original torquing commands. It will then be necessary to over-compensate for the measured drift rate, proportionate to the observed H/W scale factor, such that the actual torque commands will sufficiently cancel the current gyro drift rate.

The following analysis develops the equations required to compensate for drift characteristics caused by the H/W scale factor shift.

$$\text{Observed hardware scale factor} = \frac{(\text{Original torque command}) - (\text{Measured drift})}{(\text{Original Torque Command})} \quad (1)$$

The original torque command (also referred to as the onboard compensation) has been defined as the onboard bias divided by a software scale factor.

Therefore:

$$\text{Observed hardware scale factor} = \frac{\left(\frac{\text{Onboard bias}}{\text{Software scale factor}} \right) - (\text{Measured drift})}{\left(\frac{\text{Onboard bias}}{\text{Software scale factor}} \right)} \quad (2)$$

To compensate for this hardware scale factor shift, the torquing command must be adjusted proportionately such that the product of (Torque command) x (Observed hardware scale factor) = True hardware drift (which has not changed).

Therefore:

$$\text{New torque command} = \frac{\text{Old torque command}}{\text{Observed hardware scale factor}} \quad (3)$$

Since

$$\text{torque command} = \frac{\text{Onboard bias}}{\text{Software scale factor}} ,$$

a new torquing command can be generated by adjusting either the software scale factor term or the onboard bias term (recommended by this SCP). A new onboard bias term can be computed as follows:

$$\text{New onboard bias} = \text{New torque command} \times \text{Software scale factor}$$

$$\text{New onboard bias} = \frac{\text{Old torque command}}{\text{Observed hardware scale factor}} \times \text{Software scale factor}$$

$$\text{New onboard bias} = \frac{\left(\frac{\text{Old onboard bias}}{\text{Software scale factor}} \right) \times \text{Software scale factor}}{\text{Observed hardware scale factor}}$$

$\text{New onboard bias} = \frac{\text{Old onboard bias}}{\text{Observed hardware scale factor}}$	(4)
---	-----

This procedure will completely nullify the "drifting effects" caused by a shift in hardware scale factor; however, it will not compensate for errors generated during fine pulse torquing used throughout star alignments and during the final 2.5 minutes of IMU-to-IMU alignments. Therefore, residual gimbal errors will remain following alignments. These residuals will be seen in the torquing angles following completion of IMU-to-IMU alignments, but not in the case of star alignments. In both cases, however, the residual will be evident in the gyro delta computations, and can easily be removed by following up the initial alignment (either type) with an IMU-to-IMU alignment, which would reduce the remaining misalignment proportionately. This should be sufficient for observed scale factors above 80 percent; for larger scale factor errors, an additional alignment may be necessary.

PROCEDURE

- A. GIVEN: A shift in hardware scale factor has been determined because of a residual drift rate following a gyro bias compensation, or a residual misalignment error following an IMU alignment.
- B. Compute the observed hardware scale factor using equation (2) (software scale factor terms defined in table 2.12-I).
- C. Compute the new onboard bias using equation (4).

- D. Build and uplink the desired onboard bias using the procedures described in SCP 2.4.
- E. Remove misalignment errors as necessary (based upon RM threshold and star alignment schedules).

NOTE: Uplink gyro bias load to Backup Flight System (BFS) per Entry Checklist Procedure.

ALTERNATE METHOD FOR SCALE FACTOR COMPENSATION

For scale factor shifts that exceed 50 percent it may be inconvenient for the crew to perform multiple IMU-to-IMU alignments following each scheduled alignment. The option exists to adjust the S/W scale factor term, proportionately, via a GMEM procedure. This method would compensate for the H/W scale factor effects entirely; i.e., including the torquing phases of IMU alignments.

Perform the following procedures:

1. Compensate for observed gyro drift error using SCP 2.4.
2. If a residual drift error exists, or subsequent IMU star alignment is unsuccessful, suspect a scale factor error.
3. Compute the original torque command:

$$\text{Original torque command} = \frac{\text{Onboard bias}}{\text{Software scale factor}}$$

4. Compute the H/W scale factor:

$$\text{Observed H/W scale factor} = \frac{\text{Original torque command} - \text{measured drift}}{\text{Original torque command}}$$

5. Compute a new scale factor:

$$\text{New S/W scale factor} = \text{Observed H/W scale factor} \times \text{Current S/W scale factor}$$

6. Update scale factor terms with G-MEM Read/Write to the Primary Avionics Software System (PASS) and the Backup Flight System (BFS).
7. If not already performed in step 2, reload the previous gyro drift bias compensation terms.

NOTE: An OPS transition will be required to incorporate the new scale factor terms in the PASS (not required in the BFS).

TABLE 2.12-I.- IMU TORQUER - SCALE FACTOR (SOFTWARE)

Parameter	MSID
KTX (1)	V99G2500CC
KTX (2)	V99G2501CC
KTX (3)	V99G2502CC
KTY (1)	V99G2503CC
KTY (2)	V99G2504CC
KTY (3)	V99G2505CC
KTZ (1)	V99G2506CC
KTZ (2)	V99G2507CC
KTZ (3)	V99G2508CC

NOTE: These parameters are available in the IMU data books issued before each flight.

TABLE 2.IX-II. - SAMPLE COMPENSATION METHOD/RESULTS

H/W Drift	Onboard Bias	S/W Scale Factor	Torque CMD	H/W Scale Factor	H/W CMD	Measured Error	Remarks
5.0	5.0	1.0	5.0	1.0	-5.0	0.0	Compensated drift
5.0	5.0	1.0	5.0	0.6	-3.0	2.0	-40 percent shift in hardware scale factor
5.0	5.0	0.6	8.33	0.6	-5.0	0	Compensation via software scale factor
5.0	8.33	1.0	8.33	0.6	-5.0	0	Compensation via onboard bias
5.0	5.0	1.0	5.0	1.4	-7.0	-2.0	+40 percent shift in H/W scale factor
5.0	5.0	1.4	3.57	1.4	-5.0	0	Compensation via S/W scale factor
5.0	3.57	1.0	3.57	1.4	-5.0	0	Compensation via onboard bias

TITLE

IMU ACCELEROMETER SCALE FACTOR ERROR DETERMINATION

PURPOSE

To calculate and compensate an IMU accelerometer scale factor error.

GENERAL

WARNING: This procedure is governed by FCOH SOP 3.1, COMMAND POLICY FOR MOD, and cannot be modified without prior approval of the FOIG or the Flight Director (during real-time operations). Safety critical steps are marked by a box.

Restrictions:

OI Load: all

OPS Mode: PASS (OPS 2 and MM 301 of OPS 3) BFS (MM 301 of OPS 3)

Major Function: GNC

Vehicles: all

Crew/MCC coordination: information only

Time Constraints: none

Hazardous: This load is commanded to the vehicle in attempt to improve the capability of an already degraded IMU. It replaces the IMU accelerometer software scale factor terms with new values to remove IMU accelerometer scale factors observed prelaunch or during powered flight. If scale factor errors are present on more than one IMU, this procedure will not yield the desired results. If the uplink replaces the I-loaded IMU software scale factor terms with erroneous values, the IMU accelerometer output could be degraded further. If the effected IMU is selected by RM, the vehicle state vector may be polluted.

Require safing: no

BACKGROUND

Inertial measurement unit (IMU) accelerometer errors may manifest themselves as either constant (bias) or acceleration-varying (scale factor) differences between IMU's. The procedures necessary to detect, measure, and remove a bias error are described in SCP 2.5. This SCP provides the procedures to identify and correct scale factor errors on the order of approximately 3 percent or higher

A scale factor error is indicated during dynamic flight (ascent, entry, or on-orbit OMS burns) by measured accelerometer errors that vary in magnitude as a function of the sensed vehicle acceleration. With no vehicle acceleration, scale factor errors appear as constant acceleration errors and are indistinguishable from bias errors. Hardware history and analysis indicate the majority of scale factor shifts are too small to be detected on orbit. Therefore, if an

accelerometer error is detected on orbit, the assumption will always be made that the error is entirely bias.

This procedure is designed to identify a scale factor using relative acceleration errors between IMU's as input data. At least one good IMU is necessary in order to accurately calculate scale factors. If scale factor errors exist on more than one IMU, the good IMU can be identified post-MECO by comparing both erroneous platforms with a playback of ascent data. If all IMUs have scale factor errors, this procedure does not apply and no conclusions can be drawn. This procedure assumes observed error in the NULL ACC comp is due to only a scale factor shift and not a scale factor plus a bias shift.

Since this procedure uses data of limited precision, it will not return an IMU to the same precision achieved by preflight calibration. The procedure can accurately calculate scale factor error less than 2 percent; however, it is doubtful that the correction factor can improve scale factor errors which are less than 3 percent due to data noise. For these small scale factors, correction could further degrade the IMU. The corrected IMU may still have too much error to pass RM but the correction will improve the chances of a safe return if the affected unit is the last remaining IMU.

Figure 2.13-1 shows the flow of acceleration data from hardware through software.

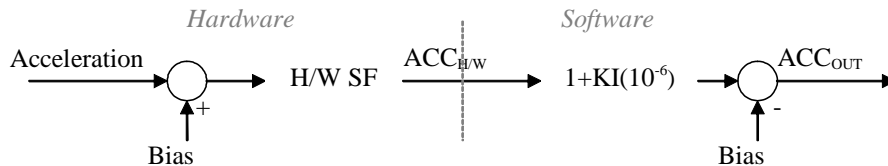


Figure 2.13-1 - Flow of acceleration data from hardware through software.

The accelerometers sense an actual acceleration ($ACC_{S/W}$) and the hardware, which is imperfect, measures an acceleration ($ACC_{H/W}$) which is in error by a bias and scale factor error.

$$ACC_{H/W} = (ACC_{IN} + Bias)SF_{H/W} \quad (1)$$

Where $SF_{H/W}$ = the hardware scale factor error

The software then corrects for these errors:

$$ACC_{OUT} = [ACC_{H/W} (1 + KI(10^{-6}))] - Bias \quad (2)$$

Where KI = the software scale factor correction

If the bias and scale factor corrections in the software are perfect, then ACC_{OUT} would exactly equal the actual acceleration.

Solving Eq. 1 and 2 for $ACC_{H/W}$ and equating yields:

$$(ACC_{IN} + Bias)SF_{H/W} = \frac{ACC_{OUT} + Bias}{1 + KI(10^{-6})} \quad (3)$$

$$\frac{ACC_{IN} + Bias}{ACC_{OUT} + Bias} SF_{H/W} = \frac{1}{1 + KI(10^{-6})} \quad (4)$$

$$SF_{H/W} = \frac{1}{1 + KI(10^{-6})} \quad (5)$$

If a shift in $SF_{H/W}$ occurs, ACC_{IN} will not equal ACC_{OUT} , and Eq. 5 is no longer valid. A new $SF_{H/W}$ can be computed with Eq. 6. This equation is not valid if either IMU has a bias error.

$$SF_{H/W} = \frac{ACC_{BAD} + Bias}{(ACC_{GOOD} + Bias)(1 + KI(10^{-6}))} \quad (6)$$

The ACC_{BAD} is the output of the bad axis of the IMU with the shifted scale factor. ACC_{GOOD} is the output of a good IMU transformed into the bad IMU's coordinate system.

However, the value of the new KI is desired in order to perform the compensation uplink. The new KI can be obtained with Eq. 7 and 8.

$$SF_{H/W} = \frac{1}{1 + KI_{NEW}(10^{-6})} \quad (7)$$

$$KI_{NEW} = \left(\frac{1}{SF_{H/W}} - 1 \right) 10^{+6} \quad (8)$$

PROCEDURES

A. DATA COLLECTION

1. Obtain the I-loaded accelerometer bias for the affected IMU axis. The obtained value will be in μg .
2. Obtain the I-loaded KI term for the affected IMU axis. If KSC prelaunch calibration data is not available, perform a memory read (SCP 11.19). The HAL name of the KI term for PASS is CGMS_ACC_SFLO. The BFS KI terms are KIX, KIY, and KIZ.
3. **IF POSSIBLE:** Obtain REF VEL values for the affected IMU axis and the same axis of a good IMU from the IMU Summary display during vehicle acceleration. The ground reference should be set to the affected IMU such that the REF VEL value of the good IMU is in the reference frame of the affected IMU. Values should be obtained for as many time periods as available with each period lasting approximately 10 seconds.

ELSE: Pull Data from ODRC: This data can also be obtained for a previous period of acceleration using ODRC. Pull M50 VEL values from ODRC using the MSIDs in the table below.

TABLE 2.13-1. M50 VEL MSIDS.

IMU	X	Y	Z
1	V95L0065C	V95L0066C	V95L0067C
2	V95L1065C	V95L1066C	V95L1067C
3	V95L2065C	V95L2066C	V95L2067C

B. CALCULATE THE SCALE FACTOR COMPENSATION

The scale factor and KI compensation can be calculated manually or with the PC-based application called IMUAccSF.

Manual Calculation

The following procedure assumes a good IMU can be identified and should be performed for each affected axis of the bad IMU.

1. **If necessary**, convert M50 VEL values from the good and bad IMUs to the coordinate frame of the bad IMU with the corresponding REFSMMATS obtained from the REFS/ROLLS/QUATS display:

$$\begin{matrix} \text{REFVel}_{1X} \\ \text{REFVel}_{1Y} \\ \text{REFVel}_{1Z} \end{matrix} = \begin{matrix} \text{REFSMMAT} \\ \text{of bad IMU} \end{matrix}^T \begin{matrix} \text{V95L0065C} \\ \text{V95L0066C} \\ \text{V95L0067C} \end{matrix}$$

$$\begin{matrix} \text{REFVel}_{2X} \\ \text{REFVel}_{2Y} \\ \text{REFVel}_{2Z} \end{matrix} = \begin{matrix} \text{REFSMMAT} \\ \text{of bad IMU} \end{matrix}^T \begin{matrix} \text{V95L1065C} \\ \text{V95L1066C} \\ \text{V95L1067C} \end{matrix}$$

$$\begin{matrix} \text{REFVel}_{3X} \\ \text{REFVel}_{3Y} \\ \text{REFVel}_{3Z} \end{matrix} = \begin{matrix} \text{REFSMMAT} \\ \text{of bad IMU} \end{matrix}^T \begin{matrix} \text{V95L2065C} \\ \text{V95L2066C} \\ \text{V95L2067C} \end{matrix}$$

Note: Multiplying by the transpose of the REFSMMAT of the bad IMU resolves the sensed velocity from any IMU into the bad IMU's reference frame.

2. Calculate the measured acceleration for the failed IMU axis for each time period. The time difference should be in units of seconds.

$$ACC_{BAD} = \frac{\Delta BREFVel}{\Delta t} = \frac{BREFVel_f - BREFVel_i}{t_f - t_i}$$

Where: *BREFVel* = REF VEL value of the bad IMU
t_i = time at the beginning of the period
t_f = time at the end of the period

3. Calculate the measured acceleration for the good IMU for each time period. The time difference should be in units of seconds.

$$ACC_{GOOD} = \frac{\Delta GREFVel}{\Delta t} = \frac{GREFVel_f - GREFVel_i}{t_f - t_i}$$

Where: $GREFVel$ = REF VEL value of the good IMU

4. Convert the I-Loaded accelerometer bias value from part A step 1 into ft/s².

$$Bias[ft/s^2] = (Bias[\mu g]) \left(10^{-6} \left[\frac{g}{\mu g} \right] \right) \left(32.17 \left[\frac{ft/s^2}{g} \right] \right)$$

5. Determine the ratio of the bad IMU output to the good IMU output. This equation is not valid if either IMU has a bias error.

$$Ratio = \frac{ACC_{BAD} + Bias[ft/s^2]}{ACC_{GOOD} + Bias[ft/s^2]}$$

6. Find *AvgRatio* by taking the average of all the *Ratios* for that axis of that IMU over all time periods.
7. Calculate the scale factor as noted below. The calculated scale factor is the percentage of the actual acceleration sensed by the affected IMU.

$$SF = AvgRatio * \frac{1}{1 + KI(10^{-6})}$$

Where: KI = I-loaded KI value obtained in Step 2.

8. Calculate the new KI term.

$$KI_{NEW} = \left(\frac{1 - SF}{SF} \right) 10^6$$

EXAMPLE

Data for this example was collected from the Next Generation Flight Controller Trainer (NGFCT) in July 2004 with a scale factor on each axis of IMU 1 during ascent. The I-loaded X-axis accelerometer bias is -124 µg and the KI value is 1. The following M50 VEL data was collected:

TABLE 2.13-2. M50 VEL IN FT/S OF THE GOOD AND BAD IMU.

Data Sample	1	2	3	4
Time (OMET)	000/00:01:24	000/00:01:38	000/00:01:54	000/00:02:12
Failed IMU X-Axis	-69778.90	-70236.06	-70667.22	-70922.29
Failed IMU-Y Axis	25135.25	24716.08	24171.23	23847.84
Failed IMU-Z Axis	42519.57	43250.66	44073.04	44552.40
Good IMU X-Axis	-70108.47	-70605.39	-71074.07	-71351.30
Good IMU-Y Axis	23887.98	23432.40	22840.15	22488.65
Good IMU-Z Axis	42344.13	43138.78	44032.65	44553.69

The corresponding REFSMMAT to convert to IMU 1 references frame is:

$$\begin{vmatrix} 0.7538633943 & -0.1059024334 & 0.6484389901 \\ -0.6569151878 & -0.1400158405 & 0.7408491969 \\ 0.0123340152 & -0.9844694734 & -0.1751219034 \end{vmatrix}$$

Converting the M50 data into REF VEL with the transpose of the REFSMMATS yields:

TABLE 2.13-3. VELOCITY RESOLVED INTO THE BAD IMU'S REFERENCE FRAME.

Data Sample	1	2	3	4
Time (OMET)	000/00:01:24	000/00:01:38	000/00:01:54	000/00:02:12
Failed IMU X-Axis	-68591.05	-68651.31	-68608.28	-68582.22
Failed IMU-Y Axis	-37988.80	-38601.43	-39289.09	-39688.71
Failed IMU-Z Axis	-34072.04	-34807.05	-35634.30	-36123.23
Good IMU X-Axis	-68022.31	-68087.84	-68041.08	-68012.74
Good IMU-Y Axis	-37606.54	-38272.44	-39019.87	-39454.24
Good IMU-Z Axis	-35179.06	-35977.96	-36877.17	-37408.59

The above data samples can be used to make 3 time periods. The manual calculation procedure is performed below for the X axis only. Detailed computation is shown for time period 1 where OMET has been converted into seconds. The -124 µg accelerometer bias is equal to -0.004 ft/s².

$$ACC_{BAD_1} = \frac{-68651.31 - (-68591.05)}{98 - 84} = -4.3043$$

$$ACC_{GOOD_1} = \frac{-68087.64 - (-68022.31)}{98 - 84} = -4.6808$$

$$Ratio_1 = \frac{-4.3043 + (-0.004)}{-4.6808 + (-0.004)} = 0.9196$$

TABLE 2.13-4. CALCULATED RATIOS FOR THE X-AXIS ONLY OF EACH DATA SAMPLE.

Time Period	X Axis ACC _{BAD}	X Axis ACC _{GOOD}	Ratio
1	-4.3043	-4.6808	0.9196
2	2.6892	2.9226	0.9200
3	1.4480	1.5743	0.9195
Average:			0.9197

$$SF = 0.9197 * \frac{1}{1 + (1)(10^{-6})} = 0.9196 \approx 92\%$$

This scale factor value means the affected IMU is sensing 92% of the actual acceleration and has an 8% scale factor.

$$KI_{NEW} = \left(\frac{1 - 0.9197}{0.9197} \right) 10^6 = 87274.6$$

IMUAccSF PC-Based Application

IMUAccSF can be used to calculate an IMU scale factor or to verify hand calculations. The tool is located in S:\Divisions\DF\Private\DF62\PROGRAMS\UNCERT

The following procedure assumes a good IMU can be identified and should be performed for each affected axis of the bad IMU.

1. Start the IMUAccSF tool. Select the data input type, failed axis, and enter the collected data into the corresponding fields on the *Input Data* tab. Click on "<" and ">" to toggle between data samples.
 - a. If using M50 VEL data, enter the appropriate REFSMMAT obtained from the REFS/ROLLS/QUATS display.
 - b. If using REF VEL data, only the data fields relating to the failed axis are required.
2. On the *SF Calculation* tab and click "Calculate" to perform the computations.
3. Save data by typing in a data path and clicking "Create Report". Once a report has been created, the input data can be read from the report using the "Load Data from Report" feature on the *Input Data* tab.

EXAMPLE

The screen shots below show the automated calculation of the manual scale factor calculation example above.

IMU Accelerometer Scale Factor Error Determination

Input Data | SF Calculation | Instructions

Failed IMU Axis Accelerometer Bias: -124 (µg)

Initial Failed IMU Axis KI: 1

Number of Samples: 4

Type in data or load from existing report
D:\Documents and Settings\kkranzus\Ascent_8.txt

Load Data From Report | Clear Fields

Input Data: REF VEL M50 VEL < >

Data Sample	1	2	3	4
Time (OMET)	000 0c 01 24	000 0c 01 3E	000 0c 01 54	000 0c 02 12
Failed IMU X-Axis	-69778.90	-70236.06	-70667.22	-70922.29
Failed IMU Y-Axis	25135.25	24716.08	24171.23	23847.84
Failed IMU Z-Axis	42519.57	43250.66	44073.04	44552.40
Good IMU X-Axis	-70108.47	-70605.39	-71074.07	-71351.30
Good IMU Y-Axis	23887.98	23432.40	22840.15	22488.65
Good IMU Z-Axis	42344.13	43138.78	44032.65	44553.69

REFSMATS

	1	2	3	Failed Axis
Failed IMU 1	0.7538633943	-.1059024334	.6484389901	<input checked="" type="radio"/> X
2	-.6569151878	-.1400158405	.7408491969	<input type="radio"/> Y
3	.0123340152	-.9844694734	-.1751219034	<input type="radio"/> Z

IMU Accelerometer Scale Factor Error Determination

Input Data | SF Calculation | Instructions

Calculate

Scale Factor: 91.9637757615406 ← % of actual acceleration sensed by affected IM

New KI: 87384.6704521689 ← Value for uplink correction

Calculations are accurate to two decimal places.

Create Report

Save Path: D:\Documents and Settings\kkranzus\Desktop\Ascent_8.txt

Example: D:\Documents and Settings\username\Desktop\SFReport.txt

C. LOADING THE COMMAND INTO THE COMMAND SERVER

1. Call up the IMU Accel Scale Factor Command display from GNC DNAV. The display is shown in Figure 2.13-2.

NOTE: A Command Manager must be running on any workstation that runs command applications. Start or Stop a Command Manager from the Master DNAV/Global Apps/Command Server menu.

2. Build DSM 43401 with I-Load values (values should be verified by variable parameters - see Table 11.19-II for HAL names and array sequence) of all axes of all IMU's to preserve capability to remove correction(s) if necessary.
3. Build DSM 43402 with the new KI values determined in part B for the appropriate axis(es) and I-Load values for all other axis. Each load must have a valid compensation value for each axis of each IMU. DSM's 43403-43450 are available if subsequent scale factor corrections are required.
4. Hardcopy the command display and store on the Command Server.

D. VERIFICATION OF COMMAND SERVER LOAD

Verify the load has been correctly built by viewing the Server feedback on the command display, comparing DSM numbers and the data values for each IMU axis.

File				
IMU Accel Scale Factor				
DSM #	DSM Title	GMT Gen		
43402	IMU Acc SF load	015:10:42:26		
	hex	UG/G	UG/G	
IMU 1 X	c21e0000	-30.00000000	-30.00000000	
	Y c2180000	-24.00000000	-24.00000000	
	Z 41b00000	11.00000000	11.00000000	
IMU 2 X	c1f00000	-15.00000000	-15.00000000	
	Y 41800000	8.00000000	8.00000000	
	Z c1700000	-7.00000000	-7.00000000	
IMU 3 X	422d0000	45.00000000	45.00000000	
	Y c2370000	-55.00000000	-55.00000000	
	Z 427d0000	125.00000000	125.00000000	
<input type="button" value="Store"/> <input type="button" value="Delete"/> <input type="button" value="Clear"/> <input type="button" value="Exit"/>				
Command Advisories				

Figure 2.13-2 - IMU Accelerometer Scale Factor Command Display

E. NOTIFICATION AND APPROVAL

1. Advise the GNC FCR by DSM number that the loads have been built, verified and the correction is ready for uplink.
2. The GNC FCR will verify the loads are correct.
3. The GNC FCR will receive Flight Director approval to perform the correction uplink. The GNC FCR uplink command request to INCO will include a confirmation of Flight Director approval, the GPC major function destination, and the DSM number of the command.
4. The GNC FCR will monitor the INCO loop until command actions are completed. INCO will notify the GNC FCR when the actions are completed. The GNC FCR will monitor Command Tracking displays to verify that the correct commands have been executed.

F. VERIFICATION OF UPLINK ONBOARD

1. When the uplink is complete, record the uplink time in the IMU Log Book and verify correct uplinked values (for all axes and IMU's) using variable parameters.

NOTE: If uplink causes erroneous onboard scale factor values, request to uplink "immediately" DSM 43401 (generated in part C step 2) corresponding to the original I-loaded scale factor terms.
2. As a second uplink check, restart accel comps to verify nominal on-orbit values.

G. TRACKING OF LOADS BUILT

1. Once the load has been uplinked and IMU performance has been verified, the original I-loaded scale factor terms and the latest uplinked terms should remain stored in the Command Server. Other SF loads should be deleted.
2. Since the backup flight system (BFS) is not active on orbit, it has not tracked the updates made to the onboard accelerometer software scale factor terms in the GNC GPC's. It is therefore necessary to update these values in the BFS. This is planned to occur in MM 301 of OPS 3 at deorbit burn minus 46 minutes (per Entry Checklist). The uplink is performed as described above by uplinking the most recent DSM loads to the BFS GPC. There is no method of verifying that the values have been uplinked correctly.

REFERENCES

1. IMU SOP, FSSR, STS83-0013B, p. 4.5-49, June 30, 1987.
2. IMU Technical Description, Singer - Kearfott Division, DOC Y254A176. p. 222, June 15, 1976.
3. Shuttle Data Processing Complex (SDPC) Software, Volume 1, Book 5. p. 5.3-172-176, March 23, 1995.

TITLE

IMU STATE VECTOR MANAGEMENT DURING ENTRY

PURPOSE

The purpose of this SCP is to capture information regarding IMU State Vector management during the entry timeframe.

BACKGROUND

From transition to OPS 3 until the preland phase of flight, Entry Navigation software maintains 3 separate state vectors using the associated IMU sensed velocities as inputs. These state vectors are sent to the Kalman Filter to incorporate measured data from GPS, TACANs, MLS, and Air Data. The 3 filtered state vectors are then sent to the Vector Select software module, which uses a selection filtering scheme to produce a single selected state vector.

When an IMU is commfaulted in OPS 3, IMU RM software deselects the IMU and Entry Navigation cannot use the IMU's sensed velocities to update the associated state vector. Therefore, over time if there is acceleration on the Orbiter, the associated state vector will diverge from the selected state vector. If the commfault is subsequently cleared, Entry Navigation will resume propagating the associated state vector using IMU sensed velocities. If the associated state vector has diverged by a significant amount, it may be necessary to update the associated state vector with the selected state vector before the IMU is reselected. OI-29 and subsequent flight software loads automatically replace the associated state vector with the selected state vector when an IMU is reselected following a commfault. Prior to OI-29, the only way to do this was to have the crew perform a Nav Delta Zero, which replaces all 3 IMU associated state vectors with the selected state vector. Nav Delta Zero is still an option that can be used to maintain a state vector associated with an IMU that has a degraded velocity output.

PROCEDURE

Before performing a Nav Delta Zero to maintain a state vector associated with an IMU with a degraded velocity output, the following should be kept in mind:

1. A Nav Delta Zero will not be performed in the PASS between 200,000 feet altitude and initial TACAN processing.
2. For AOA, a Nav Delta Zero will not be performed between Ops 3 transition and initial TACAN processing to maintain the state vector of a third IMU. A second IMU state vector may be maintained with a Nav Delta Zero if prior to 200,000 feet.

Rationale: A Nav Delta Zero several minutes prior to TACAN processing changes the covariance matrix such that initial TACAN range velocity gains are dramatically increased. In the presence of nominal TACAN range residuals (2nm), this causes undesirable downrange velocity transients at initial TACAN processing. For smaller Nav state errors, the resultant velocity transients are acceptable. For larger state errors (2 sigma), MCC delta state limits may be exceeded for a Nav Delta Zero performed in this region. Since MCC knowledge of Nav state

errors is questionable during this period of entry, it is assumed that they may be large enough to cause an undesirable transient. An altitude of 200,000 feet is a convenient reference point about 5 minutes before nominal TACAN processing. Five minutes is the minimum advisable time delay between a Nav Delta Zero and initial TACAN processing in order to allow the TACAN velocity gains to shrink sufficiently. A Nav Delta Zero should be delayed until after initial TACAN processing in order to avoid the velocity transients. Otherwise, the magnitude of the navigation errors may exceed delta state and guidance constraint limits. The navigation errors can violate limits for several minutes until TACAN alone is able to bring the errors under control, and guidance capability to recover from the errors is reduced during this timeframe.

On an AOA, a Nav Delta Zero is undesirable anytime in OPS 3 prior to TACAN processing, as it would result in replacing the unique AOA covariance matrix. This covariance was developed for the navigation errors and different uncertainty distributions associated with an AOA (ref. A/EFTP #75, February 15, 1991). On an AOA, a Nav Delta Zero may be performed to maintain the state vector associated with a degraded IMU (if one IMU has already failed) due to the increased risk of flying with no IMU redundancy. However, the window from 200,000 feet altitude to initial TACAN processing should still be protected from Nav Delta Zero updates per the above discussion.

The crew can take CSS when down to one IMU to protect against the next worst failure.

TITLE

IMU COMPENSATION CRITERIA AND GYROCOMPASS GOODNESS TEST

BACKGROUND

The IMU C-Criteria provides the basis for accepting or rejecting the results of an IMU calibration. Similarly, the Gyrocompass Goodness Test provides the criteria for accepting or rejecting the results of the IMU preflight alignment.

The IMU calibrations include the Hangar Cal A, which must be performed after any extended ground interval of greater than 120 days or within 21 days prior to launch (OMRSD requirement) and the preflight cal, performed approximately 7 hours prior to launch. As a minimum, Hangar Cal A will be performed at least once a year.

KSC is responsible for the implementation of the C-Criteria and will inform JSC of all results. The planning team flight controllers on console during prelaunch operation will be made aware, by KSC and/or the MOIR, of any violation to the C-Criteria after the preflight cal is complete. The results of the Gyrocompass Goodness Test as computed by the onboard software (FAIL indication only) can be seen on the SENSORS PRELAUNCH display.

PROCEDURE

The following discussion will be divided in two sections: the preflight calibration requirements as specified in the C-Criteria and the Gyrocompass Goodness Test.

A. *IMU C-CRITERIA*

The main objective of the C-Criteria, is to compute the change in each inertial element parameter from the most recent previous calibration to the calibration just completed. The computed change in each parameter is divided by its one sigma stability requirement in order to obtain the shift of each parameter between calibrations. It must be emphasized that all parameters calibrated during the Hangar Cal A, are not calibrated during the preflight cal. Only the preflight cal terms will be addressed in this SCP.

For each calibration, the IMU must have been powered up for at least 22.5 hours in the standby mode in order to achieve thermal stability, followed by at least 1.5 hours in the operate mode. If repeated calibrations are performed within 17 hours of the first calibration and the IMU remained in the operate mode, then the short term limits apply. However, the long term limits will apply if at any time in between calibrations, the IMU is taken to standby or to off.

If a return to standby is necessary after the IMU's have been accepted for performance, then the IN-OPERATE time shall equal at least three times the IN-STANDBY time with a minimum of 10 minutes and a maximum of 1.5 hours before reacceptance for performance data.

How the C-Criteria is implemented during each preflight calibration is as follows (remember, the parameter shifts are computed as the change of the parameter between consecutive calcs):

The three sigma shift allowed for a parameter on the first calibration, is to encompass the possibility of trending. Trending, which is observable when the unit is first calibrated after being powered off for a prolonged period of time, is due to the degradation of the unit as its operational life increases. However, not all parameters will exhibit the same trending characteristics, since some parameters are more stable than others. All parameters shall have a change of two sigma or less to pass.

If the three sigma limits are violated, the IMU will be declared failed, resulting in a launch scrub.

If the IMU cal terms fall between the pass and fail limits, a retest is performed. The parameters must have a change of two sigma or less on the retest. In the event that a parameter exceeds the two sigma limit in the retest the following actions will be taken: (A) If the failed parameter failed the preceding test, the IMU will be declared failed. (B) If the failed parameter passed the preceding test, and the difference is greater than three sigma, another retest is required. (C) If the failed parameter passed the preceding test and the difference is three sigma or less and time does not permit a retest, the parameter history will be reviewed by the KSC IMU engineers and the MOIR IMU engineers to determine the IMU health.

B. GYROCOMPASS GOODNESS TEST

The Gyrocompass Goodness Test compares the IMU/IMU relative alignment accuracies against test limits about each of the Orbiter axes. The test limits are based on three-sigma numbers for that axis. The test limits were determined by assuming that a valid Hangar Cal C (HCC) was performed in the Orbiter Processing Facility (OPF) to determine the IMU relative attitude error, normally called the MIJB or MB terms (I, J = 1, 2 or 3).

The MIJB terms or relative attitude error angles between IMU pairs (M12BX, Y, Z, etc.) will be derived from data obtained during horizontal gyrocompass calibration (a preflight cal followed by three gyrocompass alignments). This data will be processed offline to provide the required attitude error angles which are derived from the horizontal gyrocompass alignment data. After the last GCA has been run in the horizontal position, the MB term values shall be loaded into the appropriate locations of all checkpoint areas of the mass memory units. These parameters are to be used only when the vehicle is in the vertical position. If an IMU is replaced while the vehicle is in the vertical position, the values for the relative attitude error angles (MIJB-X, -Y and -Z) between the new IMU and the two remaining IMU's shall be set to zero and the GCA misalignment limits will be changed to reflect 360, 268, and 268 arc sec errors in the X-, Y-, and Z-axis respectively.

The IMU/IMU relative alignment accuracies, determined in arcseconds, are computed by the onboard software and the KSC LPS. The flight controllers in the MCC will be alerted of an IMU failure by the FAIL indications on the SENSORS PRELAUNCH display. A fail indication for any IMU will be indicative of a bad IMU or at least that an IMU gyro had problems during the alignment. It is not unlikely for an IMU to be close to its limits during the Terminal Countdown Demonstration Test (TCDDT) due to the limited amount of standby time the units have had prior to the alignment.

The three-sigma alignment limits are computed as follows:

1. Test limit about the Orbiter X-axis.

IMU i Gyrocompass azimuth align required	=	60 arc sec (1 sigma)
IMU i Resolver error after HCC compensation	=	19.75 arc sec (1 sigma)
IMU j Gyrocompass azimuth align required	=	60 arc sec (1 sigma)
IMU j Resolver error after HCC compensation	=	19.75 arc sec (1 sigma)
RSS	=	89.33 arc sec (1 sigma), 268 arc sec (3 sigma)

2. Test limit about the Orbiter Y-axis.

IMU i Gyrocompass align required	=	20 arc sec (1 sigma)
IMU i Resolver error after HCC compensation	=	19.75 arc sec (1 sigma)
IMU j Gyrocompass align required	=	20 arc sec (1 sigma)
IMU j Resolver error after HCC compensation	=	19.15 arc sec (1 sigma)
RSS	=	39.75 arc sec (1 sigma), 119 arc sec (3 sigma)

3. Test limit about the Orbiter Z-axis.

IMU i Gyrocompass align required	=	20 arc sec (1 sigma)
IMU i No resolver error compensation	=	60 arc sec (1 sigma)
IMU j Gyrocompass align required	=	20 arc sec (1 sigma)
IMU j No resolver error compensation	=	60 arc sec (1 sigma)
RSS	=	89.44 arc sec (1 sigma), 268 arc sec (3 sigma)

The same limits but without the resolver error compensation (take the resolver error compensation in X and Y above and multiply them by three) are as follows:

Error about X = 360 arc sec (3 sigma)
Error about Y = 268 arc sec (3 sigma)
Error about Z = 268 arc sec (3 sigma)

Notice that the error about the Z-axis has not changed. The reason is that during the HCC, which is performed in the OPF, the Z-axis of the Orbiter is in the vertical direction, a position which will not provide a more accurate computation of the resolver error compensation of better than the three sigma specification or 60 arcsecs.

Table 2.15-I shows the IMU C-Criteria as written in the Space Shuttle Operations and Maintenance Requirements Document (OMRSD), V71 File III.

REFERENCE

1. Space Shuttle Operations and Maintenance Requirements and Specifications Document (OMRSD), vol. 71, File III, Orbiter OMRSD Navigation and Air Data Sensors.

Table 2.15-I HAINS IMU Preflight Calibration C-Criteria

PARAMETER	PASS	Retest Required	Unit Failed	ONE σ Short Term	ONE σ Long Term
KIX X ACC SF LO μ G/G	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	± 25 PPM	± 60 PPM
KIY Y ACC SF LO μ G/G	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	± 25 PPM	± 60 PPM
KIZ Z ACC SF LO μ G/G	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	± 25 PPM	± 60 PPM
KOX X ACC BIAS LO μ G	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	± 50 μ G	± 50 μ G
KOY Y ACC BIAS LO μ G	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	± 50 μ G	± 50 μ G
KOZ Z ACC BIAS LO μ G	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	± 50 μ G	± 50 μ G
KIXH X ACC SF HI μ G/G	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	± 25 PPM	± 60 PPM
KIYH Y ACC SF HI μ G/G	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	± 25 PPM	± 60 PPM
KIZH Z ACC SF HI μ G/G	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	± 25 PPM	± 60 PPM
KOXH X ACC BIAS HI μ G	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	± 50 μ G	± 50 μ G
KOYH Y ACC BIAS HI μ G	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	± 50 μ G	± 50 μ G
KOZH Z ACC BIAS HI μ G	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	± 50 μ G	± 50 μ G
DFX X GYRO BIAS $^{\circ}$ /hr	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	$\pm .006$ $^{\circ}$ /hr	$\pm .006$ $^{\circ}$ /hr
DFY Y GYRO BIAS $^{\circ}$ /hr	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	$\pm .006$ $^{\circ}$ /hr	$\pm .006$ $^{\circ}$ /hr
DFZ Z GYRO BIAS $^{\circ}$ /hr	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	$\pm .006$ $^{\circ}$ /hr	$\pm .006$ $^{\circ}$ /hr
DSX X GY SPN AX MU $^{\circ}$ /hr/g	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	$\pm .015$ $^{\circ}$ /hr/g	$\pm .015$ $^{\circ}$ /hr/g
DSZ Z GY SPN AX MU $^{\circ}$ /hr/g	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	$\pm .015$ $^{\circ}$ /hr/g	$\pm .015$ $^{\circ}$ /hr/g
DOZ Z GY OUT AX MU $^{\circ}$ /hr/g	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	$\pm .015$ $^{\circ}$ /hr/g	$\pm .015$ $^{\circ}$ /hr/g
DFR RED GYRO BIAS $^{\circ}$ /hr	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	$\pm .05$ $^{\circ}$ /hr	$\pm .05$ $^{\circ}$ /hr
DIR R GY IN AX MU $^{\circ}$ /hr/g	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	$\pm .05$ $^{\circ}$ /hr/g	$\pm .05$ $^{\circ}$ /hr/g
DOR R GY OUT AX MU $^{\circ}$ /hr/g	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	$\pm .05$ $^{\circ}$ /hr/g	$\pm .05$ $^{\circ}$ /hr/g
DSR R GY SPN AX MU $^{\circ}$ /hr/g	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	$\pm .05$ $^{\circ}$ /hr/g	$\pm .05$ $^{\circ}$ /hr/g
DDFR RGM DELTA RES $^{\circ}$ /hr	$\leq 2\sigma$	$2\sigma < x \leq 3\sigma$	$> 3\sigma$	$\pm .05$ $^{\circ}$ /hr	$\pm .05$ $^{\circ}$ /hr

TITLE

MM 101 IMU MISALIGNMENT CORRECTION UPLINK

PURPOSE

To define the procedures for accomplishing the correction of IMU misalignment via uplinks of the onboard gyro bias compensations in Major Mode 101.

GENERAL

WARNING: This procedure is governed by FCOH SOP 3.1, COMMAND POLICY FOR MOD, and cannot be modified without prior approval of the FOIG or the Flight Director (during real time mission operations). Safety critical steps are marked by a box.

Restrictions:

OI LOAD: All

OPS Mode: PASS OPS 101

Major Function: GNC

Vehicles: All

Crew/MCC Coordination: Information only.

Time Constraints: The second load must be uplinked 60 seconds after the first uplink.

Hazardous: The sequence and timing of uplinks is critical to the success of this procedure. The IMU misalignment correction could be unsuccessful if the first uplink is on board for more than 60+/- 5 sec.

Require Safing: No

PROCEDURE

The IMU preflight calibration calculated the initial gyro bias compensations. These values are available on the downlist during OPS 9 only. Once the preflight calibration is complete, the Sensors officer will build and store these initial gyro bias compensations in the Command Server per GNC Console Handbook Standard Console Procedure (SCP) 2.4, IMU Drift Calculation. This will be stored as DSM 43101.

The prelaunch alignment performance analysis subsystem (PAPAS) of the inertial reference alignment monitoring system (IRAMS) has the capability to determine IMU misalignment. From these data, the PAPAS can calculate gyro bias compensation values which will, if uplinked to the GPC's, torque out the measured misalignment of the IMU's. This procedure makes use of the torquing commands already generated by the GPC's to return the IMU's to a near-zero misalignment. The onboard compensation commands are modified via ground uplink for a period of 1 minute before the initial calibration compensations are restored. This process is called IMU misalignment correction.

Following the OPS 9 to OPS 1 transition, the MOIR/IMU console will monitor the PAPAS to determine if an IMU will violate a launch redline prior to the currently planned liftoff. If a redline

violation is predicted to occur prior to the currently planned liftoff, MOIR/IMU will contact the GNC officer on the GNC COORD loop to coordinate the IMU misalignment correction procedure.

If the misalignment correction must be performed, GNC will notify the FD that a misalignment correction is required. Per OMI S0007, the FD will notify the NASA Test Director (NTD) at KSC that the correction is required and the uplink is ready to be performed. Once NTD approves the correction, the FD will give permission to INCO and GNC to uplink the correction.

MOIR/IMU will verbally transmit the compensation values generated by the PAPAS program to the GNC and Sensors officers over the GNC COORD loop. If all IMU's are to be corrected, the values will be read in the following order: IMU 1 X-axis, IMU 1 Y-axis, IMU 1 Z-axis, IMU 2 X-axis, IMU 2 Y-axis, IMU 2 Z-axis, IMU 3 X-axis, IMU 3 Y-axis, IMU 3 Z-axis. If only one or two IMU's are to be corrected, the values will be read in the order of X-axis, Y-axis, Z-axis for those IMU's only.

The Sensors officer will build the gyro bias compensation load and store it in the Command Server. This load will be built as DSM 43102.

A. VERIFICATION OF COMMAND SERVER LOAD

1. GNC, Sensors, and MOIR/IMU will verify that the correct compensation values are loaded in the Command Server by viewing the IMU GYRO command display. The MOIR/IMU console is required to give a "Go for uplink" call to the GNC officer on the GNC COORD loop to ensure that the proper values were passed to the MCC.

B. NOTIFICATION AND APPROVAL

1. Once verification is complete, the GNC FCR will receive Flight Director approval to perform the uplink and will advise INCO of the requested uplink with confirmation of Flight Director approval, the GPC major function destination, and DSM number of the commands. Due to time and sequence criticality of the command, a flight note describing the required sequence will be provided to the INCO officer and Flight Director if time permits. The Flight Director will direct INCO to proceed with the uplink sequence described below in Step 2. The GNC FCR will monitor the loop until all command actions are completed. The GNC FCR will monitor command tracking displays to verify that the correct commands have been executed.

2. INCO will uplink the DSM 43102 to the two-stage buffer per FCOH SOP 3.2.3. Once onboard, INCO will command a buffer execute and note the time of the execute. INCO will notify GNC on the MOCR GNC/PROP loop that the DSM 43102 is onboard. INCO will then uplink DSM 43101 to the two-stage buffer. One minute following the buffer execute for DSM 43102, INCO will command a buffer execute for DSM 43101 and announce on the MOCR GNC/PROP loop that DSM 43101 is onboard. The total time DSM 43102 is onboard should not exceed 60 ± 5 seconds.

NOTE: Redundant rate fail BITE's may be annunciated during the time that the correction is in progress. These BITE's should cease to be issued following the uplink of the initial gyro bias compensations (DSM 43101).

C. VERIFICATON OF UPLINK ONBOARD

1. The GNC officer will notify the FD that the misalignment correction procedure is complete and that the initial IMU misalignment looks either good or bad.
2. The GNC and Sensors officers will verify through the IMU GYRO DELTA and RSS computations on the IMU SUMMARY Display that the relative misalignment between the IMU's has been reduced. They shall also verify that all IMU parameters are within nominal LCC limits. The MOIR/IMU console will evaluate the effects of the misalignment correction and notify the GNC on the GNC COORD loop that the correction was either successful, marginal, or unsuccessful. GNC and MOIR/IMU will then coordinate to determine if the IMU's are currently go for launch or if further action is required.

D. TRACKING OF LOAD

1. The GNC officer will notify the FD of the effects of the misalignment correction and the current IMU health. If further action is required, it will be coordinated at this time.
2. If the misalignment correction was successful, the FD will notify the NTD that the IMU misalignment correction and performance verification are complete per OMI S0007.
3. When no further misalignment corrections are required, the Sensors officer will delete DSM 43102 from the Command Server to preclude the inadvertent transmission of this load.

REFERENCES

This SCP was formerly documented in JSC-12805, FINAL, REV E, PCN-3 dated July 29, 1994 as FCOH SOP 3.2.7 "MM 101 IMU MISALIGNMENT CORRECTION".

TITLE

MASS MEMORY UNIT STORAGE OF IMU CALIBRATION TERMS

PURPOSE

This SCP lists all IMU calibration parameters that are stored on the mass memory units (MMU's). Additionally, the values are given for all of these parameters as they apply to the IMU math model in the SMS.

BACKGROUND

After preflight calibration of the IMU's in OPS 9, the cal term values are written to the mass memory units in the event of a cold start or initial program load (IPL) of the GPC's. Cal terms are read from a MMU in OPS 2, 3, or 9 by executing item 19 on GNC SPEC 21. When this option is executed, all data stored in block 51530 are read from the selected MMU and loaded into a buffer in GPC memory. Then, data are transferred into the major function base for only those IMU's that have been selected (items 10, 11, 12). Two software modules provide insight into what is stored on the MMU's. These modules are GX4DIS and CGMMRW. For those interested, 512 halfwords are stored in block 51530 of the SDL Mass Memory Patch Program as shown in figure 2.17-1 (consult DPS/DF2 for more information about this software). The first 510 halfwords are the values for the parameters listed in table 2.17-I. The last two halfwords are used as filler and checksum values.

Whenever an IPL or cold start (recovery of the GNC major function base from the MMU's) is performed, such action causes flight software to be read into the selected GPC's and destroys the current major function base. The flight software contains general values of the calibration terms. It is necessary to update these with the values determined in the preflight cal and stored on the MMU's (reference FRP-1 of the Malfunction Procedures book). Changes to any of the cal terms (e.g., gyro or accelerometer bias compensations), made via ground uplink must be re-uplinked. (The MMU read option has only been exercised once in flight; it was done mistakenly on STS-5. The recovery was to re-uplink the current gyro and accelerometer bias loads.)

Table 2.17-I lists the English, HAL, and FSSR names of the IMU terms stored in block 51530 of each MMU. In addition to cal data, several vehicle specific transformation matrices are stored in this block. The terms are listed in table 2.17-I in the order that they are read off mass memory. Each calibration parameter is structured as a 3 by 3 matrix array where rows one to three correspond to IMU's one to three. The number of columns is dependent upon each cal parameter. Several parameters only have one term for each IMU, hence the data is stored in a 3 by 1 array. Other parameters have as many as five and six terms per IMU. Most parameters, though, require a 3 by 3 format because they describe terms for each axis of each IMU. The 'FSSR Name' column of table 2.17-I provides insight into what terms are represented by each column of a particular matrix.

The SMS uses a math model to simulate the IMU. The calibration values for each SMS IMU are unique just as are those for the real IMU's. The SMS values for all calibration parameters are listed in table 2.17-III. Both hex and decimal representations are shown.

The remainder of this SCP contains IMU calibration term/MMU information taken from the Computer Program Development Specification, vol. V, book 5, pages 4-174 to 4-181. This book is part of the level B Vehicle Utility (VU) Checkout Software requirements.

An MM WRITE ITEM EXEC shall cause selected, predefined, IMU calibration data to be written from their locations in main memory to a nonflight program area on MM. An MM READ ITEM EXEC shall cause the predefined calibration parameter to be read from MM, and shall overlay the locations in main memory with the values retrieved from MM. All checkpoint data will be initialized to math model IMU's for the initial MM build. The GPC main memory shall be initialized to factory calibration data.

The checkpoint area on MM shall include all IMU calibration parameters. See table 2.17-II for MM area format. The checkpoint area supports access by the Backup Flight System (BFS) and has been laid out to include all calibration terms. It also allows the user to use math model IMU's or real IMU's by use of the checkpoint feature.

REFERENCE

Computer Program Development Specification (CPDS), vol. V, book 5, pp. 4-174 to 4-181.

TABLE 2.17-I. - IMU CAL PARAMETERS ON MASS MEMORY

English name	Size	HAL name	FSSR name
LOW GAIN ACCEL SCALE FACTOR	(3x3)	CGMS_ACC_SFLO	KIX, KIY, KIZ
LOW GAIN ACCEL BIAS	(3x3)	CGMS_ACC_BILO	KOX, KOY, KOZ
HI GAIN ACCEL SCALE FACTOR	(3x3)	CGMS_ACC_SFHI	KIXH, KIYH, KIZH
HI GAIN ACCEL BIAS	(3x3)	CGMS_ACC_BIHI	KOXH, KOYH, KOZH
GYRO TORQUER SCALE FACTOR	(3x3)	CGMS_TORSCFA	KTX, KTY, KTZ
GYRO RESTRAINT	(3x3)	CGMS_GYREST	DFX, DFY, DFZ
ACCEL SYMMETRY FACTOR	(3x3)	CGMS_ACC_SYMLO	KSX, KSY, KSZ
PITCH, AZ, IR RESOLVER OFFSET		CGMS_RESOFFSET	RO, PO, AZO, IRO
*REL MISALIGNMENT ERRORS	(3x3)	CGMS_MB	M12BX(Y,Z), M13BX(Y,Z), M23BX(Y,Z)
RED, GYRO INPUT, OUTPUT, SPIN AXIS, MASS UNBALANCE	(3x3)	CGMS_RED_DIOSR	DIR, DOR, DSR
RED. GYRO SCALE FACTOR	(3x3)	CGMS_RED_KXYZR	KXR, KYR, KZR
ACCEL MISALIGNMENT	(3x5)	CGMS_ACC_MISAL	DELTXZ, DELTYX, DELTYZ, DELTZX, DELTZY
GYRO MISALIGNMENT	(3x6)	CGMS_GYMSALG	BXY, BXZ, BYX, BYZ, BZX, BZY
GYRO SPIN AXIS MASS UNBALANCE	(3x2)	CGMS_GYMSPIN	DSX, DSZ
GYRO IN AXIS MASS UNBALANCE	(3x2)	CGMS_GYMIN	DIX, DIZ
GYRO OUT AXIS MASS UNBALANCE	(3x1)	CGMS_GYMOUT	DOZ
ROLL/PITCH NONORTHOGONALITY	(3x1)	CGMS_RGDP	DP
RED. GYRO RESTRAINT	(3x1)	CGMS_RED_DFR	DFR
ACCEL SCALE FACTOR SENSITIVITY -1	(3x3)	CGMS_KAL	KAX, KAY, KAZ
ACCEL SCALE FACTOR SENSITIVITY -2	(3x3)	CGMS_KBL	KBX, KBY, KBZ
HI GAIN ACCEL SF SENSITIVITY -1	(3x3)	CGMS_KAH	KAXH, KAYH, KAZH
HI GAIN ACCEL SF SENSITIVITY -2	(3x3)	CGMS_KBH	KBXH, KBYH, KBZH
NAV BASE TO ROLL MATRICES	(3 3x3)	CGMS_INBRL	
NAV BASE TO CASE MATRICES	(3 3x3)	CGMS_TNBCASE	
NAV BASE TO BODY MATRIX	(3x3)	CGMS_TNBBODY	

TABLE 2.17-II. - IMU CHECKOUT MM AREA FORMAT

MM Location SEE MIP. The format is floating point variable, length is 16 bit half words. (Single precision.)		
<u>HALFWORD</u>	<u>MSID - FSSR</u>	<u>UNITS</u>
1-6	V99A2520CC - KIX (1) V99A2523CC - KIY (1) V99A2526CC - KIZ (1)	MG/G
7-12	V99A2521CC - KIX (2) V99A2524CC - KIY (2) V99A2527CC - KIZ (2)	MG/G
13-18	V99A2522CC - KIX (3) V99A2525CC - KIY (3) V99A2528CC - KIZ (3)	MG/G
19-24	V99G2530CD - KOX (1) V99G2533CD - KOY (1) V99G2536CD - KOZ (1)	MG
25-30	V99G2531CD - KOX (2) V99G2534CD - KOY (2) V99G2537CD - KOZ (2)	MG
31-36	V99G2532CD - KOX (3) V99G2535CD - KOY (3) V99G2538CD - KOZ (3)	MG
37-42	V99G2681CC - KIXH (1) V99G2684CC - KIYH (1) V99G2687CC - KIZH (1)	MG/G
43-48	V99G2682CC - KIXH (2) V99G2685CC - KIYH (2) V99G2688CC - KIZH (2)	MG/G
49-54	V99G2683CC - KIXH (3) V99G2686CC - KIYH (3) V99G2689CC - KIZH (3)	MG/G
55-60	V99G2670CC - KOXH (1) V99G2673CC - KOYH (1) V99G2676CC - KOZH (1)	MG
61-66	V99G2671CC - KOXH (2) V99G2674CC - KOYH (2) V99G2677CC - KOZH (2)	MG
67-72	V99G2672CC - KOXH (3) V99G2675CC - KOYH (3) V99G2678CC - KOZH (3)	MG
73-78	V99G2500CC - KTX (1) V99G2503CC - KTY (1) V99G2506CC - KTZ (1)	DEG/HR/DEG/HR

TABLE 2.17-II. - CONTINUED

MM Location SEE MIP. The format is floating point variable, length is 16 bit half words. (Single precision.)		
<u>HALFWORD</u>	<u>MSID - FSSR</u>	<u>UNITS</u>
79-84	V99G2501CC - KTX (2) V99G2504CC - KTY (2) V99G2507CC - KTZ (2)	DEG/HR/DEG/HR
85-90	V99G2502CC - KTX (3) V99G2505CC - KTX (3) V99G2508CC - KTX (3)	DEG/HR/DEG/HR
91-96	V99R2560CD - DFX (1) V99R2563CD - DFY (1) V99R2566CD - DFZ (1)	RAD/SEC*
97-102	V99R2561CD - DFX (2) V99R2564CD - DFY (2) V99R2567CD - DFZ (2)	RAD/SEC*
103-108	V99R2562CD - DFX (3) V99R2565CD - DFY (3) V99R2568CD - DFZ (3)	RAD/SEC*
109-114	V99A2510CC - KSX (1) V99A2513CC - KSY (1) V99A2526CC - KSZ (1)	MG/G
115-120	V99A2511CC - KSX (2) V99A2514CC - KSY (2) V99A2517CC - KSZ (2)	MG/G
121-126	V99A2512CC - KSX (3) V99A2515CC - KSY (3) V99A2518CC - KSZ (3)	MG/G
127-134	V90H7650C - RO (1) V99H2620CC - PO (1) V99H2610CC - AZO (1) V99H2615CC - IRO (1)	RAD
135-142	V90H7651C - RO (2) V99H2621CC - PO (2) V99H2611CC - AZO (2) V99H2616CC - IRO (2)	RAD
143-150	V90H7652C - RO (3) V99H2622CC - PO (3) V99H2612CC - AZO (3) V99H2617CC - IRO (3)	RAD
151-156	V99U3551C - M12B_N V99U3552C - M12B_W V99U3553C - M12B_U	RAD
157-162	V99U3554C - M13B_N V99U3555C - M13B_W V99U3556C - M13B_U	RAD

* - Flight software uses rad/sec; MCC uses deg/hr.

TABLE 2.17-II. - CONTINUED

<u>HALFWORD</u>	<u>MSID - FSSR</u>	<u>UNITS</u>
163-168	V99U3557C - M23B_N V99U3558C - M23B_W V99U3559C - M23B_U	RAD
169-174	V99U5955C - DIR (1) V99U5958C - DOR (1) V99U5961C - DSR (1)	RAD/SEC/G
175-180	V99U5956C - DIR (2) V99U5959C - DOR (2) V99U5962C - DSR (2)	RAD/SEC/G
181-186	V99U5957C - DIR (3) V99U5960C - DOR (3) V99U5963C - DSR (3)	RAD/SEC/G
187-192	V99U5964C - KXR (1) V99U5967C - KYR (1) V99U5970C - KZR (1)	DEG/HR/DEG/HR
193-198	V99U5965C - KXR (2) V99U5968C - KYR (2) V99U5971C - KZR (2)	DEG/HR/DEG/HR
199-204	V99U5966C - KXR (3) V99U5969C - KYR (3) V99U5972C - KZR (3)	DEG/HR/DEG/HR
205-214	V99H2552CC - DELTXZ (1) V99H2540CC - DELTYX (1) V99H2549CC - DELTYZ (1) V99H2543CC - DELTZX (1) V99H2546CC - DELTZY (1)	RAD
215-224	V99H2553CC - DELTXZ (2) V99H2541CC - DELTYX (2) V99H2550CC - DELTYZ (2) V99H2544CC - DELTZX (2) V99H2547CC - DELTZY (2)	RAD
225-234	V99H2554CC - DELTXZ (3) V99H2542CC - DELTYX (3) V99H2551CC - DELTYZ (3) V99H2545CC - DELTZX (3) V99H2548CC - DELTZY (3)	RAD
235-246	V99H2590CC - BXY (1) V99H2593CC - BXZ (1) V99H2596CC - BYX (1) V99H2599CC - BYZ (1) V99H2602CC - BZX (1) V99H2605CC - BZY (1)	RAD
247-258	V99H2591CC - BXY (2) V99H2594CC - BXZ (2) V99H2597CC - BYX (2) V99H2600CC - BYZ (2) V99H2603CC - BZX (2) V99H2606CC - BZY (2)	RAD

TABLE 2.17-II. - CONTINUED

<u>HALFWORD</u>	<u>MSID - FSSR</u>	<u>UNITS</u>
259-270	V99H2592CC - BXY (3) V99H2595CC - BXZ (3) V99H2598CC - BYX (3) V99H2601CC - BYZ (3) V99H2604CC - BZX (3) V99H2607CC - BZY (3)	RAD
271-274	V99U2576CC - DSX (1) V99U2579CC - DSZ (1)	RAD/SEC/G
275-278	V99U2577CC - DSX (2) V99U2580CC - DSZ (2)	RAD/SEC/G
279-282	V99U2578CC - DSX (3) V99U2581CC - DSZ (3)	RAD/SEC/G
283-286	V99U2570CC - DIX (1) V99U2573CC - DIZ (1)	RAD/SEC/G
287-290	V99U2571CC - DIX (2) V99U2574CC - DIZ (2)	RAD/SEC/G
291-294	V99U2572CC - DIX (3) V99U2575CC - DIZ (3)	RAD/SEC/G
295-300	V99U2582CC - DOZ (1) V99U2583CC - DOZ (2) V99U2584CC - DOZ (3)	RAD/SEC/G
301-306	V99H2660CC - DP (1) V99H2661CC - DP (2) V99H2662CC - DP (3)	RAD
307-312	V99U5952C - DFR (1) V99U5953C - DFR (2) V99U5954C - DFR (3)	RAD/SEC
313-330	V99U5978C - KAX (1) V99U5981C - KAY (1) V99U5984C - KAZ (1) V99U5979C - KAX (2) V99U5982C - KAY (2) V99U5985C - KAZ (2) V99U5980C - KAX (3) V99U5983C - KAY (3) V99U5986C - KAZ (3)	MG/G

TABLE 2.17-II. - CONTINUED

<u>HALFWORD</u>	<u>MSID - FSSR</u>	<u>UNITS</u>
331-348	V99U5987C - KBX (1) V99U5990C - KBY (1) V99U5993C - KBZ (1) V99U5988C - KBX (2) V99U5991C - KBY (2) V99U5994C - KBZ (2) V99U5989C - KBX (3) V99U5992C - KBY (3) V99U5995C - KBZ (3)	MG/G
349-384	V98U7927C - KAXH (1) V98U7930C - KAYH (1) V98U7933C - KAZH (1) V98U7928C - KAXH (2) V98U7931C - KAYH (2) V98U7934C - KAZH (2) V98U7929C - KAXH (3) V98U7932C - KAYH (3) V98U7935C - KAZH (3) V98U7936C - KBXH (1) V98U7939C - KBYH (1) V98U7942C - KBZH (1) V98U7937C - KBXH (2) V98U7940C - KBYH (2) V98U7943C - KBZH (2) V98U7938C - KBXH (3) V98U7941C - KBYH (3) V98U7944C - KBZH (3)	MG/G
385-438	V96U7105C - TNB_RL1 (1,1) V96U7108C - TNB_RL1 (1,2) V96U7111C - TNB_RL1 (1,3) V96U7114C - TNB_RL1 (2,1) V96U7117C - TNB_RL1 (2,2) V96U7120C - TNB_RL1 (2,3) V96U7123C - TNB_RL1 (3,1) V96U7126C - TNB_RL1 (3,2) V96U7129C - TNB_RL1 (3,3) V96U7106C - TNB_RL2 (1,1) V96U7109C - TNB_RL2 (1,2) V96U7112C - TNB_RL2 (1,3) V96U7115C - TNB_RL2 (2,1) V96U7118C - TNB_RL2 (2,2) V96U7121C - TNB_RL2 (2,3) V96U7124C - TNB_RL2 (3,1) V96U7127C - TNB_RL2 (3,2) V96U7130C - TNB_RL2 (3,3)	ND

TABLE 2.17-II. - CONTINUED

<u>HALFWORD</u>	<u>MSID - FSSR</u>	<u>UNITS</u>
385-438 (Cont)	V96U7107C - TNB_RL3 (1,1) V96U7110C - TNB_RL3 (1,2) V96U7113C - TNB_RL3 (1,3) V96U7116C - TNB_RL3 (2,1) V96U7119C - TNB_RL3 (2,2) V96U7122C - TNB_RL3 (2,3) V96U7125C - TNB_RL3 (3,1) V96U7128C - TNB_RL3 (3,2) V96U7131C - TNB_RL3 (3,3)	ND
439-492	V96U7132C - TNB_CASE 1 (1,1) V96U7135C - TNB_CASE 1 (1,2) V96U7138C - TNB_CASE 1 (1,3) V96U7141C - TNB_CASE 1 (2,1) V96U7144C - TNB_CASE 1 (2,2) V96U7147C - TNB_CASE 1 (2,3) V96U7150C - TNB_CASE 1 (3,1) V96U7153C - TNB_CASE 1 (3,2) V96U7156C - TNB_CASE 1 (3,3) V96U7133C - TNB_CASE 2 (1,1) V96U7136C - TNB_CASE 2 (1,2) V96U7139C - TNB_CASE 2 (1,3) V96U7142C - TNB_CASE 2 (2,1) V96U7145C - TNB_CASE 2 (2,2) V96U7148C - TNB_CASE 2 (2,3) V96U7151C - TNB_CASE 2 (3,1) V96U7154C - TNB_CASE 2 (3,2) V96U7157C - TNB_CASE 2 (3,3) V96U7134C - TNB_CASE 3 (1,1) V96U7137C - TNB_CASE 3 (1,2) V96U7140C - TNB_CASE 3 (1,3) V96U7143C - TNB_CASE 3 (2,1) V96U7146C - TNB_CASE 3 (2,2) V96U7149C - TNB_CASE 3 (2,3) V96U7152C - TNB_CASE 3 (3,1) V96U7155C - TNB_CASE 3 (3,2) V96U7158C - TNB_CASE 3 (3,3)	ND
493-510	V96U7096C - TNBBODY (1,1) V96U7097C - TNBBODY (1,2) V96U7098C - TNBBODY (1,3) V96U7099C - TNBBODY (2,1) V96U7100C - TNBBODY (2,2) V96U7101C - TNBBODY (2,3) V96U7102C - TNBBODY (3,1) V96U7103C - TNBBODY (3,2) V96U7104C - TNBBODY (3,3)	ND
511-512	CHECKSUM (REFERENCE SS-P-0002-150D par. 4.5)	

TABLE 2.17-III.- CAL VALUES FOR THE SMS MATH MODELED IMU'S

LOW GAIN ACCEL SCALE FACTOR (KIX, KIY, KIZ)*					
44B3,4200	C4A5,7800	44D4,D000	45890	-42360	54480
C48B,C400	C485,CA00	C4BC,7000	-35780	-34250	-48240
449B,0000	4475,8000	C4E2,E000	39680	30080	-58080

LOW GAIN ACCEL BIAS (KOX, KOY, KOZ)					
C27C,0000	C225,0000	428D,0000	-124	-37	141
C22F,0000	C250,0000	4274,0000	-47	-80	116
423F,0000	C264,0000	421D,0000	63	-100	29

HIGH GAIN ACCEL SCALE FACTOR (KIXH, KIYH, KIZH)					
44B3,4200	C4A5,7800	44D4,D000	45890	-42360	54480
C48B,C400	C485,CA00	C4BC,7000	-35780	-34250	-48240
449B,0000	4475,8000	C4E2,E000	39680	30080	-58080

HIGH GAIN ACCEL BIAS (KOXH, KOYH, KOZH)					
4447,6800	C441,9500	4492,4400	18280	-16789	37444
C445,B200	C434,4000	C47F,9A00	-17842	-13376	-32666
4437,FC00	4431,7A00	C49A,7900	14332	12666	-39545

GYRO TORQUER SCALE FACTOR (KTX, KTY, KTZ)					
4110,0000	4110,0000	4110,0000	1.0	1.0	1.0
4110,0000	4110,0000	4110,0000	1.0	1.0	1.0
4110,0000	4110,0000	4110,0000	1.0	1.0	1.0

TABLE 2.17-III.- CONTINUED

GYRO RESTRAINT (DRIFT COMPENSATION; DFX, DFY, DFZ)		
3AA6,94AA	3AD0,39D4	BB20,8909
BAF9,DEFE	3ABB,673F	BB1B,5464
3B18,BA11	BABB,673F	3A68,1CEA
$3.878509449 \times 10^{-8}$	$4.848136811 \times 10^{-8}$	$-1.212034203 \times 10^{-7}$
$-5.817764173 \times 10^{-8}$	$4.363323130 \times 10^{-8}$	$-1.018108730 \times 10^{-7}$
$9.211459941 \times 10^{-8}$	$-4.363323130 \times 10^{-8}$	$2.424068406 \times 10^{-8}$

ACCEL SYMMETRY FACTOR (KSX, KSY, KSZ)					
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0

OUTER ROLL, PITCH, AZ, IR RESOLVER OFFSET (RO, PO, AZO, IRO)							
0000,0000	0000,0000	0000,0000	0000,0000	0.0	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0000,0000	0.0	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0000,0000	0.0	0.0	0.0	0.0

RELATIVE MISALIGNMENT ERRORS (M12BX(Y,Z), M13BX(Y,Z), M23BX(Y,Z))					
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0

REDUNDANT GYRO INPUT, OUTPUT SPIN AXIS MASS UNBALANCE (DIR, DOR, DSR)					
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0

REDUNDANT GYRO SCALE FACTOR (KXR, KYR, KZR)					
40FA,67E2	4035,39B3	0000,0000	0.9781476	0.20791169	0.0
40FA,67E2	4035,39B3	0000,0000	0.9781476	0.20791169	0.0
40FA,67E2	4035,39B3	0000,0000	0.9781476	0.20791169	0.0

TABLE 2.17-III.- CONTINUED

ACCEL MISALIGNMENT (DELTAXZ, DELTAYX, DELTAYZ, DELTAZX, DELTAZY)				
0000,0000	0000,0000	0000,0000	0000,0000	0000,0000
0000,0000	0000,0000	0000,0000	0000,0000	0000,0000
0000,0000	0000,0000	0000,0000	0000,0000	0000,0000
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

GYRO MISALIGNMENT (BXY, BXZ, BYX, BYZ, BZX, BZY)					
0000,0000	0000,0000	0000,0000	0000,0000	0000,0000	0000,0000
0000,0000	0000,0000	0000,0000	0000,0000	0000,0000	0000,0000
0000,0000	0000,0000	0000,0000	0000,0000	0000,0000	0000,0000
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0

GYRO SPIN AXIS MASS UNBALANCE (DSX, DSZ)			
0000,0000	0000,0000	0.0	0.0
0000,0000	0000,0000	0.0	0.0
0000,0000	0000,0000	0.0	0.0

GYRO IN AXIS MASS UNBALANCE (DIX, DIZ)			
0000,0000	0000,0000	0.0	0.0
0000,0000	0000,0000	0.0	0.0
0000,0000	0000,0000	0.0	0.0

GYRO OUT AXIS MASS UNBALANCE (DOZ)	
0000	0.0
0000	0.0
0000	0.0

TABLE 2.17-III.- CONTINUED

ROLL/PITCH NONORTHOGONALITY (DP)	
0000	0.0
0000	0.0
0000	0.0

REDUNDANT GYRO RESTRAINT (DFR)	
0000	0.0
0000	0.0
0000	0.0

ACCEL SCALE FACTOR SENSITIVITY -1 (KAX, KAY, KAZ)					
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0

ACCEL SCALE FACTOR SENSITIVITY -2 (KBX, KBY, KBZ)					
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0

HIGH GAIN ACCEL SCALE FACTOR SENSITIVITY -1 (KAXH, KAYH, KAZH)					
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0

HIGH GAIN ACCEL SCALE FACTOR SENSITIVITY -2 (KBXH, KBYH, KBZH)					
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0
0000,0000	0000,0000	0000,0000	0.0	0.0	0.0

TABLE 2.17-III.- CONTINUED

NAV BASE TO ROLL MATRICES (TNB_RL1 (1,1) - TNB_RL1 (3,3))						
IMU1	4110,0000	0000,0000	0000,0000	1.0	0.0	0.0
	0000,0000	4110,0000	0000,0000	0.0	1.0	0.0
	0000,0000	0000,0000	4110,0000	0.0	0.0	1.0
(TNB_RL2 (1,1) - TNB_RL2 (3,3))						
IMU2	4110,0000	0000,0000	0000,0000	1.0	0.0	0.0
	0000,0000	4110,0000	0000,0000	0.0	1.0	0.0
	0000,0000	0000,0000	4110,0000	0.0	0.0	1.0
(TNB_RL3 (1,1) - TNB_RL3 (3,3))						
IMU3	4110,0000	0000,0000	4110,0000	1.0	0.0	0.0
	0000,0000	4110,0000	0000,0000	0.0	1.0	0.0
	0000,0000	0000,0000	4110,0000	0.0	0.0	1.0

NAV BASE TO CASE MATRICES (TNB_CASE 1 (1,1) - TNB_CASE 1 (3,3))						
IMU1	4110,0000	0000,0000	0000,0000	1.0	0.0	0.0
	0000,0000	4110,0000	0000,0000	0.0	1.0	0.0
	0000,0000	0000,0000	4110,0000	0.0	0.0	1.0
(TNB_CASE 2 (1,1) - TNB_CASE 2 (3,3))						
IMU2	4110,0000	0000,0000	0000,0000	1.0	0.0	0.0
	0000,0000	4110,0000	0000,0000	0.0	1.0	0.0
	0000,0000	0000,0000	4110,0000	0.0	0.0	1.0
(TNB_CASE 2 (1,1) - TNB_CASE 2 (3,3))						
IMU3	4110,0000	0000,0000	4110,0000	1.0	0.0	0.0
	0000,0000	4110,0000	0000,0000	0.0	1.0	0.0
	0000,0000	0000,0000	4110,0000	0.0	0.0	1.0

NAV BASE TO BODY MATRIX (TNBBODY (1,1) - TNBBODY (3,3))						
40FB,AIA7	0000,0000	C02F,1770		0.98293535	0.0	-0.18395135
	0000,0000	4110,0000	0000,0000	0.0	1.0	0.0
	402F,1770	0000,0000	40FB,AIA7	0.18395135	0.0	0.98293535

TITLE

RECOVERY OF IMU ATT REFERENCE IN THE PASS AFTER A BFS ENGAGE

INTRODUCTION

IMPORTANT: Allow yourself enough time to read and review this SCP before the crew enters MAL GPC FRP-4. Preparation steps are required. It can take up to 30 minutes to review this SCP if you are not familiar with the procedure. Reviewing this procedure before the MAL is started is not required; however, it will make the procedure run much smoother and allow a faster execution.

The DPS Malfunction Procedure, PASS Recovery After BFS Engage, GPC FRP-4 is run on-orbit to recover the PASS software after a BFS engage. The IMU attitude reference recovery portion of DPS GPC FRP-4 is located in step 10 of the malfunction procedure. There are three methods to recover IMU attitude reference in the PASS after a BFS engage has been performed. If there is good communication with the crew (not including the zone of exclusion) and good uplink capability, IMU attitude reference is recovered with a series of IMU to IMU matrix alignments, aligning each IMU to itself individually. This is the nominal method of recovery. IMU attitude reference may also be recovered with a series of MCC uplinks and IMU to IMU torquing alignments, however, this method is complicated and was made obsolete with the addition of an IMU to IMU matrix alignment capability in the OI-32 software load. A copy of the IMU to IMU torquing alignment recovery method may be found in the GNC archives for reference (S:\Divisions\DS\Private\DS62\GNC_SCP\Archived). Otherwise, IMU attitude reference may be recovered using the heads-up display (HUD) or crew optical alignment sight (COAS) and a matrix alignment.

This SCP includes definitions, a summary, a step-by-step procedure, and an example explaining the flight controller and crew actions necessary to recover IMU attitude reference using the IMU to IMU matrix alignment method. The steps required for the HUD or COAS recovery method are also included in the step-by-step procedure. The summary provides an overview of the IMU reference recovery and the assumptions made in the FRP procedure. The summary should only be used for review and each case should be evaluated on an individual basis to ensure that the FRP procedure assumptions are valid. The step-by-step procedure should be performed by the GNC Sensors Operator or GNC Support Operator before the crew begins execution of step 10 in DPS GPC FRP-4. Rationale and technical reasoning behind each step in the recovery process is provided.

DEFINITIONS

DESIRED REFSMMAT:

An onboard software term which defines the position at which it is desired to align a platform.

CURRENT REFSMMAT:

An onboard software term which defines the position at which onboard software assumes each IMU platform is located. Normally (not always), the current REFSMMAT is equal to the desired REFSMMAT.

PRESENT REFSMMAT:

An onboard software term which defines the position of the IMU platform as determined by an external reference, either another IMU during an IMU to IMU alignment, or star vectors during a star align.

TRUE REFSMMAT:

An MCC term which defines the actual position at which each IMU platform is located.

LOSS OF ATTITUDE REFERENCE:

An MCC term which defines a significant deference between an IMU's true and current REFSMMATs (>1.4 degree star tracker limit).

SUMMARY

When performing recovery of the PASS after a BFS engage, the nominal method of IMU attitude reference recovery involves a series of IMU to IMU matrix alignments, aligning each IMU to itself individually. Before an IMU attitude reference recovery is attempted, the PASS GPCs are IPL'd and loaded with either GNC or SM software. The IPL process automatically assigns the identity matrix to all the PASS IMU REFSMMATs (desired and current). However, the platform positions remain at their original position prior to the BFS engagement. For an ascent BFS engage, the IMU platforms will remain at their prelaunch defined REFSMMAT positions, excluding any drift and misalignment imposed during the ascent phase of flight. Once the PASS GPCs are IPL'd, the onboard PASS software will assume that the platforms are located at the position represented by identity. Since the onboard current REFSMMATs incorrectly indicate IMU platform position relative to M50, the attitude reference is lost.

The objective of the recovery procedure is to supply the GPCs with a current REFSMMAT that correctly represents the platforms positions with respect to M50 coordinates without torquing the platforms from their current optimal skewed attitudes. This is accomplished by a matrix alignment of each IMU to itself, which replaces the current REFSMMAT with an uplinked desired REFSMMAT, and will regain attitude reference.

In executing the recovery process, the MCC will uplink the prelaunch IMU REFSMMATs to the desired REFSMMAT slot. Note: If the IMUs were aligned to any orientation other than the prelaunch defined REFSMMAT positions, the most recent REFSMMAT defining the IMU orientations should be uplinked to the desired slot instead. This new desired REFSMMAT will correctly define the true IMU platform positions, however, any torquing angles generated when selecting an IMU as a reference for alignment will be erroneous. IMU to IMU matrix alignment software sets the current REFSMMAT equal to the desired REFSMMAT for any IMU that is matrix aligned to itself. At the completion of the IMU matrix alignment to itself, the PASS GPCs will have accurate insight into the platform position of the IMU relative to M50. The recovery of attitude reference on the remaining IMU(s) is accomplished by matrix aligning each IMU to itself individually, thus maintaining the optimum entry skewing between all three IMUs.

ASSUMPTIONS

Caution should be taken to ensure that each assumption made in DPS FRP-4 applies for the specific case that the procedure is to be run under. The PASS RECOVERY AFTER BFS ENGAGE procedure makes the following assumptions:

- The BFS engage occurs while in OPS 1 or 3.
- TRANS DAP control is acceptable, which implies:
 - PRCS attitude control is acceptable.
 - Orbiter only mass properties.
 - No notch filters.
- IMU Operate discrettes are set to their default setting (STBY) after each PASS GPC is re-IPL'ed, which implies:
 - The IMU Operate discrettes must be manually set to OPER on SPEC 21 prior to disengaging the BFS and/or reassigning flight critical strings to the PASS GPCs (otherwise any IMU Operate discrete not set to OPER will cage once the PASS assumes control of the flight critical MDMs).
- All 3 IMUs are available, which implies:
 - No IMU failures.
 - No powerdowns (i.e. Group B PWRDN)
- IMU gyro and accel bias compensations return to their pre-flight calibration terms, which implies:
 - No knowledge of IMU gyro and accel bias compensations uplinked while on-orbit.
- All other LRU compensations return to their default settings, which implies:
 - No knowledge of RGA, AA, etc. compensations uplinked in OPS 2 or MM 301.
- Universal Pointing settings will return to their default settings once the PASS is moded to OPS 2, which implies:
 - Inertial attitude hold at current attitude when moded to OPS 2.
 - UNIV PTG TRK attitude set as follows (TG=2, BV=1, P=0, Y=0, OM=0)
 - UNIV PTG MNVR attitude set as follows (P=0, Y=0, OM=0).
- All DAPs return to their pre-flight I-loaded configuration, which implies:
 - No knowledge of DAP settings manually edited once on-orbit.
 - No knowledge of DAP uplinks performed on-orbit (i.e. notch filters & mass properties).
- All Star ID slots return to their pre-flight I-loaded configuration, which implies:
 - No knowledge of any star uplinks performed once on-orbit.
- Elevon Park is lost, if previously performed.

PROCEDURE

NOTE: It is important that the crew executes the procedures in step 10 of GPC FRP-4 as written. IMU selections, DAP configurations, notes and cautions should be monitored closely as the crew performs the procedure. In order to avoid delay and to ensure success of the reference recovery, the following parts of this SCP procedure should be performed by the GNC Sensors Operator or GNC Support Operator before the crew begins execution of step 10 "PASS IMU Attitude Reference Recovery" in DPS GPC FRP-4. Part one below has the flight controllers build REFSMMAT loads for uplink; part two contains rationale and technical reasoning behind each section in GPC FRP-4 step 10.

- 1. Build the IMU REFSMMAT load and send it to the Command Server with the REFSMMAT values that define the platform orientations. This load should be built and verified before the crew enters step 10 of GPC FRP-4 to avoid delay in the PASS recovery process.**
 - a. Choose a best IMU. This IMU will be used to hold an inertial attitude while the other IMUs are recovered in the recovery alignment, step 10n of DPS GPC FRP-4. The best

IMU must be called up to the crew and will be the only IMU to remain selected in step 10j.

- b. Choose either one of the other two IMUs as the first IMU to be recovered. This IMU is called the recovery IMU and is the IMU to be aligned in step 10n of DPS GPC FRP-4. The third IMU is the remaining IMU.
- c. Verify that the original launch REFSMMATs are stored in the Command Server as DSM 43001 and also stored in the workstation under the file name "initial" (see SCP 10.11).

If the platforms are in their prelaunch positions, DSM 43001 may be used as the uplink in step 10m of DPS GPC FRP-4.

2. Nominally DSM 43001 will be uplinked in step 10m of DPS GPC FRP-4 (DSM 43002, normalized REFSMMATs, may be substituted for DSM 43001, if available). Coordinate these uplink times with the INCO Officer and ensure uplink capability will be available. Step 10 should be executed during AOS. Communication with the crew and uplink capability are both necessary for successful procedure completion using the IMU to IMU matrix alignment method of recovery.
3. Follow the crew closely through step 10, IMU attitude reference recovery of DPS GPC FRP-4. The following steps are numbered as they are shown in GPC FRP-4 and include important actions for the GNC Flight Controller during the execution of the procedure.

DPS GPC FRP-4

10. PASS IMU attitude reference recovery:

- A. Star tracker power is checked. If the BFS was engaged on orbit then the star trackers may already be powered.
- B. The IMUs are moded to operate in the PASS. This must be performed before BFS disengagement to ensure that the IMU operate discrete will be set in the PASS. The asterisk will not appear until the BFS is disengaged. Therefore, the crew item entries must be verified.

If no comm or no uplink capability, the crew will perform the IMU attitude reference recovery using the HUD or COAS and a matrix alignment in steps C through I.

- C. Any two IMUs will be deselected in the PASS. The IMU left selected by RM will be the first to be recovered in the procedure with a matrix alignment using HUD or COAS star data.
- D. While still on the BFS with a good attitude reference, a maneuver to an inertial attitude is performed which will simplify the manual maneuver to the second star in the HUD or COAS recovery procedure.
- E. The BFS is disengaged. If communication with the crew is available, DPS will give the crew a GO for disengagement. The crew will go to INRTL DAP and will REF the ADI to aid in the HUD or COAS recovery of IMUs.

- F. A mass memory read of the IMU gyro and accel compensations is performed immediately to minimize the time that the IMUs are allowed to drift at their uncompensated rates.
- G. The IMU attitude reference is recovered using GNC SSR-2, Matrix (Torque) Align Using HUD Star Data.
- H. All IMUs are reselected after the HUD recovery procedure is complete
- I. Skip steps J through W and continue in step 11.

NOTE: A star tracker align will need to be performed to verify that the matrix align using HUD star data was a good alignment. This will be performed once comm is reestablished with the crew.

If good comm and uplink capabilities exist, then steps J through W are performed.

- J. Two IMUs are deselected in the PASS. The best IMU chosen in part 1 of this SCP should remain selected.
- K. The BFS is disengaged. Once the disengagement is performed, the IMUs will be drifting uncompensated. HAINS uncompensated drift rates are low enough that the errors accumulated will not be significant, assuming a reasonably prompt completion of DPS FRP-4. The IMU gyro and accel bias terms are not loaded into the GPCs until a mass memory read is performed in step L, therefore the crew should perform the disengagement steps and the mass memory in a timely manner.
- L. A mass memory read of the IMU gyro and accel compensations is performed.
- M. Uplink the PASS recovery REFSMMAT load determined in part 1 of this SCP.

WARNING: The verification and command steps in GNC SCP 10.11 REFLOAD USER'S GUIDE must be followed during execution of the uplink (step C. Verification of Command Server Load, step D. Notification and Approval, step E. Verification, step F. Tracking of Loads Built). Do not allow the crew to proceed until the uplink is complete.

- N. An IMU to IMU matrix alignment is performed aligning the recovery IMU, selected in step 1b of this SCP, to itself. This will establish a good attitude reference on the recovery IMU by replacing the current REFSMMAT with the desired REFSMMAT for that IMU only, without physically moving the platform. An IMU to IMU matrix alignment is an instantaneous, purely mathematical, alignment. Step N is repeated for the remaining deselected IMU, replacing that IMU's current REFSMMAT with the correct desired REFSMMAT. The IMU to IMU matrix alignments are performed one at a time restoring a good platform to M50 reference for each IMU.
- O. The DAP is configured to inertial with pulse rotation settings, which is equivalent to free drift in the trans dap and during orbit operations.
- P. All three IMUs are deselected, leaving no IMUs selected momentarily.

- Q. The two IMUs recovered in step 10n are reselected. Attitude reference is now reestablished using these IMUs. Relative misalignments between the two recovered IMUs should be small and well within the star tracker limit of 1.4 degrees.
- R. The DAP is configured to an inertial attitude hold with discrete rotation settings. This will snapshot the current orbiter attitude using the correct attitude provided by the two recovered IMUs.
- S. Step 10n is repeated, matrix aligning the best IMU to itself while it is deselected.
- T. All recovered IMUs are reselected. This will reestablish three level IMU RM with the platforms at optimal entry skew. IMU to IMU compares and torquing angles, once stars are acquired, should be small.

With acceptable results the following steps (U - W) may be delayed until a convenient time. While not expected, if IMU errors accumulated during ascent and during this procedure approach the 1.4 degree star tracker limit the alignment should be performed without delay. When considering delaying the star tracker alignment, remember that the attitude errors associated with this procedure do not appear in the IMU delta comps.

U.- W. A star tracker alignment is performed to eliminate the attitude errors accumulated during ascent and during the execution of this procedure.

EXAMPLE

The following torquing angle example is intended only to show what to expect. Actual numbers depend on REFSMMATs.

Best IMU: IMU 1
Recovery IMU: IMU 2
Remaining IMU: IMU 3

At the beginning of the IMU to IMU matrix alignment in step 10n of GPC FRP-4, IMU 2 is selected as the reference IMU and torquing angles are as follows:

	TORQUING ANGLES		
	X	Y	Z
IMU 1	+80.03	- 60.00	+6.52
IMU 2	+8.03	+94.00	+90.92
IMU 3	- 105.55	- 30.57	- 107.60

All three IMUs should have high torquing angles due to the large misalignment of the reference IMU relative to M50 (i.e. the current REFSMMAT is not equal to the true REFSMMAT). The reference IMU has large torquing angles due to the large difference between its desired and current REFSMMATs. Its current REFSMMAT is identity and its desired was set to its prelaunch REFSMMAT via uplink in step 10m of GPC FRP-4. Large torquing angles for the reference IMU can be expected anytime the IMU's current REFSMMAT is not equal to its desired REFSMMAT. Large torquing angles for the other IMUs, not selected as the reference IMU, can be expected anytime the reference IMU's current REFSMMAT is not equal to its true REFSMMAT (i.e. the reference IMU has a bad M50 representation).

When IMU 3 is selected as the reference IMU during the second IMU to IMU matrix alignment in step 10n of GPC FRP-4, the torquing angles on all IMUs will again be large due to its current REFSMMAT being different from the desired and true REFSMMAT. After IMU 3 is recovered IMU 2 to IMU 3 compares, attitude, gyro, and accel data, will be good.

At the completion of step 10t in GPC FRP-4 all of the IMU to IMU compares (attitude, gyro, and accel) should be close to zero and attitude reference should be verified via torquing angles using the star trackers.

CONTINGENCY PROCEDURE

If the alignments were unsuccessful, or IMU attitude reference is lost, a HUD or COAS recovery of IMUs can be performed.

TITLE

RECOVERY OF AN IMU WITH A TRANS WORD 1 FAIL BITE
(LOSS OF PULSE TORQUING BITE, MODE STATUS 8040)

PURPOSE

The following is an explanation of how to recover an IMU which has either a real, or a false Transmission Word 1 Fail (Loss of Pulse Torquing) BITE. The two cases are discussed separately here, because the resulting IMU performance is very different (prior to performing the procedure).

BACKGROUND

The SCP procedures should be entered at the appropriate place, depending on the failure case (real/false BITE). The procedures are in two separate parts:

- I) Real BITE
- II) False BITE

Once entering the procedure, it should be followed in a step-by-step manner, and will in some cases include the use of other FDF procedures and/or SCPs.

NOTE: For all cases, consider the merits of masking the BITE prior to entry. This decision depends on the exact case (whatever combination of conditions, real or false BITE), and the expected performance of the IMU during entry (based on the procedures that have/have not been performed).

PROCEDURES

I) REAL BITE

When a Transmission Word 1 Fail BITE is present and it is real, the IMU will not use the GPC pulse torquing commands, and will drift at the uncompensated drift rate. This will ultimately result in the IMU failing RM due to attitude misalignment.

The current Flight Rules do not require MDF for this case (ref. Rule A8-59, IMU BITE FAILURE DEFINITION, and Rule A8-1001, GNC GO/NO-GO CRITERIA). In the case of a HAINS IMU, the uncompensated drift rates are very small, and the IMU could actually remain usable (for entry purposes) for several hours or days.

It is recommended that one of the options in SCP 2.11 Recovery from Loss of IMU Gyro Pulse Torquing be implemented on entry day, in an attempt to recover the IMU for entry.

II) FALSE BITE

When a Transmission Word 1 Fail BITE is present and is false, the IMU will be "overtorqued", due to the GPC retransmitting pulses that the IMU has already received. This results in the IMU being misaligned very rapidly, and failing RM due to attitude misalignment. It can also result in the annunciation of a Redundant Rate Fail BITE, due to the high torquing rates that build up.

The following procedure should be performed to recover the IMU (OPS 2/301).

1. Manually deselect the affected IMU (SPEC 21/51).
2. Zero-out the GPC gyro pulse torquing commands to the IMU by following GNC SCP 2.4 IMU DRIFT and utilizing all zeros as the IMU gyro bias terms for the affected IMU only. This will be accomplished by building and uplinking DSM (4310X) with a 0 in each of the X, Y, and Z gyro axes of the affected IMU and the most recent gyro bias terms in the other two IMUs. When verifying a good uplink, the gyro drift bias terms for the effected IMU should be all zeros.
3. Command the IMU to standby (STBY) on SPEC 21.
4. Verify that the command word 1 (CMD WD 1, IMU SUMMARY display) has been zeroed-out. This is the purpose of taking the IMU to STBY.
5. Command the IMU to operate (OPER) on SPEC 21.
6. Verify in OPER (and deselected), and perform a GNC I/O Reset.
7. Acquire stars, and perform a matrix IMU alignment using star data, aligning the affected IMU only. The stars for the matrix alignment must be acquired after the IMU is taken to OPER and a GNC I/O Reset is performed. If stars are not readily available, a matrix alignment using IMU data may be performed (OI-32 and sub software loads) to regain attitude reference of the affected IMU.

NOTE: Both of these procedures will change the affected IMU's REFSMMAT and thus the two-level RM coverage is substantially altered for that IMU (i.e. skewing is different, so error vector projections are not as effective and thus isolation capability is degraded).

8. Verify good alignment via the workstation ground computation gyro deltas, and resolver deltas.
9. Reselect the IMU (if desired) and monitor drift rates.
10. Retrieve the new REFSMMAT from telemetry by following GNC SCP 10.12 ENTREF, and uplink to the DESIRED REFSMMAT by following GNC SCP 10.11 REFSLOAD USER'S GUIDE. This is done to provide the crew/MCC with correct torquing angles for drift monitoring.

CAUTION: DO NOT align the IMU again with anything other than a Matrix alignment. You don't want to send even one single (0.007 deg/hr) GPC pulse torquing command to the IMU, because then you'll have to work the entire procedure over again.

With the above procedure completed, the IMU will continue to drift at the uncompensated drift rate for the remaining time on-orbit. For a HAINS IMU, these rates are very low, and the IMU could be usable for several hours/days after completing the above procedure

At this point, most of the ramifications of the false BITE are behind you, and you now have the equivalent of a real TRANS WORD 1 FAIL BITE (i.e. the IMU will drift at the uncompensated rate), except that you cannot do IMU/IMU or star alignments to the IMU with the BITE for fear of sending out any pulse torquing commands.

The next step is to perform matrix alignment(s) as required/desired to keep the IMU usable while on-orbit. Then, prior to entry, perform a final matrix alignment.

11. For entry, perform a matrix alignment on the affected IMU only (OPS 2/301). Perform this alignment as close to the time of the deorbit burn as possible to reduce the amount of misalignment on the IMU at EI. For most cases it will be easiest to use the D/O verification stars for this alignment.
12. Verify the proper PASS/BFS configuration (SEL/DES) for OPS 3/entry, and consider masking the BITE.

NOTE: It is possible to do an IMU/IMU alignment in step 10 (and cancel the alignment prior to the start of pulse torquing), and then perform the Matrix alignment. The benefit of doing this is that the two-level RM coverage is retained. [Be certain that the proper DESIRED REFSMMATs are onboard prior to the IMU/IMU alignment. This will be the case if no uplinks have been performed to this point.] The way to do this would be to have the crew monitor the alignment (torquing angles), and have them execute the align cancel just before the bi-directional slew starts (misalignment within a 2 to 3 degrees). [Bi-directional slew occurs as part of the large angle torquing function (LAT), and is performed at the end of the LAT'ing (slewing), and prior to the start of pulse torquing.] This is complicated (difficult to identify when LAT'ing has ended and the slew actually begins, and the slow update rate of the displayed torquing angles (every 2 seconds) makes predictions tricky) and is not the recommended method. If you try this method and it doesn't work (i.e. pulse torquing commands are sent), you can re-perform the procedure using the matrix alignment, and you have lost nothing but time. This method was not included in the steps of the procedure outlined above, because it is more complex and the only gain is the two-level coverage. This choice should be made on a case-by-case basis.

RELATIVE WORKSTATION DISPLAYS

TITLE
IMU SUMMARY

TITLE

PRE-DEORBIT IMU-TO-IMU ALIGNMENT

PURPOSE

To discuss the D/O Prep book procedure for resetting the IMU Redundancy Management (RM) thresholds. The nominal procedure calls for IMU 1 to be aligned to itself, for the sole purpose of resetting the IMU RM thresholds. Among other things, this procedure replaces the previous requirement to reskew the IMUs when performing entry at the 2-level for IMUs. The pre-deorbit IMU-to-IMU alignment procedure requires no actual platform movement for any of the IMUs. However, there are several possible scenarios (waveoff, IMU failure, IMU drift, Ascent Abort, etc.) where an actual alignment might be desirable. This SCP provides information relative to performing the nominal procedure, and some guidelines for the off-nominal situations which can require some special provisions for the alignment.

BACKGROUND

The IMU-to-IMU (IMU/IMU) alignment is performed at TIG-70 minutes in order to reset the IMU RM threshold. This is done to provide 2-level attitude failure coverage during the entry phase (reference Flight Rule A8-110, IMU SYSTEMS MANAGEMENT). The rule does not specify the type of IMU/IMU alignment that will be performed, but rather it gives the GNC flight control team the latitude to perform the type of alignment applicable to the given situation on entry day. The nominal procedure has the crew align IMU 1 to itself. The procedure is performed for every nominal entry (even at the 3-level) because it is simple, and requires very little time (Reference A/E FTP Minutes #84, 11/15/91). For entry with two IMUs, performing this procedure precludes having to reskew the IMUs. It also provides RM coverage at the 2-level for cases not previously covered. Per the old Rule (re-skew for entry when at the 2-level prior to deorbit), if deorbit occurred with three IMUs and a subsequent failure resulted in only two IMUs being available during entry, there would have been very inadequate attitude RM coverage at the 2-level [0% probability of isolation for Z axis (critical axis) failures, average of approx. 30% for XY plane failures]. The current Rule and procedures provide the best possible coverage during deorbit and entry phases, given the current skewing options and RM thresholds.

The time at which to perform the alignment is derived from the original design of the 2-level RM thresholds, where the RM designers assumed that the deorbit alignment was performed at TIG - 70 minutes. This was in fact the deorbit star alignment time for STS-1, STS-2, and STS-3, but on flights since then, the deorbit star alignment has been performed one rev earlier (TIG - 165 minutes) due to crew workload constraints (Reference A/E FTP Minutes #79, 6/21/91).

For the nominal case (nominal here includes the case of one IMU failed and non-recoverable), the alignment will be IMU 1/IMU 1 only. This is a very special alignment case where the platforms actually do not move, but the threshold does reset. The only intent of this alignment is to reset the thresholds, and it is (nominally) not a

requirement to actually align the platforms (i.e. no platform movement is actually required).

PROCEDURE

The procedure in the Deorbit Prep book is called out as follows:

TIG - 01:06, IMU/IMU ALIGNMENT (Omit if BFS), block 22.

Block 22 appears in the D/O Prep book as follows:

<u>IMU/IMU ALIGNMENT</u>	22
C	1. 1 : GNC 21 IMU ALIGN
	2. REF IMU - ITEM 14 + <u>1</u> EXEC √TYPE, ITEM 15 - TORQUE
	3. ALIGN IMU 1 - ITEM 10 EXEC (*) √IMU 2, 3 ITEM 11, 12 - (no *)
	4. √MCC If no comm: EXEC - ITEM 16 EXEC (*) Red MET __ __/ __ __ : __ __
	5. √EXEC, ITEM 16 - (no *) (5-10 sec)

The rationale for the procedure can be found in the Deorbit Prep Flight Procedures Handbook. Basically, select IMU 1 as a reference IMU for the alignment (step 2), and select IMU 1 to be aligned (step 3). Verify that IMUs 2 and 3 are not selected for alignment (step 3), and execute the alignment (step 4). The "√MCC If no comm" statement means that if they have comm, the crew will stop and tell the MCC that they are ready to proceed, and if they do not have comm, then they will proceed. We don't want to unnecessarily slow down the crew, however it is desirable to verify the proper configuration prior to executing the alignment. Step 5 is to verify that the alignment has completed, and it will only require 5-10 seconds to complete. This procedure is for the nominal case.

Note that the IMU/IMU alignment, where the reference IMU is the only IMU aligned, is a very special alignment case in the software. The software does not perform large angle torquing (LAT) and does not call the LAT_FUNC module for this case. Instead,

the alignment is performed by the same module that performs star alignments (IMU_ORBIT_AL). This means that for this special case, there are some differences as compared to any other kind of IMU/IMU alignment. The major differences are:

- 1) The torquing angles will update once every 60 seconds, from the time the reference IMU is selected, until the EXEC (ITEM 16) is performed. The angles do not update for any other kind of IMU/IMU alignment.
- 2) The alignment will require only 5-10 seconds to complete. There is no LAT'ing, and no bi-directional slew. There is no "closed loop" (160 second) pulse torquing. The IMU does not actually move.

Also note that the procedure is written to use IMU 1 as a reference. This is arbitrary, and any one of the three IMUs could be used, if IMU 1 is failed (for example).

SPECIAL CONSIDERATIONS

A. Nominal End of Mission (NEOM)

There are cases where an alignment of one or more of the IMUs may be required. The procedure does not cover these cases. It was highly desirable to implement the simplest and shortest version of the procedure for the nominal case; this procedure does not include any steps for the crew to verify that the delta angles are less than some predetermined value, or some misalignment magnitude for which the MCC would potentially want to do an actual alignment and move the platforms.

It is recommended that consideration be given to performing actual alignments for the following:

NOTE: THERE ARE SOME EXCEPTIONS TO THESE GUIDELINES. See also B. Aborts/Launch Day Deorbits, and C. Contingency Deorbits, when applicable.

- 1) TO AVOID AN RM FAIL IMU AT THE COMPLETION OF THE ALIGNMENT.

Recall that at the completion of the alignment, the 3-level attitude fault detection (FD) threshold resets to 0.14 degrees, and the 2-level FD threshold resets to 0.27 degrees. For relative misalignments of this magnitude or greater, actual alignments should be performed to preclude an RM failure at the completion of the alignment. The annunciation of the RM failure itself may not be considered a major problem, but it is highly desirable to perform the alignment for these cases, and it makes good sense to align an IMU with this much misalignment.

2) TO SATISFY (AS MUCH AS POSSIBLE/REASONABLE) THE INTENT OF THE ORIGINAL IMU RM DESIGN.

The original RM threshold design assumed that all platforms would be brought to a common reference point (aligned) coincident with the RM thresholds being reset, whether by star alignment, or by choosing one IMU as a reference. By not actually moving the platforms (IMU 1/IMU 1), but by resetting the RM thresholds, we are actually "tricking" the RM system. This is considered acceptable for small relative misalignments, on the order of 0.05 degrees or less (per axis), or for an RSS total misalignment of 0.09 degrees or less. At this time, we think that these are good approximations for purposes of this discussion. Obviously, if this criteria is satisfied, then the criteria in part 1 is satisfied (i.e. $0.09 < 0.14$). However, the vice-versa of that is not true.

Unfortunately, it would take many Monte-Carlo runs in an attempt to evaluate the exact numbers, and the study is not warranted at this time. We accept the potential for sacrificing some small amount of RM coverage (we think extremely small) by having these very slight errors "built-in" to the system at the end of the alignment. This is a trade-off for regaining the exceptional RM coverage (by design) by resetting the RM thresholds. The main reason that any "residual" misalignment could be of concern has to do with the way RM works at the 2-level. Remember that the 2-level attitude RM uses a snapshot position of the gimbal angles at the completion of the previous alignment for the "truth" reference for each IMU, thereby defining a new zero-misalignment state.

These gimbal angles (Q_SMiSMj_O , quaternion describing relationship of IMU_i to IMU_j at the completion of the previous alignment) are thereafter compared to the current gimbal angles (Q_SMiSMj , quaternion describing the actual transformation between IMU_i and IMU_j as determined by the gimbal angles) to determine the current misalignment between the platforms. So, 2-level RM does not work like 3-level RM, in that it does not use the ideal transformation (Q_SMiSMj_I), based on the desired REFSMMATS (for each IMU) when computing the total misalignment at any given time. Thus, any relative errors between the IMUs at the end of the alignment (when the thresholds are reset) are "built-in" to the snapshot gimbal angles, and are really "swept away" in terms of misalignment that 2-level RM can detect. Again, for small relative misalignments at the time the thresholds are reset, this is not a concern.

3) TO REALIGN AN IMU THAT HAS DRIFTED SINCE THE DEORBIT STAR ALIGNMENT.

Obviously, if the IMU misalignment is greater than 0.14 deg, then the alignment should be performed to meet the guideline in part 1 above. However, it is possible that the total misalignment is less than 0.14 deg for one or more IMUs, and that an alignment would still be desirable. A total misalignment of 0.12 deg (RSS) for example, could indicate drift rates on the order of 10 to 12 sigma (for HAINS IMUs) for a single IMU, assuming drift since the previous IMU alignment. In other words, it is possible for one (or more) of the IMUs to have a total RSS misalignment of something significant, but less than 0.14 deg relative to the reference IMU. Although this IMU would not cause an RM FAIL at the completion of the alignment ($0.12 < 0.14$), it is obviously drifting (relative to the others) at a rate that might not be acceptable, and an alignment should be considered.

CAUTION: Keep in mind that it can be very difficult to determine which IMU(s) is actually drifting. The only data you have is relative data since the time of the previous star alignment. If the relative misalignments are small, leave things alone. It's not that you can do a lot of harm by picking one of the IMUs and aligning to it (they're all good enough at this point), but rather its not required, and really not desirable from a navigation standpoint (i.e. you pick an IMU to align the others to, and upset the natural MVS process). Bottom line - for small relative misalignments, an alignment is not required, not desired, and has no real benefit.

4) TO RECOVER AN IMU WHICH WOULD OTHERWISE NOT SUPPORT THE NAVIGATION REQUIREMENTS (0.25 DEG DESIRABLE, 0.5 DEG REQUIRED) FOR IMU ALIGNMENT AT ENTRY INTERFACE (EI), PER RULE A4-151, IMU ALIGNMENT.

Although this Flight Rule requirement is not violated if only one of the IMUs is misaligned at the 3-level, it is prudent in this case to perform the alignment to optimize for subsequent failure(s).

5) TO RECOVER A FAILED IMU.

If an IMU is currently failed, or would be declared failed due to misalignment at the completion of the IMU/IMU, then at least that IMU should be realigned. If the failure mode is such that an IMU/IMU alignment will not recover (or partially recover) the IMU, then it is obviously not required/desired.

Keep in mind that these are generally off-nominal cases, and the crew procedure does not have provisions for automatic implementation of these other alignment options. The crew procedure was built to 1) be as simple as possible, 2) require the least amount of time, and 3) reduce the exposure to any problems prior to deorbit, should the reference IMU fail during the

alignment. Thus, if real time changes are required, they should be worked expeditiously in this deorbit prep timeframe, in order to change the crew procedure. **The message here is to monitor the drift rates closely and anticipate if changes will be required to the TIG-70 procedure, before you get there.**

B. Aborts/Launch Day Deorbits

Special consideration should be given to the Abort-Once-Around (AOA), and any launch day deorbit case (REV 2, 3, or 7).

1. ABORT-ONCE-AROUND (AOA)

The AOA abort is the most constraining case from a navigation and IMU misalignment standpoint. The allowable navigation errors for an AOA are constrained by several variables, some of which are crossrange capability, and downrange errors as a result of Ascent navigation errors. For this reason, it is recommended that the PRE-DEORBIT IMU/IMU ALIGN PROCEDURE BE PERFORMED AS WRITTEN FOR AN AOA, and that the platforms are not actually aligned. Although there might be some relative misalignments which we would otherwise want to clean up (per the guidelines listed above in SPECIAL CONSIDERATIONS, part A. NEOM), it is more prudent to allow the natural MVS process to take place, and not pick an IMU for aligning the other IMUs. The Flight Rules (reference Flight Rule A8-110, IMU SYSTEMS MANAGEMENT) do not require a star alignment, because the predicted worst case total misalignment (originally based on a 3 sigma per axis, KT-70) is within the EI criteria of 0.5 degrees (and obviously better for the currently installed HAINS IMU 's). For this case, since an actual alignment (IMU/IMU) could make the best (and/or the selected) IMU slightly worse, it is not desirable given the more extreme navigation constraints for the AOA. If the relative misalignment will cause an IMU to fail RM at the completion of the alignment (IMU 1/IMU 1), then one option is to deselect the affected IMU, and allow the RM threshold to ramp past the misalignment. The 3-level attitude FD threshold will be about 0.23 degrees at 10 minutes prior to the deorbit burn. If the misaligned IMU is deselected, then it should be reselected prior to the deorbit burn, if at all possible.

2. REV 2, 3, OR 7 DEORBITS

For a REV 2 or REV 3 deorbit, the Flight Rules (reference Flight Rule A8-110, IMU SYSTEMS MANAGEMENT) do not require an alignment of the IMUs, by IMU star alignment, or by IMU/IMU alignment. However, they do require an IMU/IMU alignment to reset the RM thresholds, the same as for any deorbit. Although an IMU star alignment is not required per the Rules for these cases, a star alignment should be requested, if it is deemed required and if the timeline can accommodate the procedures. As for the pre-deorbit IMU/IMU alignment, the guidelines should be followed the same as for NEOM.

For a REV 7 deorbit, the only difference from the REV 2/3 case is that a star alignment(s) will be performed prior to the pre-deorbit IMU/IMU alignment. Again here, the guidelines should be followed the same as for NEOM for the pre-deorbit IMU/IMU alignment.

C. Contingency Deorbits

For all contingency deorbit prep cases, consideration should be given to not performing the pre-deorbit IMU/IMU alignment if the crew is too busy, and if three IMUs are available. The individual Contingency Deorbit procedures are listed below, with special considerations where applicable.

NOTE: THE CURRENT PROCEDURES IN THE CONTINGENCY DEORBIT PREP BOOK DO NOT INCLUDE THE PRE-DEORBIT IMU/IMU ALIGNMENT PROCEDURE. CONSIDERATION SHOULD BE GIVEN TO ADDING THE PROCEDURE AT TIG - 1:10 FOR THE CASES 1, 2, 4 AND 5 BELOW. FOR THE OTHER CASES LISTED BELOW, THE ALIGNMENT IS NOT REQUIRED, AS EXPLAINED IN THE INDIVIDUAL PARAGRAPHS.

1. LAUNCH DAY DEORBIT PREP (REV 2)

See B. Aborts/Launch Day Deorbits, REV 2 guidelines for the pre-deorbit IMU/IMU alignment at TIG - 1:10.

2. LAUNCH DAY DEORBIT PREP (REV 3)

See B. Aborts/Launch Day Deorbits, REV 3 guidelines for the pre-deorbit IMU/IMU alignment at TIG - 1:10.

3. LOSS OF 2 FUEL CELLS LAUNCH DAY DEORBIT PREP (REV 2/3)

This procedure has a callout at TIG - 1:15, IMU RECOVERY, FRP-3, for recovery of IMUs lost due to bus failures or powerdown. If performed, this procedure will also accomplish the intent of the pre-deorbit IMU/IMU alignment. If not performed, replace this procedure with the normal pre-deorbit IMU/IMU alignment procedure (uplink to the crew). See B. Aborts/Launch Day Deorbits, REV 2/3 guidelines for performing the pre-deorbit IMU/IMU alignment.

4. LOSS OF 2 FUEL CELLS DEORBIT PREP

This procedure has a callout at TIG - 2:00, IMU ALIGNMENT, for performing the pre-deorbit IMU star alignment. See A. NEOM for guidelines for performing the pre-deorbit IMU/IMU alignment at TIG - 1:10.

5. LOSS OF FES DEORBIT PREP

See A. NEOM for guidelines for performing the pre-deorbit IMU/IMU alignment at TIG - 1:10.

6. LOSS OF 2 H2O LOOPS

The pre-deorbit IMU/IMU alignment is not required for this case. This procedure has a callout at TIG - 0:47, IMU ALIGN, Block 10 for performing the pre-deorbit IMU star alignment. If performed, this procedure will accomplish the intent of the pre-deorbit IMU/IMU alignment. If not performed, the EI-10 procedures in the Loss of 2 H2O Loops Deorbit Prep/Entry part of the book will accomplish an alignment at the step titled, IMU ACTIVATION (If IMUs 1, 3 off).

7. LOSS OF 2 H2O LOOPS DEORBIT PREP

The pre-deorbit IMU/IMU alignment is not required for this case. This procedure assumes that one of three Loss of 2 H2O Loops powerdown procedures (ORB PKT PWRDN, ASC PKT PWRDWN, or the one in step 6 above) have already been performed. In any case, the EI-10 procedures in the Loss of 2 H2O Loops Deorbit Prep/Entry part of the book will accomplish an alignment at the step titled, IMU ACTIVATION (If IMUs 1, 3 off).

8. EMERGENCY DEORBIT PREP

The pre-deorbit IMU/IMU alignment is not required for this case. This procedure is tailored for (but not limited to) the cabin leak scenario, and is built for a worst-case scenario where the procedure is entered just 20 minutes prior to deorbit TIG. For this reason, the pre-deorbit IMU/IMU alignment is not required. If possible, an IMU/IMU alignment should be performed sometime (even post TIG and pre-EI, if required to realign the platforms) depending on the time since the previous star alignment. If such an alignment is performed, then the threshold reset is accomplished. If not, and at some point during the entry there are only two IMUs, then some consideration should be given to performing the alignment (one IMU to itself, unless the other IMU is badly misaligned) to reset the RM thresholds and provide 2-level coverage for entry.

9. LOSS OF 2 FREON LOOPS DEORBIT PREP The pre-deorbit IMU/IMU alignment is not required for this case. This is a stand alone procedure, which requires immediate deorbit to the first available landing site. It assumes that either the ORB PKT or the ENT PKT powerdown procedures have been performed. The procedures require IMU/IMU alignments to stay on the coolest IMU, and otherwise plan for a single-IMU entry.

ADDITIONAL NOTES

A. Historical Information

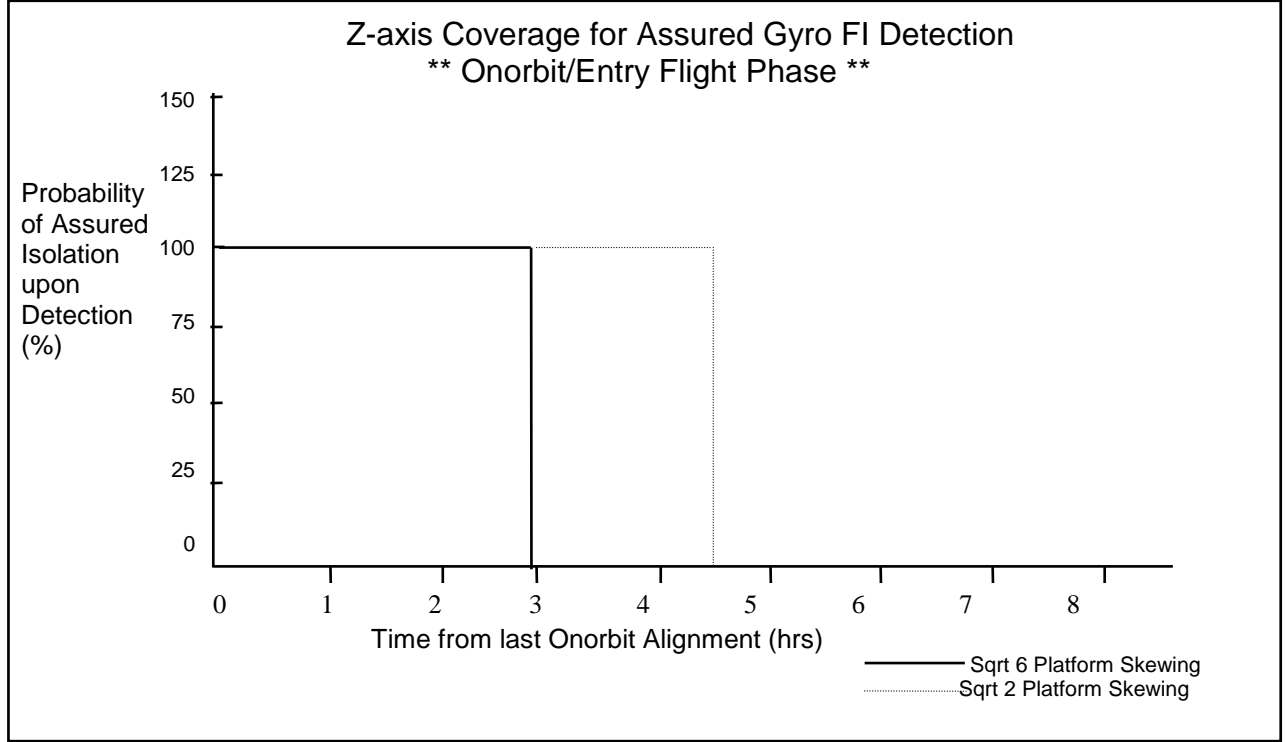
This section is an excerpt from an Informal Note, STATUS OF IMU ATTITUDE RM AND SKEWING ISSUES, dated August 26, 1991, written by DF62/L. E. Cain. The information included here is taken from the section of the note titled, Skewing for Entry.

As a result of the IMU failure on STS-41, we investigated the rationale for our Flight Rule which used to require optimization of the IMU skew for entry. A lot of research was done from which we determined that there are significant benefits to reskewing to the "square root of 2" skew orientation when at the 2-level for entry. We outlined these benefits and updated the rationale for the rule to state more clearly the reasons for performing the reskew (Ref. A/E FTP #74, Jan. 18, 1991). The "square root of 2" skew has benefits over the nominal "square root of 6" skew, as was explained in the rationale of the Rule. However, those benefits are not fully realized until approximately three hours after the last on orbit alignment (nominally performed at TIG - 2:45). During those three hours, the Z axis coverage is identical to that for the "square root of 6" skew, and the XY plane coverage for the "square root of 2" skew is reduced by about 10 percent or less as compared to the nominal "square root of 6" skew. After three hours, the Z axis coverage remains the same for the "square root of 2" skew, but drops off to zero percent probability of isolation for the "square root of 6" skew. The XY plane coverage is also better in the "square root of 2" skew than in the "square root of 6" skew after the three hour time period. [At this point it may help to look at the attached plots, page 2.20-10] These were the drivers for wanting to reskew at the 2-level for entry, but the information that was not previously known is that the benefits are not realized until the three hours have passed, and that during the first three hours, the nominal "square root of 6" skew is actually better.

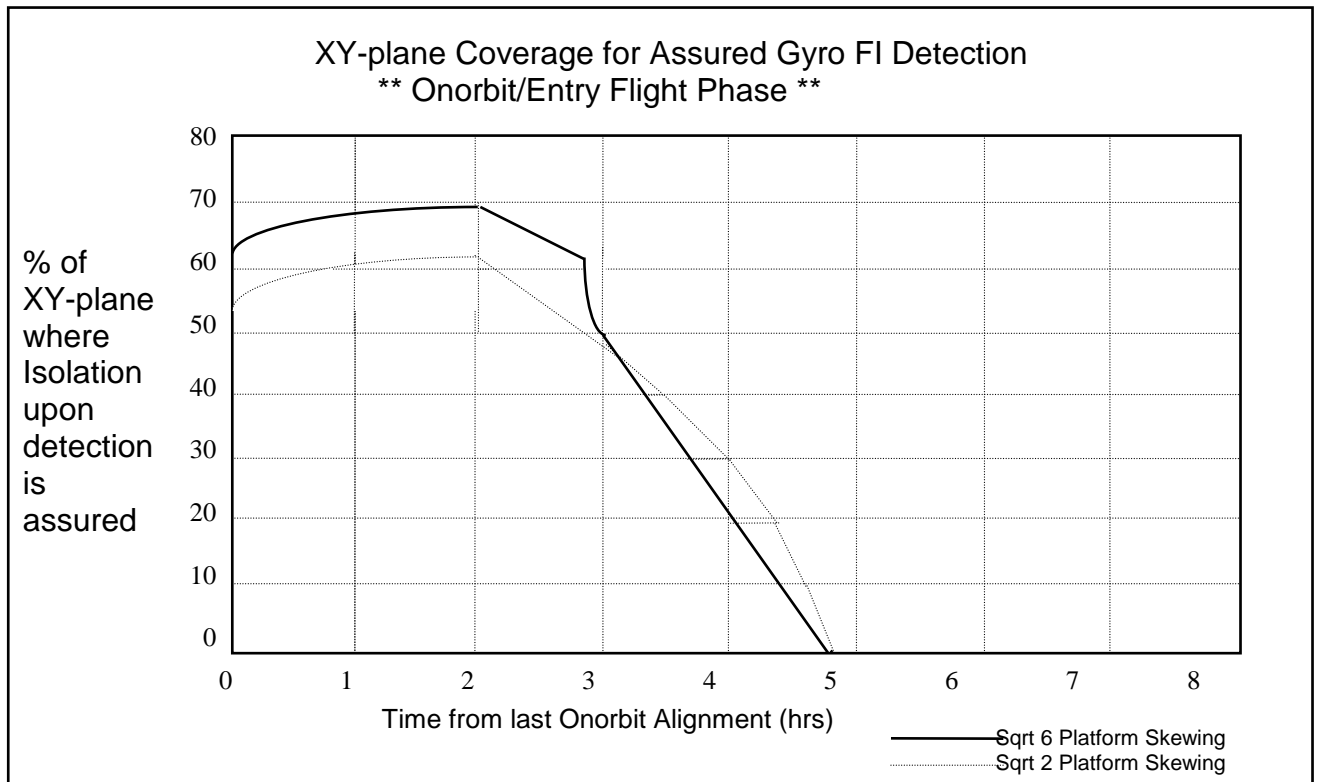
Since the FD and FI thresholds are reset after each IMU alignment, our best option is to remain in the "square root of 6" skew for entry, and perform an IMU/IMU alignment 70 minutes prior to the D/O TIG. If this is done, we will have the best possible isolation capability for entry, given the current FD/FI thresholds and the skew orientations with which we are familiar today. It is believed that there is a better skew orientation out there ("Symmetric Square Root of 2") which would provide better overall coverage in all flight phases given the thresholds that we have today. All known options are being investigated with the intent of establishing why we have what we have today, and if there are changes that are worth making. In the mean time, given the choice between performing the reskew and performing an IMU/IMU alignment at TIG - 70 minutes, we should do the alignment and not the reskew. This information was discussed at the A/E Flight Techniques Panel, and most recently on August 16, 1991.

As a result of these discussions, the Flight Rules were changed and now require performing a pre-deorbit IMU/IMU alignment to reset the RM thresholds. There are no longer any rules which require reskewing of the IMUs.

Comparison of Z-axis Coverage of Sqrt 6 and Sqrt 2 Skews:



Comparison of XY-plane Coverage of Sqrt 6 and Sqrt 2 Skews:



TITLE

IMU REFSMMAT PROGRAMS

PURPOSE

This is a quick reference listing all GNC programs available to work with the IMU REFSMMAT's and provide some guidance on their use.

BACKGROUND

Each IMU is associated with a REFSMMAT, a matrix in software which describes the orientation of the IMU stable platform with respect to the M50 inertial coordinate system. Occasionally these REFSMMAT's require manipulation because of failures.

The convention is that REFSMMAT files on the workstation will be stored in a subdirectory named 'refs' under the flight directory. It takes three REFSMMAT's to make a load (one for each IMU). Each REFSMMAT is a separate matrix and is stored in a separate file, but the names of the files are related. For a REFSMMAT load named 'final', the filenames will be 'final.ref1', 'final.ref2', and 'final.ref3'. The corresponding command display file will be named 'final.gcs'.

DESCRIPTION

The following programs can be used to retrieve, enter, view, manipulate, and build command files for the IMU REFSMMAT's:

1. ENTREF – a shell script that can be used to retrieve from telemetry, manually enter, view, edit, delete, or print REFSMMAT files. This script will call GETREFS to retrieve the REFSMMAT's from telemetry. (SCP 10.12)
2. NREF – a shell script used to normalize the REFSMMAT's and generate the command display file. This script will allow the user to retrieve the REFSMMAT's from telemetry by calling GETREFS, retrieve an existing REFSMMAT file, or manually enter the REFSMMAT's. The script then normalizes the input REFSMMAT's and calls REFSLOAD to generate the output command display file. (SCP 2.10)
3. GETREFS – a program that reads REFSMMAT's on telemetry and generates the three REFSMMAT files; 'filename.ref1' for IMU 1, 'filename.ref2' for IMU 2 and 'filename.ref3' for IMU 3. This program is called by other programs and scripts. (SCP 10.13)
4. REFSLOAD – a program which formats REFSMMAT files into a command display file ('filename.gcs') which can be read by the REFSMMAT Command Display in order to store the load in the Command Server. (SCP 10.11)
5. MQEUT – a program which can read and write REFSMMAT files. This program can be used to manually enter or manipulate the REFSMMAT matrices. (SCP 10.5)

There is a shell script for each vehicle that can be run from the GNC DNAV under 'Realtime', 'Send Launch REFSMMAT' which calls two of the above programs. These scripts call GETREFS to retrieve the telemetry REFSMMAT's and saves them in files named 'launch'. The scripts then call REFSLOAD using the retrieved REFSMMAT 'launch' file as input to generate the command load file named 'initial'.

HOW TO RETRIEVE TELEMETRY REFSMMATS

There are three shell scripts which run GETREFS to retrieve the telemetry REFSMMAT's. The launch REFSMMAT's are easily retrieved using the script on DNAV (Realtime>Send Launch REFSMMAT>OV10x). If the REFSMMAT's have changed during the mission, either ENTREF or NREF can be used to retrieve the new REFSMMAT's. If the Current REFSMMAT is going to be uplinked as the Desired REFSMMAT, then using NREF is the better choice. If the Current REFSMMAT is going to be manipulated before uplink, then ENTREF may be the better choice.

MANUAL INPUT REFSMMATS

If the REFSMMAT's must be entered manually, there are several methods of doing it. Either shell script ENTREF or NREF will allow the user to enter manual REFSMMAT's using the GNC matrix program 'MX'. The MX program could be used directly from a XTERM window to build the REFSMMAT files, but the two shell scripts are more user friendly. Also the program MQEUT can be used to manually enter the REFSMMAT matrices and generate the appropriate REFSMMAT files. This is the obvious choice if MQEUT will be used to manipulate the matrices before uplink. A REFSMMAT load can be manually entered directly into the command display, but this is not the recommended way of building a REFSMMAT load (see next section).

HOW TO BUILD A REFSMMAT COMMAND LOAD

There are only two ways to build a REFSMMAT command load:

1. Use program REFSLOAD
2. Enter numbers manually into the GNC GCS Display REFSMMAT

The recommended way is to use the program REFSLOAD, since this will avoid any manual input errors. It is safest to build the REFSMMAT command load using NREF, which calls REFSLOAD, because this script will orthogonalize the final load and generates the report on the orthogonality of the input as well as the output files.

TITLE

RECOVERY OF IMU ATT REFERENCE USING ISS ATTITUDE

PURPOSE

To provide a means for recovering from complete loss of IMU attitude reference while docked to ISS.

DEFINITIONS

DESIRED REFSMMAT:

An onboard software term which defines the position at which it is desired to align a platform.

CURRENT REFSMMAT:

An onboard software term which defines the position at which onboard software assumes each IMU platform is located. Normally (not always), the current REFSMMAT is equal to the desired REFSMMAT.

PRESENT REFSMMAT:

An onboard software term which defines the position of the IMU platform as determined by an external reference, either another IMU during an IMU to IMU alignment or IMU Matrix align, or star vectors during a star align.

LOSS OF ATTITUDE REFERENCE:

An MCC term which defines a significant difference between an IMU's true and current REFSMMATs (>1.4 degree star tracker limit).

BACKGROUND

The normal method of recovering from loss of all IMU attitude reference is to perform a HUD/COAS alignment. However, while docked to ISS, changing attitude to point the HUD/COAS at stars and the process of taking marks are impractical, if not impossible. This procedure uses the known orbiter to ISS relative attitude and the known ISS inertial attitude to determine the present REFSMMAT (the real orientation) of each IMU. Once the present REFSMMAT is determined, it can be uplinked to the desired REFSMMAT slot. After the uplink is complete, an IMU Matrix alignment is performed, aligning the IMU to itself. This will set the current REFSMMAT equal to the desired, which in this case is also the present REFSMMAT.

The alignment will not have the accuracy of a normal star alignment. The primary reason for the poor accuracy is the structural flexure between the two vehicles that is expected to be at least several tenths of a degree per axis. This relative attitude error occurs both at the initial relative attitude determination (relative attitude calibration) and at any point in time where the relative attitude is to be used to determine the IMU platform attitude. Another less significant error

source is the misalignment of both the orbiter and the station inertial systems at the time of relative attitude calibration, and the station inertial system at the time of IMU recovery.

The alignment is not expected to be accurate enough for a safe entry, but it will likely be accurate enough that the star trackers can be used and it will certainly be accurate enough to aid the crew in locating HUD/COAS stars after undocking, in case that should be necessary. The best alignment accuracy that can reasonably be expected is on the order of 0.5 degree; the worst alignment accuracy could be larger than the line of sight identification limit of 1.4 degree. The 1.4 degree limit, however, is not an absolute one. When the IMU misalignment exceeds 1.4 degrees, a band appears in the celestial sphere perpendicular to the axis of misalignment such that any star in the band will be measured to be more than 1.4 degrees out of position (due to IMU misalignment) and thus rejected. As IMU misalignment increases the width of this band increases. However, any star not in the band will be measured to be less than 1.4 degrees out of position and will pass the limit test. In fact, if a star line of sight happens to be very closely aligned with the IMU misalignment axis, it will pass the limit even if the IMU is misaligned by 180 degrees. Of course, a large IMU misalignment also increases the possibility of tracking some other star or object and misidentifying it as the intended star.

In case the -Y star tracker is lost, this procedure can be used to maintain IMU alignment at least sufficiently accurately for a safe separation and to aid the crew in locating HUD/COAS stars. For attitude reference maintenance, rather than performing the full procedure, it would be preferable to use the calculated present REFSMMAT to determine appropriate changes to the drift compensation to cause the IMUs to drift back to the desired position. It must be remembered that, for a typical remaining docked duration (after -Y star tracker failure) with typical IMU drift performance, it may be preferable to accept the drift error rather than to accept the errors inherent in using station attitude to determine orbiter IMU position.

EQUATIONS

Soon after docking, when the inertial references of both vehicles are believed to be good, and when the relative structural oscillations are near the center of their range, a relative attitude calibration is established by recording the inertial quaternions Q_{B_I} for the orbiter and Q_{J2K_ISS} for station. These quaternions are used to calculate the orbiter to station relative body attitude:

$$Q_{B_ISS} = Q_{B_I} * Q_{M50_J2K} * Q_{J2K_ISS} \quad \text{EQ. 1}$$

Where

Q_{B_ISS} represents the rotation from the orbiter body frame to the ISS body frame.

Q_{B_I} is a downlisted quaternion (QBI) representing the rotation from the orbiter body frame to the M50 reference coordinate frame (I is the same as M50 when the IMU is well aligned) as determined by the onboard selected IMU. It is the basic orbiter attitude quaternion.

Q_{J2K_ISS} is a downlisted quaternion representing the rotation from the J2K (J2000) reference coordinate frame to the ISS body frame as determined by the ISS inertial reference system. It is the basic ISS attitude quaternion.

Q_{M50_J2K} is a constant quaternion representing the rotation from the M50 reference frame to the J2K reference frame. The angle of rotation is 0.6984 degree.

If all IMU reference is lost while docked, the orbiter to station relative attitude calibration quaternion can be used to recover IMU reference. The recovery consists of three parts:

- 1) Present REFSMMAT determination from ISS
- 2) Present REFSMMAT uplinked into the Desired REFSMMAT's slot
- 3) Matrix Align the IMU to itself

After uplinking the present REFSMMAT, determined by ISS, to the desired REFSMMAT slot and then performing the IMU Matrix align, aligning the IMU to itself, the current REFSMMAT is set equal to the desired REFSMMAT. We then have a good IMU attitude reference.

NOTE: The method used before OI-32 to recover IMU attitude reference was to calculate the fictitious desired REFSMMAT to be used in a modified IMU/IMU alignment to recover one IMU. The other IMU(s) would then be recovered using normal onboard procedures. However, this method is complicated and was made obsolete with the addition of the IMU matrix alignment capability in the OI-32 software load mentioned. The old SCP can be found in the archive GNC SCPs at S:\Divisions\DS\Private\DS62\GNC_SCP\Archived.

The equation for determining the present REFSMMAT from ISS attitude is:

$$Q_{P_M50} = Q_{P_I} * Q_{I_B} * Q_{B_ISS} * Q_{ISS_J2K} * Q_{J2K_M50} \quad \text{EQ. 2}$$

Where

Q_{P_M50} represents the rotation from the present platform position to the M50 reference frame as measured from station attitude. This is the quaternion equivalent of the present REFSMMAT.

Q_{P_I} represents the rotation from the present platform position to an inertial frame that is not M50 because the IMU is badly misaligned. It is numerically equal to the quaternion equivalent of the current REFSMMAT. Since the current REFSMMAT represents the rotation of a well aligned IMU platform to the M50 frame, it also represents the rotation of a poorly aligned IMU platform to some other inertial frame that is itself rotated from M50 by the same amount as the IMU platform misalignment.

Q_{I_B} represents the rotation from the erroneous inertial frame to the orbiter. It is the conjugate of the orbiter attitude as computed onboard and downlisted. The inertial frame I is the same as that referred to above rather than M50 because the flight software is computing it from the gimbal angles of the misaligned IMU and its current REFSMMAT. The source of this quaternion can be the downlisted (conjugated) QBI or it can be calculated from the downlisted quaternion equivalent of gimbal angles - QRSM. An important difference between the two source options is that QRSM is available in the downlist for all three IMUs and QBI is available only for the onboard selected IMU. The QRSM option has calculations that are more extensive and vehicle specific navigation base to body orientation and IMU location (1, 2, or 3) specific roll to NB misalignments must be included.

Q_{B_ISS} is the orbiter to station relative orientation quaternion from Equation 1.

Q_{ISS_J2K} is the conjugate of the downlisted ISS attitude quaternion corresponding to the same time that Q_{I_B} is calculated.

Q_{J2K_M50} represents the rotation from then J2K reference frame to the M50 reference frame. It is the conjugate of the quaternion constant Q_{M50_J2K} .

The equation for calculating Q_{B_I} from the QRSM quaternion is:

$$Q_{B_I} = Q_{B_NB} * Q_{NB_R} * Q_{R_SM} * Q_{C_M50} \quad \text{EQ. 3}$$

Where

Q_{B_NB} represents the rotation from the orbiter body to the navigation base reference frame that is defined to be the same as the IMU 1 mounting position. It is a vehicle specific ILOAD.

Q_{NB_R} represents the rotation from the NB frame to the IMU Roll axis (equivalent to the IMU case). The NB to Roll quaternions are determined by IMU mounting location specific ILOAD calibration parameters; they actually represent the misalignment of the mounting locations from the NB frame. Because each IMU is calibrated internally to compensate for the misalignment between the roll (case) axis and the IMU mounting position, the NB to Roll quaternion for position 1 is identity.

Q_{R_SM} represents the rotation from the IMU Roll axis to the stable member (platform). It is the downlisted QRSM and is derived from gimbal angles and several correction terms.

Q_{C_M50} represents the rotation from a properly aligned platform to the M50 reference frame. It is the quaternion equivalent of the current REFSMMAT.

Note that the equation (and the FSW which computes QBI) assumes that SM and C are the same and that I and M50 are the same. A mathematical purist might insist that identity quaternions Q_{SM_C} and Q_{M50_I} be added to the equation to resolve the label incompatibility. Since multiplying by an identity quaternion is equivalent to multiplying by one in an algebraic equation, including the quaternion multiplication steps in a spreadsheet or in manual calculations would be a waste of effort and spreadsheet cells.

The equation for determining the torquing angles that will return the IMU to its proper current REFSMMAT position is:

$$Q_{P_C} = Q_{P_M50} * Q_{M50_C} \quad \text{EQ. 4}$$

Where

Q_{P_C} represents the rotation from present platform to current platform. The torquing angles to move the platform back to the current REFSMMAT orientation can be extracted from this quaternion.

Q_{P_M50} is the result of EQ. 2.

Q_{M50_C} is the conjugate of the quaternion equivalent of the current REFSMMAT.

SPREADSHEET DESCRIPTION

The QRSM spreadsheet is the certified Workstation version. There is also a certified QBI and QRSM PC version in the V drive.

Figures 2.22-1, 2.22-2, and 2.22-3 are spreadsheet samples which will be useful as reference while reading through this description. The samples were generated from data taken from a docked simulation where the QRSM version of this procedure was used to recover IMU reference. Because the QBI version samples were generated mathematically from the simulation data, the three input data sets (one for each IMU) actually represent the same data point and therefore the ISS attitude quaternions are identical for each IMU. In an actual application of the QBI version, the ISS attitude quaternion will be different for each IMU.

All input cells are highlighted yellow. Cells that contain data intended to indicate problems (such as an incorrect input or spreadsheet corruption) are highlighted red or have red characters. Output data is highlighted blue (purple on the workstation version). The colored highlights will appear as various shades of gray on monochrome printouts.

Quaternions and matrices are checked for normalcy through the spreadsheet. Quaternion magnitude (RSS of the four elements) should be unity; the downlisted QBI (orbiter attitude) is always slightly less than unity and the downlisted QJ2K_ISS (ISS attitude) may be slightly less than or slightly greater than unity. Both should be unity to an accuracy of at least six decimal places. The rows and columns of matrices (REFSMMATs) should be unity and the angles between successive rows and successive columns should be 90 degrees. The rows and columns of the downlisted current REFSMMATs are always slightly less than unity; the angles should be 90 degrees, accurate to at least two decimal places. The slight non-unity of quaternions and matrices is a precaution against the possibility of logging GPC errors, which could occur if the magnitudes were to be slightly greater than unity. ISS computers do not have this requirement.

A deviation greater than the above specified magnitudes and angles for the input quaternions or matrices is an indication of an input error. Because the inputs are made into normal quaternions before processing through the equations, the magnitudes and angles are unity and 90 degrees well beyond the displayed precision. A deviation here indicates spreadsheet corruption.

The QRSM version is identical to the QBI version except for the input data (QRSM instead of QBI and a single input for QJ2K_ISS) and a third page of the alignment sheet that calculates QBI from the QRSM of each IMU. A single data point is taken by printing a hard copy of the display that includes QBI for the onboard selected IMU, the ISS attitude quaternion, and three QRSM quaternions, one for each IMU. The hardcopy QBI is not used, but instead the spreadsheet calculates each of the QBI quaternions that would have been on the display if the corresponding IMU had been the onboard selected IMU, thus allowing a single data point to provide all of the required attitude input data.

The QBI version requires that the onboard selected IMU be switched in order to acquire a QBI for each IMU. As each IMU is selected, a separate hardcopy is required resulting in a different ISS attitude quaternion for each IMU.

CALIBRATION SHEET

FIGURE 2.22-1 is an example of the Cal Data sheet that performs the relative attitude calibration calculations. It is identical in both versions.

The mission identification input may be composed of any characters. This cell is not used in any calculations; its contents are copied into the Alignment sheet.

The vehicle identifier is used in calculations only in the QRSM version where vehicle specific nav base to body and IMU mounting position specific NB to Roll calculations are needed. Although the input is not case sensitive, it must otherwise be entered exactly as one of the following five options: OV103, OV104, OV105, SMS, or VAR. VAR is a vehicle identifier that allows for a variable input to the QRSM version of the quaternion equivalent of the nav base to body and the IMU NB to Roll matrices. (If VAR is selected inputs must be made on page 3 in the yellow highlighted areas.) An omitted or erroneous input for the vehicle identifier will cause a message to appear below the input block in red letters. An improper input will not affect the calculation in the QBI version. The vehicle identifier and the message, if there is one, are copied into the Alignment sheet.

QBI and QJ2K_ISS are the orbiter and ISS calibration attitude inputs.

QM50_J2K is the constant quaternion representing the rotation from the M50 reference frame to the J2K reference frame.

Reference QM50_J2K is a copy of this constant quaternion. It is provided as a recovery data source in case the working quaternion is modified. To modify the working quaternion it is necessary to unprotect the spreadsheet.

SCP EQUATION 1 performs the required calculations. The result is normalized to a positive scalar by changing the signs of all elements if the first element is negative. Note that throughout this spreadsheet equations that involve multiplying 3 or more quaternions are evaluated by multiplying 2 quaternions at a time producing an intermediate result that is then multiplied by the next quaternion in sequence. This technique makes spreadsheet construction much easier by allowing the same set of multiplication formulas to be used throughout the spreadsheet rather than designing special (and very complex) formulas for each equation that has a different number of quaternion multiplications. It also simplifies debugging, and, in some cases, an intermediate result is useful.

Angles B_ISS are the total and per axis angles and angles PRY B_ISS are the Euler sequence angles representing rotation from orbiter to ISS.

The current REFSMMATs for each IMU are entered on the calibration sheet as a convenience, allowing these inputs to be made in advance of loss of reference. They are not used in the calibration calculations. They are copied to the alignment sheet according to the selections for recovery IMU, reference IMU, and backup recovery IMU. The nomenclature of "recovery", "reference" and "backup" is carried over from the pre OI-32 method of recovering the IMU's attitude reference. It was decided to keep the spreadsheet in this format, having the data broken up for each IMU, in case there is a reason to recover more than one IMU using the IMU Matrix alignment capability or to use the calculated present REFSMMAT to determine appropriate changes to the drift compensation to cause the IMUs to drift back to the desired position.

The cells below NOTE 1 are unprotected and are available for any desired user notes.

ALIGNMENT SHEET

At the top of the Alignment sheet (e.g. Figure 2.22-2a) the FLIGHT and VEH ID are copied from the Calibration Sheet.

The rest of the Alignment sheet is divided into four sections by horizontal dashed lines. The top three sections are associated respectively with the recovery IMU, the reference IMU, and the backup recovery IMU. The bottom section contains the “fictitious” desired REFSMMATs, and is no longer needed with the OI-32 capability.

IMU number (1, 2, or 3 representing location on nav base) is not an absolute requirement in the QBI version because it is not used in any of the numerical calculations. However, because the IMU number is used in matrix and quaternion label generation, its omission could easily lead to confusion.

QB_ISS is the calibrated orbiter to ISS quaternion from the calibration sheet. It is identical for all three IMUs.

CURRENT REFSMMATs are copied from the Calibration Sheet.

Present REFSMMATs are the actual positions of each IMU as determined from ISS attitude. The present REFSMMATs can be loaded to the onboard desired REFSMMATs by an uplink. The REFSMMAT would then be rolled into the current REFSMMAT slot by performing a Matrix alignment, aligning the IMU to itself.

The torquing angles are the total and per axis angles of rotation through which would move the platform back to the onboard current REFSMMAT position. These are the angles that the normal alignment process would generate if stars could be tracked. The torquing angles can be used to generate a drift compensation uplink that will overcompensate the IMU so that it will slowly drift back to the current REFSMMAT position.

The Alignment sheet, in the calculations area, (e.g. Page 2 of Figure 2.22-2b) contains the calculations that generate the present REFSMMATs. It is also divided into four sections by horizontal dashed lines. The top three sections perform calculations for the recovery IMU, the reference IMU, and the backup recovery IMU respectively. The bottom section performs an emulation of the FSW IMU/IMU calculations for the recovery IMU only. It is intended only to demonstrate that the FSW will calculate the desired torquing angles.

SCP EQUATION 2 calculates the present REFSMMAT for each IMU for display on the Alignment sheet.

SCP EQUATION 4 calculates the torquing angles of each IMU for display on the Alignment sheet.

Q_{CX_M50} where X is IMU position number 1, 2, or 3 is the quaternion equivalent of the page one input current REFSMMAT.

SCP EQUATION 5 at the bottom of the Alignment sheet, in the calculations area, is used to demonstrate that the FSW will calculate the torquing angles that are desired from the Alignment sheet.

QBI VERSION (PC VERSION)

Figures 2.22-2a and 2.22-2b are examples of the two pages of the QBI PC version Alignment sheet.

QBI and QJ2K_ISS are the input orbiter and ISS attitude quaternions recorded at IMU recovery time. Because the onboard selected IMU must be changed (and a new hardcopy made) in order to obtain a QBI reflecting the gimbal angles of each IMU, the ISS attitude quaternion associated with each IMU is also different. (In the QBI version sample spreadsheet, the ISS attitude quaternions are numerically equal because the inputs were mathematically derived from the single hardcopy data point used in the QRSM version sample spreadsheet rather than from three separate hardcopy data points. They will be different in a real case).

QRSM VERSION (PC VERSION)

With the following exceptions, the first two pages of the alignment sheet are identical to the QBI Version:

1. QRSM is input instead of QBI
2. There is a single ISS attitude quaternion input for all IMUs. The ISS attitude input is located in the section for the recovery IMU and is automatically copied into the sections for the reference and backup recovery IMUs.
3. The QI_B quaternion of SCP EQUATION 2 on page 2 (FIGURE 2.22-3b, tan highlight) is calculated on the new page 3 (FIGURE 2.22-3c) from the QRSM inputs instead of being taken as the unitized conjugate of the input QBI as in the QBI version.

The third page calculates QBI for each IMU from its corresponding QRSM. The page is divided into two sections by a horizontal dashed line. The upper part contains rows of quaternions representing the orientations of the body to nav base and the mounting points (roll) of IMU 1, 2, and 3 respectively. The columns reflect the three vehicles, the SMS, and a variable vehicle (VAR) for user input. The rightmost column beside the IMU data is the IMU data for the vehicle selected by user input on the calibration sheet; it will be equal to one of the five vehicles available to the left.

The lower section calculates QBI using SCP EQUATION 3 for the recovery IMU, the reference IMU, and the backup recovery IMU.

QRSM VERSION (WORKSTATION)

The first two versions described are PC Microsoft Excel spreadsheets. There is also a Workstation QRSM version in an Xess spreadsheet. The advantage of the Xess spreadsheet is

the ability to connect to the ISP server to acquire telemetry. Also by being on the workstation, the spreadsheet output REFSMMAT data can be exported to the appropriate directory for building the required uplink command. This reduces the possibility of errors introduced while manually typing the input data into the PC spreadsheets and the output data into the workstation. The Xess spreadsheet has two additional sheets, the Inputs sheet and the REFS Outputs sheet (examples shown in Figures 2.22-4 and 2.22-5). The Inputs sheet has the active telemetry data for QBI, QJ2K_ISS, QRSM, and the current REFSMMAT. As described later in the procedure section the data on this sheet will be captured by a COPY and PASTE to a blank section of the sheet. The REFS Outputs sheet has the appropriate current REFSMMAT ready to be exported.

DATA ACQUISITION

MCC displays, ORB/ISS Attitudes and RT PLOTS, are the sources for the required data for establishing relative attitude calibration and subsequent to loss of IMU attitude reference for recovering attitude reference by either the QBI or the QRSM method. The data may be recovered from ODRC, but care must be taken to match the time tags for the attitude quaternions QBI and QJ2K_ISS and the IMU gimbal angle quaternions (QRSM). The normal time column on ODRC data listings may be nearly a minute shifted. The time tags are not used in the calculations; they are used by the operator to make sure the attitude and gimbal data are acceptably time homogenous. Because the time shift between ISS and shuttle data streams in ODRC can cause significant errors, the recommended data source is display hardcopy of real time data or copy and paste of real time data onto workstation spreadsheet. In the real time data stream, variation in time tag difference is generally within one or two seconds. The error due to a few seconds of time shift is insignificant in comparison to other errors inherent in aligning IMUs to ISS attitude data.

PROCEDURE

Calibrating the Orb to ISS Spreadsheet

A) Select the appropriate spreadsheet

IF USING QRSM (Workstation Version):

1. Open spreadsheet from the GNC DNAV under APPS/ISS-ORB ALIGN and select RUN MASTER.
2. Rename the spreadsheet by selecting Save As and change the file name (.temp.xls4) leaving the file extension (.xls4). The file should be saved in the flight specific directory.

In the file name, include the flight day, specific event, and if it is the FCR or MPSR's copy (e.g. FD3_twohourspostdock_mpsr.xls4).

If there is a need to open this saved file later, select RUN SAVED from the GNC DNAV under APPS/ISS-ORB ALIGN.

3. Input the Mission and Vehicle into the Cal Data sheet as one of the following five options: OV103, OV104, OV105, SMS, or VAR.

The vehicle identifier is used in calculations only in the QRSM version where vehicle specific nav base to body and IMU mounting position specific NB to Roll calculations are needed.

IF USING QBI (PC Version):

4. Open spreadsheet QRSM_ISSIMUAL_MSTR .XLS. (If the QBI version is to be used, substitute the file QBI_ISSIMUAL_MSTR.XLS in this and all subsequent steps). The spreadsheet can be found on the V: drive with the GNC Certified programs or on a floppy disk in the MPSR supply cabinet.
5. Rename the spreadsheet QRSM_ISSIMUAL_XXX.XLS where XXX is flight number. If this spreadsheet is intended to represent a special structural condition where the relative attitude may be different from nominal, append a short descriptor to the file name (e.g., QRSM_ISSIMUAL_XXX_ALD, where ALD indicates airlock depress). Detailed notes concerning anything that the operator wants to record about this particular copy of the spreadsheet may be entered on the calibration sheet below note 1. Save the file to a folder named ISSIMUAL (create the folder, if necessary) on the V drive flight folder at the same level as the handover folder.

B) Calibrate Orbiter to ISS Relative Attitude (Shortly after hard mating)

6. Shortly after hard mating (allow a few minutes for structural oscillations to damp) and establishing a relative attitude calibration between the orbiter and ISS, take a snapshot of data:

IF USING QRSM (Workstation Version):

- a. On the Inputs sheet highlight, copy (values) and paste in an empty area of the sheet. The calibration data should include the QBI and QJ2K_ISS quaternions and the MET.

IF USING QBI (PC Version):

- b. Hardcopy the MCC display ORB/ISS Attitudes.

This data is intended to be used in case of loss of IMU reference shortly after docking.

C) Calibrate Orbiter to ISS Relative Attitude (After hard mating and gathering further data i.e. MMACS completes their Docking Sequence cue card steps)

7. Set-up the Orb/ISS RT Plots after hard mating:
 - a. On the Apps pulldown menu start the orbiter to ISS relative attitude delta comps and INIT both the long term and the short term comps.
 - b. On the RealTime pulldown menu activate the RTPLOT of the attitude deltas.
8. After the plots have been running for several structural oscillation cycles (generally several revs):

- a. Make a new hardcopy of the ORB/ISS Attitudes display and/or a new copy and paste of the appropriate data on the Inputs sheet when the three axes are as near as possible to the middle of their respective ranges. Take a printout of the Orb/ISS RTPLOT at the same time you take your snapshot of data.

This may have to be more a matter of picking a time when all three axes are not at their maximum excursion. The new copy is a better calibration than the one taken in step 6. The calibration data may be updated if continued monitoring of the relative attitude plots suggest a better approximation of the center point of structural oscillations or an apparently permanent shift, keeping in mind the misalignment condition of the selected IMU (i.e., don't take a new calibration point if the improvement is not significantly greater than the uncertainty in the IMU).

NOTE: A secondary calibration may be recorded for any special structural condition, such as airlock depress, that causes a temporary shift in the average relative attitude. The secondary calibration should be used only if it becomes necessary to recover IMU reference while the special structural condition is present.

9. Enter the QBI and the QJ2K_ISS quaternions. If using the workstation spreadsheet, perform a copy and paste from the Inputs sheet to the Cal Data sheet.
10. Enter the current REFSMMATs for each IMU (MCC display REFS, ROLL, and QUATS). Verify that the REFSMMATs are orthogonal (the row and column magnitudes are unity to at least 6 places and the angles between rows and columns are 90 degrees to 2 decimal places. Any variance indicates an input error. If using the workstation spreadsheet, perform a copy and paste from the Inputs sheet to the Cal Data sheet.
11. Enter any desired notes below NOTE 1
12. Save the file.

NOTE: Selecting the appropriate spreadsheet and performing step A, may be done in advance. The filenames for the main spreadsheet and for any known special structural conditions may even be done preflight. The current REFSMMATs may be entered any time after platform release.

Recovering IMU Attitude Reference Using QRSM (Workstation Version) or QBI (PC Version)

This procedure is best performed with the orbiter in free drift (ISS in control). If the orbiter must be in attitude control make the reference IMU the same as the one that is selected onboard to avoid a high rate maneuver during the alignment. The onboard selected can be the backup recovery IMU, but in that case the selected IMU must be changed if the backup alignment has to be performed.

NOTE for QBI Version: The QBI version uses spreadsheet QBI_ISSIMUAL_MSTR.XLS found in the same location as the QRSM PC version. The procedure is the same as the QRSM version procedure except that QBI instead of QRSM is input to the spreadsheet.

Since there is only one QBI computed from the gimbal angles of the onboard selected IMU, it is necessary to switch the onboard selected for each of the recovery IMUs and the reference IMU making a hardcopy of MCC display ORB/ISS Attitudes for each IMU after it is selected. Since the stack attitude changes while changing the selected IMU there is a different ISS attitude for each selected IMU QBI input. The QIBs used in the page 2 calculation of EQ. 2 are taken directly from the conjugate of the input QBIs rather than being calculated on page 3 (there is no page 3 in the QBI version). The calibration sheet is identical to the QRSM version.

1. RTPLOT Setup

- a. Reinit the **short term** orbiter to ISS relative attitude delta comp.

This is necessary because the comp became invalid when IMU reference was lost; it must be restarted in order to use it to find the midpoint of structural oscillations.

- b. Do not reinit the long term comp; it will become valid again when the IMUs are recovered and it is the quickest verification that a successful recovery has been accomplished.

2. Open the appropriate spreadsheet file.

3. Verify Calibration Data

- a. Verify that the data entered on the calibration sheet represents the correct conditions (latest calibration update or an appropriate secondary structural configuration)
- b. Verify the correct vehicle, flight, and the correct current REFSMMATs.

4. Enter the IMU location number (1, 2, or 3) for the recovery IMU.

Recall that using this procedure post OI-32, the plan is to recover only one IMU, Matrix aligning the IMU to itself once the REFSMMAT is updated. So using only the "recovery" section of the spreadsheet should be sufficient.

5. Capture the data on the Inputs sheet

IF USING QRSM (Workstation Version):

- a. When the RT plot of the short term orbiter to ISS relative attitude deltas (the plot that was reinit in step 1a) indicates that the three axes are as near as possible to the center of their ranges, mark the QJ2K_ISS, the IMU QRSM data, and the MET on the Inputs sheet and perform a copy (values) to capture the data at the same time.

Recall that the Calibration data that was snapshot and copied for the calibration data setup will also be on this sheet. Make sure to keep the data separate from each other.

- b. Paste the values to an empty area on the sheet. The pasted data becomes the saved snapshot of data for input onto the Alignment sheet.

If a rapid recovery of IMU reference is needed, the display data can be marked and copied without regard to the center point, but the recovery error will be larger. If the error is so large

that stars cannot be tracked (assuming the -Y star tracker is available) the procedure can be repeated later to refine the accuracy.

IF USING QBI (PC Version):

- c. When the RT plot of the short term orbiter to ISS relative attitude deltas indicates that the three axes are as near as possible to the center of their ranges, make a hardcopy of MCC display ORB/ISS Attitudes for the IMU currently selected onboard.
- d. Verify that a good hardcopy has been made (get it out of the printer) before proceeding to the next step-
- e. IF recovering more than one IMU (the procedure is written to recover only one IMU using an IMU matrix alignment) then proceed with steps f-h. The steps are necessary since there is only one QBI computed from the gimbal angles of the onboard selected IMU, it is necessary to switch the onboard selected for each of the recovery IMUs and the reference IMU making a hardcopy of MCC display ORB/ISS Attitudes for each IMU after it is selected.
- f. With the orbiter in free drift, switch the onboard selected IMU and make another hardcopy of MCC display ORB/ISS Attitudes. The order of recovery reference and backup recovery IMUs is not important. There is a small additional error introduced because the hardcopy data points are not at the exact same point in the structural oscillation cycle, but assuming the second and third data points are taken reasonably promptly, the error is negligible (don't take one point and then wait a half rev to take the next one). Verify that a good hardcopy has been made before continuing.
- g. With the orbiter still in free drift, switch the onboard selected IMU to the last IMU (unless it will not be used in this procedure) and make another hardcopy of MCC display ORB/ISS Attitudes. Verify that a good hardcopy has been made before continuing.
- h. If orbiter attitude control is required, before reinstating attitude control, switch back to the IMU that was the onboard selected IMU at the beginning of step f .

6. Alignment Sheet setup

IF USING QRSM (Workstation Version):

- a. Copy and paste the QRSM and the QJ2K_ISS quaternions from the Inputs sheet to the Alignment sheet.
- b. Verify all inputs with great care.

IF USING QBI (PC Version):

- c. Enter the QBI and the QJ2K_ISS quaternions on the Alignment sheet, making sure that the SEL IMU number on the hardcopy matches the IMU numbers entered for the recovery IMU, and if used, the reference IMU and the backup recovery IMU.

Note that, unlike in the QRSM version, there are separate QJ2K_ISS quaternions associated with the QBI for each IMU.

7. Verification of good data on Alignment sheet
 - a. Verify that the quaternions entered have a magnitude near 1.0 (at least six places). Any variance indicates an input error.
 - b. Verify the orthogonality of the present REFSMMATs (blue highlight, purple on the workstation).
8. Exporting the Present REFSMMAT from the Alignment sheet

IF USING QRSM (Workstation Version):

- a. The Present REFSMMAT of the Recovery IMU, to export from the spreadsheet can be found on the Alignment Sheet under Present REFSMMAT. For the other two IMUs, we will use the Current REFSMMAT on the Cal Data Sheet.
 - b. Three files are required to build the uplink REFSMMAT. One file for each IMU with the same file name and unique file extension (filename.ref1,filename.ref2, filename.ref3); naming the other two files is redundant but necessary since we always have to uplink all three REFSMMATs.
 - c. Begin by marking the 9 cells with the Recovery IMU 's REFSMMAT (Recall that for the Recovery IMU, use the Present REFSMMAT from the Alignment sheet) and select Export on the File menu. In the Export window select the file format 'Tab Separated Values'. Move to the Refs subdirectory in the flight specific directory. Type the filename with file extension (e.g. 118_mpsr.ref1). Remove the default file extension '.tsv' if it is present. Select OK to save the file. For the other two IMUs, we will also export the Present REFSMMAT;; (e.g. 118_mpsr.ref2, 118_mpsr.ref3).
9. Use the application under the Apps pull-down menu, entfref, to verify the REFSMMAT file you just created is correct with the Recovery IMU Present REFSMMAT and the other two IMUs Current REFSMMAT. In the entfref program, select option 3-view a REFSMMAT file. Type the file that you created (e.g. 118_mpsr) and it should display all three REFSMMAT, one for each IMU.
 10. Once the REFSMMAT file is verified, Build a REFSMMAT uplink load by running NREF. If using the pc spreadsheet, manually input the REFSMMATs into NREF. If using the workstation spreadsheet, read into NREF the file generated in step 8c (select option 2 – read from a file). NREF makes all rows and columns slightly less than unity at the appropriate numerical place and it provides an orthogonality check of the matrix inputs.
 11. Verify that the recovery IMU is not being used for attitude control (not selected or free drift).
 12. Uplink the REFSMMATs load.
 13. Once the uplink is complete, Matrix align the Recovery IMU to itself.

After the uplink and align is complete, the Recovery IMU has now copied its Desired REFSMMATs to the Current REFSMMATs slot (in this case we placed the Present REFSMMAT into the Desired REFSMMAT slot taken from ISS). The Recovery IMU now has a good attitude reference.

14. Select the recovered IMU and verify that the long term orbiter to ISS attitude delta RTPLOTS are restored to near normal (there is some change because this alignment is accurate only to about a degree).
15. Now that we have recovered the first IMU, uplink the original Desired (Launch) REFSMMATs for all three IMUs. This is in preparation to move the all IMUs back to their desired position.
16. Once the original Desired (Launch) REFSMMATs has been uplinked, align all three IMUs to the Recovered IMU via IMU to IMU torque align, thus restoring skew.

If necessary, the other IMUs may be recovered quickly (without waiting to uplink the original desired REFSMMATs). The other IMUs can be recovered by performing a Matrix align using IMU data and using the Recovery IMU as reference. Note: This will not restore skew but can be recovered at a later time.

IMU Alignment by Adjusting Drift Compensations

After loss of the -Y star tracker, depending on the remaining docked time, the IMUs may drift far enough to make it beneficial to use ISS attitude to correct them. In that case, the torquing angles generated by the spreadsheet, may be used to calculate drift overcompensation to be used to cause the IMUs to drift back into alignment.

1. Find torquing angles by the QRSM Version spreadsheet (the QBI Version may be used if only the onboard selected IMU is to be adjusted). Torquing angles are displayed immediately below the present REFSMMAT on the Alignment sheet for each IMU.
2. Determine the overcompensation period in hours. A too short time period will make the timing of the nominal compensation uplink at the end of the time period too critical and greater harm will be done if the nominal compensation uplink cannot be done on time – 1 hour is a good time period. Make sure there will be uplink capability at the times planned for the uplink of overcompensation and for the uplink of the nominal compensation.
3. Reverse the signs of the torquing angles and divide by the time selected in step 2.
4. Build a gyro compensation uplink by adding the result of step 3 to the nominal compensation numbers.
5. Uplink the overcompensation numbers, noting the time at which the downlisted gyro compensations change.
6. As close as possible to the end of the overcompensation period as measured from the time recorded in step 5, uplink nominal compensations.

ORBITER TO ISS CALIBRATION

Mission = STS-114
VEH = SMS

INPUTS	OUTPUTS	INPUT Checks		
QBI	QJ2K_ISS		QM50_J2K	Reference QM50_J2K
-0.126454115	-0.556238830		0.999981427	0.999981427
0.194898963	0.405341119		-0.000000002	-0.000000002
-0.898853600	-0.715641201		0.002429547	0.002429547
0.371596634	0.118973084		-0.005589575	-0.005589575
0.999999051	0.999999991		1.000000000	1.000000000

----- SCP EQUATION 1 ----->

QBI *	QM50_J2K =	QB_J2K *	QJ2K_ISS =	QB_ISS	POS SCALAR	Angles B_ISS
-0.126454235	0.999981427	-0.122191008	-0.556238835	-0.699737591	0.699737591	U = 91.188
0.194899148	-0.000000002	0.199016930	0.405341123	-0.000304552	0.000304552	X = 0.039
-0.898854453	0.002429547	-0.898055582	-0.715641207	0.714399836	-0.714399836	Y = -91.188
0.371596987	-0.005589575	0.372770425	0.118973085	-0.000292686	0.000292686	Z = 0.037
1.000000000	1.000000000	1.000000000	1.000000000	1.000000000	1.000000000	

PYR B_ISS
P = -91.188
Y = -0.001
R = 0.048

IMU 1 CURRENT REFSMMAT

0.00669540	-0.75740975	0.65290511	90.00	0.999999719
-0.22975832	0.63428628	0.73816764	90.00	0.999999724
-0.97322464	-0.15495229	-0.16977441	90.00	0.999999881
90.00	90.00	90.00		
0.99999996	0.99999942	0.99999995		

IMU 2 CURRENT REFSMMAT

-0.76662076	0.19147444	0.61288667	90.00	0.999999955
0.54355776	-0.31459677	0.77818620	90.00	0.999999968
0.34181482	0.92971247	0.13709891	90.00	0.999999382
90.00	90.00	90.00		
0.99999990	0.99999944	0.99999997		

IMU 3 CURRENT REFSMMAT

0.42533076	0.38125098	0.82081723	90.00	0.999999745
-0.64839393	-0.50437438	0.57025552	90.00	0.999999782
0.63141024	-0.77475995	0.03267503	90.00	0.999999764
90.00	90.00	90.00		
0.99999992	0.99999940	0.99999997		

NOTES:

1. The constant QM50_J2K should be valid for many years. If an error is discovered, or if the constant changes, it will be necessary to unprotect the spreadsheet in order to make the change. The Reference QM50_J2K is provided for quick recovery from an erroneous change to QM50_J2K; it is not used in any calculations. The Reference should be updated only if an error or change has been thoroughly confirmed.

FIGURE 2.22-1 Calibration Sheet

IMU ALIGNMENT FROM ISS ATTITUDE (QBI)

Recovery IMU = 1			INPUTS	OUTPUTS	Verif Checks	FLIGHT= STS-114 VEH ID = SMS	
QBI	QJ2K_ISS	QB_ISS	Present REFSMMAT for MATRIX ALIGN				
-0.35048586	0.53128642	0.69973759	-0.194084868	-0.730053656	-0.655250122	P1	
0.03045857	-0.02243681	0.00030455	-0.390820636	0.670197890	-0.630946922		
0.84090392	-0.75090629	-0.71439984	0.899772357	0.133628019	-0.415395304	M50	
0.41123294	0.39162618	0.00029269	90.00	90.00	90.00	COLUMNS	
1.00000000	0.99999999	1.00000000	1.00000000	1.00000000	1.00000000		
CURRENT REFSMMAT			90.00	90.00	90.00	ROWS	
0.00669540	-0.75740975	0.65290511	1.00000000	1.00000000	1.00000000		
-0.22975832	0.63428628	0.73816764	TORQUING ANGLES P1_C1				
-0.97322464	-0.15495229	-0.16977441	TOT= 145.735				
90.00	90.00	90.00	X= -105.120				
1.00000000	0.99999942	0.99999995	Y= 100.905				
90.00	90.00	90.00	Z= -2.592				
0.99999972	0.99999972	0.99999988					

Reference IMU = 2			Present REFSMMAT for MATRIX ALIGN				
QBI	QJ2K_ISS	QB_ISS					
-0.39697478	0.53128642	0.69973759	0.097948624	-0.650729318	-0.752965751	P2	
0.79502709	-0.02243681	0.00030455	-0.385811053	0.672605431	-0.631467945		
0.43376807	-0.75090629	-0.71439984	0.917363558	0.352353926	-0.185177787	M50	
0.14895707	0.39162618	0.00029269	90.00	90.00	90.00	COLUMNS	
1.00000000	0.99999999	1.00000000	1.00000000	1.00000000	1.00000000		
CURRENT REFSMMAT			90.00	90.00	90.00	ROWS	
-0.76662076	0.19147444	0.61288667	1.00000000	1.00000000	1.00000000		
0.54355776	-0.31459677	0.77818620	TORQUING ANGLES P2_C2				
0.34181482	0.92971247	0.13709891	TOT= 168.253				
90.00	90.00	90.00	X= -67.433				
0.99999990	0.99999944	0.99999997	Y= 30.806				
90.00	90.00	90.00	Z= 151.039				
0.99999995	0.99999997	0.99999938					

Backup Recovery IMU = 3			Present REFSMMAT for MATRIX ALIGN				
QBI	QJ2K_ISS	QB_ISS					
0.17656052	0.53128642	0.69973759	0.004170744	-0.663986313	-0.747733095	P3	
-0.80099586	-0.02243681	0.00030455	-0.893159721	-0.338750061	0.295827837		
-0.31825807	-0.75090629	-0.71439984	-0.449720266	0.666611260	-0.594458670	M50	
0.47533548	0.39162618	0.00029269	90.00	90.00	90.00	COLUMNS	
1.00000000	0.99999999	1.00000000	1.00000000	1.00000000	1.00000000		
CURRENT REFSMMAT			90.00	90.00	90.00	ROWS	
0.42533076	0.38125098	0.82081723	1.00000000	1.00000000	1.00000000		
-0.64839393	-0.50437438	0.57025552	TORQUING ANGLES P3_C3				
0.63141024	-0.77475995	0.03267503	TOT= 152.024				
90.00	90.00	90.00	X= -14.873				
0.99999992	0.99999940	0.99999997	Y= 148.706				
90.00	90.00	90.00	Z= -27.873				
0.99999975	0.99999978	0.99999976					

Recovery IMU 1			Backup Recovery IMU 3		
FICTITIOUS DESIRED REFSMMAT - Align IMU 1 to 2			FICTITIOUS DESIRED REFSMMAT - Align IMU 3 to 2		
-0.634327467	-0.063664456	-0.770438513	0.527848993	0.322486082	-0.785734158
0.744110207	-0.320479470	-0.586167987	-0.418066026	-0.706629660	-0.570872422
-0.209591661	-0.945113616	0.250662302	-0.739321471	0.629823190	-0.238173279
90.00	90.00	90.00	90.00	90.00	90.00
1.00000000	1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
90.00	90.00	90.00	90.00	90.00	90.00
1.00000000	1.00000000	1.00000000	1.00000000	1.00000000	1.00000000

FIGURE 2.22-2a QBI Version Alignment Sheet Page 1

IMU ALIGNMENT FROM ISS ATTITUDE (QBI)

page 2

C1_M50										-----SCP EQUATION 4----->		
OR <-----SCP EQUATION 2----->										Pos scal		
QP1_I*	QI_B =	QP1_B*	QB_ISS=	QP1_ISS*	QISS_J2K=	QP1_J2K*	QJ2K_M50=	QP1_M50 *	QM50_C1 =	QP1_C1	QP1_C1	QP1_C1
0.6064667	-0.3504859	0.4293584	0.6997376	-0.3446344	0.5312864	0.5177009	0.9999814	0.5149558	0.6064667	-0.2945839	0.2945839	0.2945839
-0.3681653	-0.0304586	0.0178085	0.0003046	0.0154536	0.0224368	0.3749975	0.0000000	0.3711848	0.3681653	0.6893021	-0.6893021	-0.6893021
0.6703295	-0.8409039	-0.9029480	-0.7143998	-0.9385641	0.7509063	-0.7515902	-0.0024295	-0.7549301	-0.6703295	-0.6616601	0.6616601	0.6616601
0.2175105	-0.4112329	0.0043755	0.0002927	-0.0092600	-0.3916262	0.1627107	0.0055896	0.1646904	-0.2175105	0.0169940	-0.0169940	-0.0169940
1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000
C1_M50										-----SCP EQUATION 7----->		
QC1_M50 *	QM50_P2 =	QD1_P2 *	QC2_M50 =	QD1_M50								
0.6064667	0.6295586	-0.1837714	0.1181962	-0.2719629								
-0.3681653	-0.3906792	-0.6835076	0.3204973	0.3299582								
0.6703295	0.6632938	0.7005695	0.5733513	0.5155545								
0.2175105	0.2175105	-0.1052000	0.0908173	0.7447009	-0.7425411							
0.9999999	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000							
C2_M50										-----SCP EQUATION 4----->		
OR <-----SCP EQUATION 2----->										Pos scal		
QP2_I	QI_B =	QP2_B*	QB_ISS=	QP2_ISS*	QISS_J2K=	QP2_J2K*	QJ2K_M50=	QP2_M50 *	QM50_C2=	QP2_C2	QP2_C2	QP2_C2
0.1181962	-0.3969748	0.5675131	0.6997376	-0.1909846	0.5312864	0.6317465	0.9999814	0.6295586	0.1181962	-0.1023348	0.1023348	0.1023348
0.3204973	-0.7950271	0.0164242	0.0003046	0.0139783	0.0224368	0.3941239	0.0000000	0.3906792	-0.3204973	0.3986770	-0.3986770	-0.3986770
0.5733513	-0.4337681	-0.8231928	-0.7143998	-0.9814539	0.7509063	-0.6595682	-0.0024295	-0.6632938	-0.5733513	-0.1821343	0.1821343	0.1821343
0.7447009	-0.1489571	0.0035747	0.0002927	-0.0088153	-0.3916262	0.1026283	0.0055896	0.1052000	-0.7447009	-0.8929789	0.8929789	0.8929789
1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000
C2_M50										Reference IMU 2		
C2_P2 *	C2_M50 =	D2_M50	FICTITIOUS	DESIRED	REFSMAT	ALIGN	IMU 2 TO	IMU 2				
0.1181962	0.1023348	0.1181962	0.6537498	=	0.2711518	-0.8350384	-0.4787354	D2	90.00	1.0000000		
0.3204973	0.3986770	0.3204973	0.4562752	=	-0.1613686	0.4508921	-0.8778704		90.00	1.0000000		
0.5733514	-0.1821343	0.5733513	-0.5459462		0.9489135	0.3152890	-0.0124888	M50	90.00	1.0000000		
0.7447009	-0.8929789	0.7447009	0.2576176		90.00	90.00	90.00					
1.0000001	1.0000000	1.0000000	1.0000000		1.0000000	1.0000000	1.0000000					
C3_M50										-----SCP EQUATION 4----->		
OR <-----SCP EQUATION 2----->										Pos scal		
QP3_I*	QI_B =	QP3_B*	QB_ISS=	QP3_ISS*	QISS_J2K=	QP3_J2K*	QJ2K_M50=	QP3_M50 *	QM50_C3 =	QP3_C3	QP3_C3	QP3_C3
0.4882704	0.1765605	0.3563696	0.6997376	-0.1628555	0.5312864	0.1321456	0.9999814	0.1331935	0.4882704	-0.2417147	0.2417147	0.2417147
-0.6886636	0.8009959	0.3911970	0.0003046	-0.1707000	0.0224368	0.7001076	0.0000000	0.6959489	0.6886636	0.0949318	-0.0949318	-0.0949318
0.0969786	0.3182581	-0.5771049	-0.7143998	-0.6587163	0.7509063	-0.5551367	-0.0024295	-0.5593608	-0.0969786	-0.9491633	0.9491633	0.9491633
-0.5271902	-0.4753355	-0.6220254	0.0002927	-0.7144456	-0.3916262	-0.4291970	0.0055896	-0.4301513	0.5271902	0.1779074	-0.1779074	-0.1779074
1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000
C3_M50										-----SCP EQUATION 7----->		
QC3_M50 *	QM50_P2 =	QD3_P2 *	QC2_M50 =	QD3_M50								
0.4882704	0.6295586	-0.0814374	0.1181962	0.3817873								
-0.6886634	-0.3906792	-0.2848314	0.3204973	0.7862334								
0.0969786	0.6632938	0.5184353	0.5733513	-0.0303917								
-0.5271901	-0.1052000	-0.8021620	0.7447009	-0.4849246								
0.9999997	1.0000000	1.0000000	1.0000000	1.0000000								
FSW equation (SCP EQUATION 5) - IMU/IMU for Recovery to REF										Pos scaler		
SKEW IMU 1 to IMU 2										Pos scaler		
QP1_M50 *	QM50_P2 =	QP1_P2 *	QC2_M50 =	QP1_M50 *	QM50_D1 =	QP1_D1	QP1_D1	Torquing Angles				
0.5149558	0.6295586	0.9872749	0.1181962	0.2064156	-0.2719629	-0.2945839	0.2945839	TOT =	145.735			
0.3711848	-0.3906792	0.0026806	0.3204973	0.1978836	-0.3299582	0.6893021	-0.6893021	X =	-105.120			
-0.7549301	0.6632938	-0.1589983	0.5733513	0.5455155	-0.5155545	-0.6616601	0.6616601	Y =	100.905			
0.1646904	-0.1052000	0.0007779	0.7447009	0.7878119	0.7425411	0.0169940	-0.0169940	Z =	-2.592			
1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000					

FIGURE 2.22-2b QBI Version Alignment Sheet Page 2

IMU ALIGNMENT FROM ISS ATTITUDE (QRSM)

Recovery IMU = 1			INPUTS	OUTPUTS	Verif Checks	FLIGHT= STS-114
QRSM	QJ2K_ISS	QB_ISS				VEH ID = SMS
CURRENT REFSMMAT			Present REFSMMAT for MATRIX ALIGN			
0.344116807	0.531286418	0.69973759		-0.194084868	-0.730053656	-0.655250122 P1
-0.018136542	-0.022436807	0.00030455		-0.390820636	0.670197890	-0.630946922
0.938747525	-0.750906289	-0.71439984		0.899772357	0.133628019	-0.415395304 M50
-0.002711806	0.391626179	0.00029269		90.00	90.00	90.00 COLUMNS
0.99999979	0.99999999	1.00000000		1.00000000	1.00000000	1.00000000
CURRENT REFSMMAT				90.00	90.00	90.00 ROWS
0.00669540	-0.75740975	0.65290511 C1		1.00000000	1.00000000	1.00000000
-0.22975832	0.63428628	0.73816764		TORQUING ANGLES P1_C2		
-0.97322464	-0.15495229	-0.16977441 M50		TOT=	145.735	
90.00	90.00	90.00 COLUMNS		X=	-105.120	
0.99999996	0.99999942	0.99999995		Y=	100.905	
90.00	90.00	90.00 ROWS		Z=	-2.592	
0.99999972	0.99999972	0.99999988				

Reference IMU = 2			INPUTS	OUTPUTS	Verif Checks	FLIGHT= STS-114
QRSM	QJ2K_ISS	QB_ISS				VEH ID = SMS
CURRENT REFSMMAT			Present REFSMMAT for MATRIX ALIGN			
0.489047885	0.53128642	0.69973759		0.097948624	-0.650729318	-0.752965751 P2
-0.016684186	-0.02243681	0.00030455		-0.385811053	0.672605431	-0.631467945
0.872094750	-0.75090629	-0.71439984		0.917363558	0.352353926	-0.185177787 M50
-0.002042338	0.39162618	0.00029269		90.00	90.00	90.00 COLUMNS
0.99999981	0.99999999	1.00000000		1.00000000	1.00000000	1.00000000
CURRENT REFSMMAT				90.00	90.00	90.00 ROWS
-0.76662076	0.19147444	0.61288667 C2		1.00000000	1.00000000	1.00000000
0.54355776	-0.31459677	0.77818620		TORQUING ANGLES P2_C2		
0.34181482	0.92971247	0.13709891 M50		TOT=	168.253	
90.00	90.00	90.00 COLUMNS		X=	-67.433	
0.99999990	0.99999944	0.99999997		Y=	30.806	
90.00	90.00	90.00 ROWS		Z=	151.039	
0.99999995	0.99999997	0.99999938				

Backup Recovery IMU = 3			INPUTS	OUTPUTS	Verif Checks	FLIGHT= STS-114
QRSM	QJ2K_ISS	QB_ISS				VEH ID = SMS
CURRENT REFSMMAT			Present REFSMMAT for MATRIX ALIGN			
0.301538408	0.53128642	0.69973759		0.004170744	-0.663986313	-0.747733095 P3
-0.332067549	-0.02243681	0.00030455		-0.893159721	-0.338750061	0.295827837
0.607555509	-0.75090629	-0.71439984		-0.449720266	0.666611260	-0.594458670 M50
0.655501068	0.39162618	0.00029269		90.00	90.00	90.00 COLUMNS
0.99999981	0.99999999	1.00000000		1.00000000	1.00000000	1.00000000
CURRENT REFSMMAT				90.00	90.00	90.00 ROWS
0.42533076	0.38125098	0.82081723 C3		1.00000000	1.00000000	1.00000000
-0.64839393	-0.50437438	0.57025552		TORQUING ANGLES P3_C3		
0.63141024	-0.77475995	0.03267503 M50		TOT=	152.024	
90.00	90.00	90.00 COLUMNS		X=	-14.873	
0.99999992	0.99999940	0.99999997		Y=	148.706	
90.00	90.00	90.00 ROWS		Z=	-27.873	
0.99999975	0.99999978	0.99999976				

Recovery IMU 1			Backup Recovery IMU 3		
FICTITIOUS DESIRED REFSMMAT - Align IMU 1 to 2			FICTITIOUS DESIRED REFSMMAT - Align IMU 3 to 2		
-0.634327467	-0.063664456	-0.770438513 D1	0.527848993	0.322486082	-0.785734158 D3
0.744110207	-0.320479470	-0.586167987	-0.418066026	-0.706629660	-0.570872422
-0.209591661	-0.945113616	0.250662302 M50	-0.739321471	0.629823190	-0.238173279 M50
90.00	90.00	90.00 COLUMNS	90.00	90.00	90.00 COLUMNS
1.00000000	1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
90.00	90.00	90.00 ROWS	90.00	90.00	90.00 ROWS
1.00000000	1.00000000	1.00000000	1.00000000	1.00000000	1.00000000

FIGURE 2.22-3a QRSM Version Alignment Sheet Page 1

IMU ALIGNMENT FROM ISS ATTITUDE (QRSM)

page 2

C1_M50											←-----SCP EQUATION 4-----→		
OR ←----- SCP EQUATION 2 -----→											Pos scal		
QP1_I*	QI_B =	QP1_B*	QB_ISS=	QP1_ISS*	QISS_J2K=	QP1_J2K*	QJ2K_M50=	QP1_M50*	QM50_C1 =	QP1_C1	QP1_C1		
0.6064667	-0.3504859	0.4293584	0.6997376	-0.3446344	0.5312864	0.5177009	0.9999814	0.5149558	0.6064667	-0.2945839	0.2945839		
-0.3681653	-0.0304586	0.0178085	0.0003046	0.0154536	0.0224368	0.3749975	0.0000000	0.3711848	0.3681653	0.6893021	-0.6893021		
0.6703295	-0.8409039	-0.9029480	-0.7143998	-0.9385641	0.7509063	-0.7515902	-0.0024295	-0.7549301	-0.6703295	-0.6616601	0.6616601		
0.2175105	-0.4112329	0.0043755	0.0002927	-0.0092600	-0.3916262	0.1627107	0.0055896	0.1646904	-0.2175105	0.0169940	-0.0169940		
1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000		
←----- SCP EQUATION 7 -----→													
C1_M50	QC1_M50 * QM50_P2 = QD1_P2 * QC2_M50 = QD1_M50												
0.6064667	0.6064667 0.6295586 -0.1837714 0.1181962 -0.2719629												
-0.3681653	-0.3681653 -0.3906792 -0.6835076 0.3204973 0.3299582												
0.6703294	0.6703295 0.6632938 0.7005695 0.5733513 0.5155545												
0.2175105	0.2175105 -0.1052000 0.0908173 0.7447009 -0.7425411												
0.9999999	1.0000000 1.0000000 1.0000000 1.0000000 1.0000000												
C2_M50											←-----SCP EQUATION 4-----→		
OR ←----- SCP EQUATION 2 -----→											Pos scal		
QP2_I	QI_B =	QP2_B*	QB_ISS=	QP2_ISS*	QISS_J2K=	QP2_J2K*	QJ2K_M50=	QP2_M50*	QM50_C2=	QP2_C2	QP2_C2		
0.1181962	-0.3969748	0.5675131	0.6997376	-0.1909846	0.5312864	0.6317465	0.9999814	0.6295586	0.1181962	-0.1023348	0.1023348		
0.3204973	-0.7950271	0.0164242	0.0003046	0.0139783	0.0224368	0.3941239	0.0000000	0.3906792	-0.3204973	0.3986770	-0.3986770		
0.5733513	-0.4337681	-0.8231928	-0.7143998	-0.9814539	0.7509063	-0.6595682	-0.0024295	-0.6632938	-0.5733513	-0.1821343	0.1821343		
0.7447009	-0.1489571	0.0035747	0.0002927	-0.0088153	-0.3916262	0.1026283	0.0055896	0.1052000	-0.7447009	-0.8929789	0.8929789		
1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000		
←----- SCP EQUATION 9 -----→													
C2_M50	C2_P2 * C2_M50 = D2_M50										Reference IMU 2		
0.1181962	0.1023348 0.1181962 0.6537498										FICTITIOUS DESIRED REFSMMAT ALIGN IMU 2 TO IMU 2		
0.3204973	0.3986770 0.3204973 0.4562752										=		
0.5733514	-0.1821343 0.5733513 -0.5459462										0.2711518 -0.8350384 -0.4787354 D2		
0.7447009	-0.8929789 0.7447009 0.2576176										-0.1613686 0.4508921 -0.8778704		
1.0000001	1.0000000 1.0000000 1.0000000										0.9489135 0.3152890 -0.0124888 M50		
											90.0000000 90.0000000 90.0000000		
											90.0000000 1.0000000 1.0000000		
											90.0000000 1.0000000 1.0000000		
											1.0000000 1.0000000 1.0000000		
C3_M50											←-----SCP EQUATION 4-----→		
OR ←----- SCP EQUATION 2 -----→											Pos scal		
QP3_I*	QI_B =	QP3_B*	QB_ISS=	QP3_ISS*	QISS_J2K=	QP3_J2K*	QJ2K_M50=	QP3_M50*	QM50_C3 =	QP3_C3	QP3_C3		
0.4882704	0.1765605	0.3563696	0.6997376	-0.1628555	0.5312864	0.1321456	0.9999814	0.1331935	0.4882704	-0.2417147	0.2417147		
-0.6886636	0.8009959	0.3911970	0.0003046	-0.1707000	0.0224368	0.7001076	0.0000000	0.6959489	0.6886636	0.0949318	-0.0949318		
0.0969786	0.3182581	-0.5771049	-0.7143998	-0.6587163	0.7509063	-0.5551367	-0.0024295	-0.5593608	-0.0969786	-0.9491633	0.9491633		
-0.5271902	-0.4753355	-0.6220254	0.0002927	-0.7144456	-0.3916262	-0.4291970	0.0055896	-0.4301513	0.5271902	0.1779074	-0.1779074		
1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000		
←----- SCP EQUATION 7 -----→													
C3_M50	QC3_M50 * QM50_P2 = QD3_P2 * QC2_M50 = QD3_M50												
0.4882703	0.4882704 0.6295586 -0.0814374 0.1181962 0.3817873												
-0.6886634	-0.6886636 -0.3906792 -0.2848314 0.3204973 0.7862334												
0.0969786	0.0969786 0.6632938 0.5184353 0.5733513 -0.0303917												
-0.5271901	-0.5271902 -0.1052000 -0.8021620 0.7447009 -0.4849246												
0.9999997	1.0000000 1.0000000 1.0000000 1.0000000 1.0000000												
←----- FSW equation (SCP EQUATION 5) - IMU/IMU for Recovery to REF -----→													
←----- SKEW IMU 1 to IMU 2-----→											Pos scaler		
QP1_M50 * QM50_P2 =	QP1_P2 *	QC2_M50 =	QP1_M50 * QM50_D1 =	QP1_D1	QP1_D1	Torquing Angles					TOT =		
0.5149558	0.6295586	0.9872749	0.1181962	0.2064156	-0.2719629	-0.2945839	0.2945839						145.735
0.3711848	-0.3906792	0.0026806	0.3204973	0.1978836	-0.3299582	0.6893021	-0.6893021						X =
-0.7549301	0.6632938	-0.1589983	0.5733513	0.5455155	-0.5155545	-0.6616601	0.6616601						Y =
0.1646904	-0.1052000	0.0007779	0.7447009	0.7878119	0.7425411	0.0169940	-0.0169940						Z =
1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000						-2.592

FIGURE 2.22-3b QRSM Version Alignment Sheet Page 2

IMU ALIGNMENT FROM ISS ATTITUDE (QRSM)

page 3

VAR	SMS	OV103	OV104	OV105	VEHICLE = SMS
QB_NB	QB_NB	QB_NB	QB_NB	QB_NB	FLIGHT = STS-114
0.995724698185	0.995724698185	0.995707095443	0.995726442520	0.995638856102	
0.000000000000	0.000000000000	0.000662292053	0.000228947674	-0.001173055495	
-0.092370587447	-0.092370587447	-0.092557699383	-0.092350205108	-0.093278887661	
0.000000000000	0.000000000000	-0.000117211507	0.000488512298	-0.000970194961	
1.000000000000	1.000000000000	1.000000000000	0.999999999889	1.000000000000	

VAR	SMS	OV103	OV104	OV105	This VEH
QR1_NB	QR1_NB	QR1_NB	QR1_NB	QR1_NB	QR1_NB
1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000
0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000
0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000
0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000	0.000000000000
1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000

VAR	SMS	OV103	OV104	OV105	This VEH
QR2_NB	QR2_NB	QR2_NB	QR2_NB	QR2_NB	QR2_NB
1.000000000000	1.000000000000	0.999999943286	0.999999999622	0.999999999828	1.000000000000
0.000000000000	0.000000000000	-0.000012728526	0.000001706475	-0.000002340375	0.000000000000
0.000000000000	0.000000000000	0.000001430000	-0.000007272375	-0.000012912850	0.000000000000
0.000000000000	0.000000000000	0.000336545844	-0.000026405250	-0.000013114625	0.000000000000
1.000000000000	1.000000000000	1.000000000000	0.999999999999	1.000000000000	1.000000000000

VAR	SMS	OV103	OV104	OV105	This VEH
QR3_NB	QR3_NB	QR3_NB	QR3_NB	QR3_NB	QR3_NB
1.000000000000	1.000000000000	0.999999949567	0.999999999860	0.999999999931	1.000000000000
0.000000000000	0.000000000000	0.000018373876	0.000005854900	0.000003704300	0.000000000000
0.000000000000	0.000000000000	-0.000009708925	-0.000013332450	-0.000006312175	0.000000000000
0.000000000000	0.000000000000	0.000316914241	-0.000008247475	-0.000009149225	0.000000000000
1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000

----- SCP EQUATION 3 -----

SMS	Recovery IMU 1				REFSMAT	QBI
QB_NB*	QNB_R1 =	QB_R1 *	QR1_SM1 =	QB1_SM1 *	QC1_M50 =	QB1_I
0.995724698185	1.000000000000	0.995724698185	0.344116879161	0.429358354175	0.606466721338	-0.350485862442
0.000000000000	0.000000000000	0.000000000000	-0.018136545803	-0.017808515430	-0.368165333785	0.030458565958
-0.092370587447	0.000000000000	-0.092370587447	0.938747721855	0.902948013737	0.670329459625	0.840903920107
0.000000000000	0.000000000000	0.000000000000	-0.002711806569	-0.004375496167	0.217510501969	0.411232942670
1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000

----- SCP EQUATION 3 -----

SMS	Reference IMU 2				REFSMAT	QBI
QB_NB*	QNB_R2 =	QB_R2 *	QR2_SM2 =	QB2_SM2 *	QC2_M50 =	QB2_I
0.995724698185	1.000000000000	0.995724698185	0.489047977917	0.567513069881	0.118196206440	-0.396974776899
0.000000000000	0.000000000000	0.000000000000	-0.016684189170	-0.016424207229	0.320497279082	0.795027092933
-0.092370587447	0.000000000000	-0.092370587447	0.872094915695	0.823192797709	0.573351336759	0.433768071740
0.000000000000	0.000000000000	0.000000000000	-0.002042338388	-0.003574735130	0.744700876541	0.148957067462
1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000

----- SCP EQUATION 3 -----

SMS	Backup Recovery IMU 3				This VEH	QBI
QB_NB *	QNB_R3 =	QB_R3 *	QR3_SM3 =	QB3_SM3 *	QC3_M50 =	QB3_I
0.995724698185	1.000000000000	0.995724698185	0.301538466006	0.356369568124	0.488270425576	0.176560522526
0.000000000000	0.000000000000	0.000000000000	-0.332067612879	-0.391196953982	-0.688663639673	-0.800995860473
-0.092370587447	0.000000000000	-0.092370587447	0.607555625874	0.577104856961	0.096978593235	-0.318258066551
0.000000000000	0.000000000000	0.000000000000	0.655501194098	0.622025448179	-0.527190226914	0.475335477810
1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000	1.000000000000

FIGURE 2.22-3c QRSM Version Alignment Sheet Page 3

QBI	QJ2K_ISS	IMU 1 QRSM	IMU 2 QRSM	IMU 3 QRSM
-0.60242242	0.51012707	0.52170533	-0.04047836	-0.11379904
0.60645765	-0.06809855	0.29193938	0.07827145	-0.52940941
-0.12907916	-0.33997157	0.66217899	-0.23114276	0.50253367
-0.50262427	0.78711641	0.45178938	-0.96892101	-0.67396981
MET 002/12:23:52				
IMU 1 CURRENT REFSMMAT				
0.00669540	-0.75740975	0.65290511		
-0.22975832	0.63428628	0.73816764		
-0.97322464	-0.15495229	-0.16977441		
IMU 2 CURRENT REFSMMAT				
-0.76662076	0.19147444	0.61288667		
0.54355776	-0.31459677	0.77818620		
0.34181482	0.92971247	0.13709891		
IMU 3 CURRENT REFSMMAT				
0.42533076	0.38125098	0.82081723		
-0.64839393	-0.50437438	0.57025552		
0.63141024	-0.77475995	0.03267503		
Snap Shot Data by marking and copying the above data "values" to the cells below				

Figure 2.22-4 Workstation Version Inputs Sheet

IMU 1 REFSMMAT		Primary Recovery IMU (C4)	1
0.66135943	0.37164189	0.65152591	
-0.43223063	-0.52106652	0.73597986	Reference IMU (C20)
0.61300929	-0.76835668	-0.18397725	Secondary Recovery IMU (C36)
			3
IMU 2 REFSMMAT			
0.21721190	-0.76450664	0.60691643	
0.01246959	0.62388384	0.78141689	
-0.97604430	-0.16216517	0.14504826	
IMU 3 REFSMMAT			
-0.53414163	0.17247923	0.82761321	
0.76334431	-0.32231908	0.55983558	
0.36331554	0.93078533	0.04050300	

		IMU/IMU to Self (C20)	2
IMU 1 REFSMMAT			
0.66115284	0.37630391	0.64905423	
-0.43174022	-0.51668543	0.73934811	
0.61357695	-0.76904486	-0.17914273	
IMU 2 REFSMMAT			
0.21654845	-0.76853554	0.60204642	
0.01284952	0.61886934	0.78538884	
-0.97618731	-0.16233873	0.14389051	
IMU 3 REFSMMAT			
-0.53417271	0.17735416	0.82656187	
0.76365960	-0.31814969	0.56178671	
0.36260593	0.93130301	0.03450859	

Figure 2.22-5 Workstation Version REFS Outputs Sheet

TITLE

IMU MANAGEMENT WHILE DOCKED

PURPOSE

The purpose of this SCP is to describe the STS-114 docked operations IMU drift management and provide a procedure and guidelines for similar management on future flights. This procedure does not take the place of GNC SCP 2.4 in any way, shape, or form. As was done on STS-114, SCP 2.4 must be used to calculate all gyro drift parameters, generate the associated DSM for uplink, and perform the uplink.

BACKGROUND

IMU alignment while docked to ISS is complicated by several issues. The $-Z$ star tracker is blocked by structure. The $-Y$ star tracker field of view, partially obscured by truss-mounted solar arrays, is typically limited to stars with small separation angles. Also, most flights lack frequent mated maneuvers which would allow for better stars to be captured.

The STS-114 GNC team utilized gyro bias compensations (calculated using GNC SCP 2.4) to manage IMU drift in the docked timeframe to maintain alignment Flight Rule limits, without requiring dedicated maneuvers to acquire stars. The HAINS IMU drift rates for this flight were very stable and steady, and easily compensatable to one sigma or better. The $-Y$ star tracker tracked a sufficient number of stars that had small separation angles and were therefore not auto-selected into the star table. As part of standard console operations, GNC captured the torquing angles for these stars on the ground and was able to create gyro bias compensations to slightly over-torque the platforms back to zero misalignment. The drift rate back to null was never greater than one sigma, and was targeted for a one day return to zero misalignment. This management plan worked very well on STS-114.

Following STS-114, the decision was made to allow for this management method on future flights, assuming that similar conditions exist (i.e., small and steady drift rates; plenty of small-angle star pairs). The additional benefit of this management method is that it relieves some of the crew workload.

It is important to note that, considering that small-angle star pairs inherently have a certain amount of inaccuracy, the sufficient number of stars available during STS-114 was key to building confidence in the drift rates.

METHOD

Please note that this drift calculation method is used in addition to procedures described in SCP 2.4, Procedure Part A and B. The NEW BIASes that are calculated in the following paragraphs will be used in the gyro bias uplink load. Users should return to SCP 2.4, Procedure Part C for the steps for building and uplinking the desired command.

The compensations uplinked on STS-114 served two purposes. First, they nulled the observed drift (in other words, the same "standard" MEASURED DRIFT compensation described in SCP

2.4, Procedure Part B). Second, the comps drifted the IMUs back into alignment without requiring an actual IMU Alignment procedure.

The NEW BIAS to be uplinked is calculated by using the equation:

$$\text{NEW BIAS} = (\text{CURRENT BIAS}) + (\text{MEASURED DRIFT}) + (\text{ALIGNMENT DRIFT})$$

Where the CURRENT BIAS is taken from IMU Summary and the MEASURED DRIFT is calculated by methods as described in SCP 2.4.

The ALIGNMENT DRIFT term is the value meant to drift the IMUs back to null. Its value is not allowed to exceed one sigma drift, 0.006°/hour/axis, per informal understanding with the Flight Director Office. This constraint was put in place to allow for a slow but steady return to null, to not cause a problem in the event of extended loss of comm, to maintain consistency with current IMU gyro drift management flight rules (i.e. gyro drift rates less than one sigma are acceptable and do not require compensation), and support an anytime deorbit capability.

Due to the sufficient amount of small-angle star data captured, “time-averaged” drift characteristics were calculated axis-by-axis. Flight controllers should consider age and trending of the star data. Ideally, the set of star pairs would have no stars in common between pairs, and would be composed of stars from various points in the orbit. Also, a torquing angle ‘trend’ should be taken into account (i.e., the data from previous star pairs may suggest smaller misalignment, while more recent data may suggest continued misalignment; more recent data should generally be weighted more heavily.) The FCR and MPSR operators should discuss the data and come to an agreement on the misalignment values to be used.

Once misalignments (to be treated as the negative of torquing angles in the calculations) for each axis have been agreed upon, the next step is to calculate the drift rate desired to return each axis to null in twenty-four hours. In the case that any of the calculated drift rates exceed ±1 sigma, the associated axis can simply be limited to ±1 sigma.

In an ideal case, the IMUs would all drift back to null at the twenty-four hour mark, and at that same time a new gyro bias comp will be uplinked that simply takes out the ALIGNMENT DRIFT term. In reality, the IMU drift trends will continue to be monitored and NEW BIASes recalculated and uplinked as necessary.

EXAMPLE: CALCULATING ALIGNMENT DRIFT

In the following example, IMU 3 is assumed to be in standby, and data from three recent star pairs is found to be acceptable. For purposes of the example, the three torquing angle sets will simply be averaged, and data will be rounded to three decimal places. In reality, some torquing angles will be given increased/decreased weighting based on engineering judgement of the age and separation angle of the star pair.

	1x	1y	1z	2x	2y	2z
Data Set 1	-0.031	0.126	0.090	0.076	0.204	-0.153
Data Set 2	-0.056	0.145	0.075	0.090	0.215	-0.140
Data Set 3	-0.042	0.141	0.086	0.062	0.187	-0.136
Average	-0.043	0.137	0.084	0.076	0.202	-0.143

Torquing Angles (°)

The drift rate to aim for is $-(\text{torquing angle})/24$ hours:

drift rate ($^{\circ}/\text{hr}$)	0.002	-0.006	-0.004	-0.003	-0.008	0.006
-------------------------------------	-------	--------	--------	--------	--------	-------

Because we are not allowed to exceed $\pm 0.006^{\circ}/\text{hour}$, we will limit the drift rate on IMU 2Y.

After limiting, the ALIGNMENT DRIFT values will be as follows:

Align Drift ($^{\circ}/\text{hr}$)	0.002	-0.006	-0.004	-0.003	-0.006	0.006
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REFERENCES

1. On-Orbit Flight Techniques Panel Meeting #224 Agenda and Minutes; March 17, 2006

TITLE

STAR TRACKER BITE

PURPOSE

The purpose of this SCP is to identify the cause and operational impacts of star tracker failures annunciated by star tracker built-in-test equipment (BITE).

BACKGROUND

Star tracker BITE provides for self-detection and annunciation of internal malfunctions. The following categories of star tracker failures are discussed in this SCP: continuously monitored BITE, self-test BITE, reset initialization BITE, and other failures identified by self-test indications.

Continuously Monitored BITE :	Pressurization failure Power supply failure Transmission word failure CCD temperature failure EEPROM failure
Self-Test BITE:	Position bias and/or magnitude error RAM/ROM failure
Reset Initialization BITE:	Watch-dog Time-out failure
Failures ID'd by Self-Test:	Shutter/bright object sensor failure BITE star not acquired Self-test command not accepted Failure to return from self-test mode

The preflight self-test is scheduled for T - Time = 1 day 3 hours 30 min after which the star tracker is powered down. The star tracker is powered up again in the post insertion timeframe (scheduled MET = 1 hr 30 min). The nominal inflight self-test is no longer run. Inflight self-tests are run if there are indications that a star tracker is not operating nominally.

CONTINUOUSLY MONITORED BITE

The internal pressure of the star tracker housing, the star tracker internal power supplies, the Charge-Coupled Device (CCD) temperatures and the Electrically-Erasable-Program-Read-Only-Memory (EEPROM) status are continuously monitored for an out-of tolerance condition. In addition, the transmission word failure logic is continuously tested to identify any problems encountered during the reception of commands from the MDM.

SELF-TEST BITE

For an inflight self-test, the crew first verifies that there are no BITE indications, no Bright Object Alert (BOA) and that the shutter is open. The test, initiated by an input on the STAR TRACKER/COAS CONTROL display (SPEC 22), lasts approximately 10 seconds.

For the Solid State Star Tracker (SSST), when the GPC sends the self-test command, the SSST's CPU will initiate the Watchdog timer and RAM/ROM tests. These tests last for approximately 200 to 240 msec and are performed prior to the self-test comparisons made by the star tracker SOP. If any of these BITES fail, the star tracker good bit is set to logic 0 (bad) but the self-test fail flag will not be set.

INITIALIZATION: CHECK FOR NO-BRIGHT OBJECT ALERT

The GPC software self-test module (GY1) first checks for the absence of a bright object alert (BOA) signal. If a bright object is present (the Sun or Sun-lit Earth), the test is terminated and NO TARGET is displayed on the bottom left of SPEC 22. This occurs because the self test is designed to check the bright object sensor (BOS) by activating an artificial bright object LED which causes it to issue a BOA.

PART I: SEARCH FOR BITE STAR

For the first part of the GPC self-test, the offset mode test, the BITE star shall be acquired within two searches of the OFFSET FOV (2.4 sec) when a self test is commanded and an offset command of H = +4.137, V = -4.137, and a threshold command (input CMD word bits 5,6) = 0,0 are issued. The data words are monitored for the following:

BOA OFF = 0	Artificial Bright Object On
OSC = 1	Shutter Closed
STM = 1	Self-test Mode Engaged
SP = 1	Star Present
PBITE = 0	No Position Error
MBITE = 0	No Magnitude Error

If all of these conditions are not met within 3 seconds of the self-test command, the self-test fail flag is set.

PART II: CHECK FOR FL ON STAR PRESENT

For the second part of the GPC self-test, the wrong offset position test, the command word is set to position the one degree search field of view location to where there is no star (the horizontal offset command reverses polarity). If the star tracker fail bit is not set in 3 seconds, the self-test fail flag is set. This is designed to detect a failed on star present discrete. A BITE indication is expected in this part of the test.

PART III: CHECK FOR FL ON SELF-TEST MODE

In the third part of the GPC self-test, the command word is set to all zeroes and the self-test mode bit (bit 4 in Hardware Data Word 1) is monitored to make sure the star tracker returns from the self-test mode within 1 second; if not, the self-test fail flag is set. If the self-test fail flag is set by any or all of the three phases of the SOP controlled self-test, ST FAIL will be displayed on the bottom left of SPEC 22. If not set, ST PASS will be displayed on SPEC 22.

SELF-TEST PECULIARITIES

Several star trackers have unique characteristics which can cause a self-test failure even when the star tracker is operating nominally. Waivers have been written for these star trackers.

Serial Number	Peculiarity
2	BITE star Magnitude builds up too slowly
8	BITE star outside the 1 by 1 degree offset window
9	Unusually bright BITE star

Further discussion of these characteristics are included in the Star Tracker Self-Test SCP 3.2.

RESET INITIALIZATION BITE

In addition to continuously monitored and self-test BITEs, the SSST has reset initialization BITEs. Reset initialization BITEs are only performed after a self-test reset, Watchdog timer reset and/or a power-on reset. The Watchdog timer check is performed after all three resets. However, the RAM/ROM tests are performed only after self-test and power-on resets.

BITE ANNUNCIATION AND VERIFICATION

When a star tracker BITE is annunciated on SPEC 22, the crew will alert the MCC. All BITE status indications reflected in Hardware Data Words 1, 2, and 3 can be verified on CRANS display "GNC ORBIT STATUS."

Table 3.1-I summarizes star tracker telemetry parameters used to troubleshoot star tracker problems and to evaluate self-test results. Table 3.1-II identifies the parameters in the three Star Tracker Hardware Data Words to the GPC. Table 3.1-III contains characteristics, causes, and possible impacts of individual BITEs.

TABLE 3.1-I. - STAR TRACKER BITE SUMMARY

STAR TRACKER STATUS				
PARAMETER NAME	STATUS INDICATION		MSID -Z	(-Y)
TRKR FAIL (TRKR GOOD bit)	FAIL if HW WD 1,	bit 0 = 0	V71X5021B	(5521)
PRESSURE FAIL	FAIL if HW WD 2,	bit 15 = 1	V71X5056B	(5556)
PWR SUP FL (GOOD bit)	FAIL if HW WD 3,	bit 14 = 0	V71X5075B	(5575)
TRANS WD FL (GOOD bit)	FAIL if HW WD 1,	bit 2 = 0	V71X5023B	(5523)
BRIGHT OBJECT (OFF bit)	ALERT if HW WD 3,	bit 15 = 0	V71X5076B	(5576)
TGT SUPPRESS	SUPP if HW WD 1,	bit 1 = 1	V71X5022B	(5522)
SHUTTER CLOSE (CLS bit)	OPEN if HW WD 1, CLS if HW WD 1,	bit 3 = 0 bit 3 = 1	V71X5024B	(5524)
BIT CT - EEPROM	FAIL if HW WD 2,	bit 12 = 1	V71X5053B	(5553)
MANCH - RAM/ROM	FAIL if HW WD 2,	bit 13 = 1	V71X5054B	(5554)
PARITY - WATCHDOG	FAIL if HW WD 2,	bit 14 = 1	V71X5055B	(5555)
ST ANG ERROR	ERR if HW WD 3,	bit 12 = 1	V71X5073B	(5573)
ST MAG ERROR	ERR if HW WD 3,	bit 13 = 1	V71X5074B	(5574)
SELF-TEST CMD	ST if CMD WD ,	bit 1 = 1	V71K5322B	(5822)
SELF-TEST ENG	ST if HW WD 1,	bit 4 = 1	V71X5025B	(5525)
1* - CCD TEMPERATURE	1 - 1 if HW WD 1,	bit 6 = 1-1	V71X5027B	(5527)
0* - CCD TEMPERATURE	0 - 1 if HW WD 1,	bit 7 = 0-1	V71X5028B	(5528)
OFFSET CMD	OFFS if CMD WD ,	bit 0 = 1	V71K5321B	(5821)

* For IDT star tracker S/N 8 and higher, bits 6 and 7 of Hardware Word 1 are used to represent star tracker temperature. These bits are not used by the star tracker nor the GPC, they are for monitoring only. The temperature transducers were added to the IDT star trackers to better calibrate the pressure transducers which were causing false pressure fails on earlier models.

TABLE 3.1-I. - CONCLUDED

STAR TRACKER STATUS			
PARAMETER NAME	STATUS INDICATION	MSID -Z	(-Y)
MODE/STATUS WD (DATA WD 1)	4 DIGIT HEX WD	V71M5020P	(5520)
HORIZ DATA WD (DATA WD 2)	4 DIGIT HEX WD	V71M5040P	(5540)
VERT DATA WD (DATA WD 3)	4 DIGIT HEX WD	V71M5060P	(5560)
CMD WD	4 DIGIT HEX WD	V71M5320P	(5820)
PWR ON CMD	OFF or ON	V71S5400X	(5900)
SHUTTER CMD	AUTO or OPEN	V71K5324B	(5824)
SHUTTER POS	OPEN or CLOSED	V71X5024B	(5524)
THRESHOLD MSB	0 or 1	V71K5325B	(5825)
THRESHOLD LSB	0 or 1	V71K5326B	(5826)
STAR PRES	PR if HW WD 1, bit 5 = 1	V71X5026B	(5526)
HORIZ POS	4 DIGIT HEX WD	V71H5041B	(5541)
VERTICAL POS	4 DIGIT HEX WD	V71H5061B	(5561)
STAR ID	0 unless tracking	V95J4925C	(4926)
STR TRK STATUS (FL = 1)	1 if STATUS WD, bit 15 = 1	V95J4929C	(4930)

TABLE 3.1-II. - STAR TRACKER DATA WORDS TO THE GPC

HARDWARE DATA WORD 1 (BITE WORD OR MODE/STATUS WORD)				
BIT #	PARAMETER NAME	STATUS	MSID	-Z (-Y)
	HARDWARE DATA WORD 1		V71M5020P	(5520)
0	TRACKER GOOD	1 = GOOD	V71M5021B	(5521)
1	TARGET SUPPRESSED	1 = SUPPRESSED	V71M5022B	(5522)
2	TRANSMISSION WORD GOOD	1 = GOOD	V71M5023B	(5523)
3	SHUTTER CLOSED	1 = CLOSED	V71M5024B	(5524)
4	SELF-TEST MODE ENGAGED	1 = SELF-TEST	V71M5025B	(5525)
5	STAR PRESENT	1 = STAR PRES	V71M5026B	(5526)
6-7	HV RANGE - CCD TEMP	0* or 1* - 0 = GOOD	* bits 6 & 7 are not latched for IDT S/N 8 & higher, but used to monitor temperature	
8-15	STAR MAGNITUDE			

HARDWARE DATA WORD 2 (HORIZONTAL DATA WORD)				
BIT #	PARAMETER NAME	STATUS	MSID	-Z (-Y)
	HARDWARE DATA WORD 2		V71M5040P	(5540)
0	HORIZONTAL POSITION SIGN	0 = NEG, 1 = POS	V71H5041B	(5541)
1-11	HORIZONTAL POSITION		V71H5041B	(5541)
12	BIT COUNT - EEPROM	1 = ERROR	V71X5053B	(5553)
13	MANCHESTER - RAM/ROM	1 = ERROR	V71X5054B	(5554)
14	PARITY - WATCHDOG ERR	1 = ERROR	V71X5055B	(5555)
15	PRESSURIZATION FAIL	1 = FAIL	V71X5056B	(5556)

TABLE 3.1-II. - CONCLUDED

HARDWARE DATA WORD 3 (VERTICAL DATA WORD)				
BIT #	PARAMETER NAME	STATUS	MSID	-Z (Y)
	HARDWARE DATA WORD 3		V71M5060P	(5560)
0	VERTICAL POSITION SIGN	0 = NEG, 1 = POS	V71M5061B	(5561)
1-11	VERTICAL POSITION		V71M5061B	(5561)
12	SELF-TEST ANGLE ERROR	1 = ERROR	V71X5073B	(5573)
13	SELF-TEST MAGNITUDE ERR	1 = ERROR	V71X5074B	(5574)
14	POWER SUPPLY GOOD	1 = GOOD	V71X5075B	(5575)
15	BRIGHT OBJECT ALERT OFF	1 = NO BRT OBJECT	V71X5076B	(5576)

TABLE 3.1-III - STAR TRACKER BITES TABLE OF CONTENTS

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STAR TRACKER: IDT

BITE: Tracker Fail

TYPE: Continuously Monitored BITE

ONBOARD ANNUNCIATION:

SPEC 22: ST FAIL and BITE Indication

MCC (GNC) ANNUNCIATION:

MSID -Z (-Y)

TRKR FAIL

V71X5021B (5521)

H/W DATA WD 1 (MODE/STAT WD)

V71M5020P (5520)

1st hex char = 2

1st bit (bit 0) = 0

2 = 0010 = TRKR FL, NO TGT SUPP, TRANS WD GOOD, SHUT OP

This character is nominally A = 1010 (IF NO TRACKER FAIL)

CAUSE:

A star tracker fail indication results from any of the following failures:

- pressure fail BITE,
- power supply fail BITE,
- self-test position bias and/or magnitude error, or
- bright object alert (BOA) off during self-test.

POSSIBLE IMPACT:

If a star tracker fail indication exists, BITE will be displayed on SPEC 22. Determine the cause by checking the Star Tracker BITE STATUS on CRANS GNC ORBIT STATUS display. Go to the appropriate BITE in this SCP (3.1) to determine the impacts.

COMMENTS:

N/A

STAR TRACKER: SSST

BITE: Tracker Fail

TYPE: Continuously Monitored BITE

ONBOARD ANNUNCIATION:

SPEC 22: ST FAIL and BITE Indication

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
TRKR FAIL	V71X5021B		(5521)
H/W DATA WD 1 (MODE/STAT WD)	V71M5020P		(5520)
1st hex char = 2			
1st bit (bit 0) = 0			
2 = 0010 = <u>TRKR FL</u> , NO TGT SUPP, TRANS WD GOOD, SHUT OP			
This character is nominally A = 1010 (IF NO TRACKER FAIL)			

CAUSE:

A star tracker fail indication results from any of the following failures:

- power supply fail BITE,
- charge-coupled device (CCD) temperature fail BITE,
- RAM/ROM fail BITE,
- self-test position bias and/or magnitude error,
- pressure fail BITE during self-test,
- Watchdog time-out fail BITE during self-test,
- EEPROM fail BITE during self-test (or the fourth EEPROM failure), or
- bright object alert (BOA) off during self-test.

POSSIBLE IMPACT:

If a star tracker fail indication exists, BITE will be displayed on SPEC 22. Determine the cause by checking the Star Tracker BITE STATUS on CRANS GNC ORBIT STATUS display. Go to the appropriate BITE in this SCP (3.1) to determine the impacts.

COMMENTS:

Self-test does not have to be engaged for the fourth EEPROM failure to set the star tracker Fail BITE, (see EEPROM Fail BITE for more information).

STAR TRACKER: IDT and SSST

BITE: Pressurization Failure

TYPE: Continuously Monitored BITE

ONBOARD ANNUNCIATION:

SPEC 22: BITE Indication

MCC (GNC) ANNUNCIATION:

MSID -Z (-Y)

PRESSURE FAIL V71X5056B (5556)

H/W DATA WD 2 (HORIZ WD) V71M5040P (5540)

4th hex char = 1

4th bit (bit 15) = 1

(IDT) 1 = 0001 = NO BIT CNT ER, NO MANCH FL, NO PAR ER, PRESS FL
(SSST) 1 = 0001 = NO EEPROM FL, NO RAM/ROM FL, NO WATCHDOG FL, PRESS FL
This character is nominally 0 = 0000 (IF NO PRESSURE FAIL)

CAUSE:

A pressurization failure BITE is required, per Procurement Spec MC431-0128, to be set when the star tracker internal housing internal pressure drops below 14.9 psia. However, the actual trip limit for each S/N is typically set slightly higher during calibration to 15.2 to 15.3 psia in order to guarantee that the spec is met. (The trip limit for each S/N may be found in the unit's latest Acceptance Test Procedure Data Pack.) A continuous monitor of the star tracker pressurized case is provided to the interface adapter unit (IAU) from which a GO/NO GO pressure signal is sent.

The star trackers are pressurized with argon to 17.58 psia at 25 deg C. The Star Tracker Purge and Re-pressurization procedure contained in OMRSD File III, V71AE0.040 provides the equation to correct for pressurizations at temperatures other than 25 deg C.

POSSIBLE IMPACT:

Pressure loss should not affect star tracker performance. The problem with pressurization loss is that the star tracker may lose pressure on orbit and then ingest moisture during reentry thru the atmosphere. The star tracker would then be removed, cleaned, and tested after the flight.

COMMENTS:

A star tracker with a pressure fail indication will still be considered good for launch. A pressure failure will cause the IDT star tracker good bit to be set false (logic 0). This is true for the SSST only during self-test. Different configurations of IDT star trackers are being flown. The earlier IDT models have experienced pressurization failures. The later IDT models have been improved and certified for 100 flights.

STAR TRACKER: IDT

BITE: Power Supply Failure

TYPE: Continuously Monitored BITE

ONBOARD ANNUNCIATION:

SPEC 22: BITE Indication

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
PWR SUP FAIL	V71X5075B		(5575)
H/W DATA WD 3 (VERT WD) 4th hex char = 1 3rd bit (bit 14) = 0 1 = 0001 = NO ANG ER, NO MAG ER, <u>PWR SUP FL</u> , NO BRT OBJ This character is nominally = 3 = 0011 (IF NO PWR SUPPLY FAILURE)	V71M5060P		(5560)

CAUSE:

A power supply failure results from any of the three internal star tracker power supplies dropping below minimum operational levels. The +5 V and ±15 V power supplies are continuously monitored for an out-of-tolerance condition.

POSSIBLE IMPACT:

The internal power supplies, which are regulated and not affected by small input power fluctuations, provide reference voltage throughout the star tracker and may affect any part of star tracker operation.

COMMENTS:

Power supply failure indication may have been a transient (-Z Tracker on MN A - O14, -Y Tracker on MN B - O15).

STAR TRACKER: SSST

BITE: Power Supply Failure

TYPE: Continuously Monitored BITE

ONBOARD ANNUNCIATION:

SPEC 22: BITE Indication

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
PWR SUP FAIL	V71X5075B		(5575)
H/W DATA WD 3 (HORIZ WD) 4th hex char = 1 3rd bit (bit 14) = 0 1 = 0001 = NO ANG ER, NO MAG ER, <u>PWR SUP FL</u> , NO BRT OBJ This character is nominally = 3 = 0011 (IF NO PWR SUPPLY FAILURE)	V71M5060P		(5560)

CAUSE:

A power supply failure results if any of the three internal star tracker power supplies are not within $\pm 12\%$ of nominal voltage levels. The +5 Vdc and ± 15 Vdc power supplies are continuously monitored for an out-of-tolerance condition.

A power supply failure also results if any of the 7 focal plane voltages exceed the $\pm 12\%$ tolerance from its calibrated value. The three internal power supplies and the ± 15 VA, \pm HORIZ, \pm VERT, and +VDC voltages that power the CCD focal plane are continuously monitored for an out-of-tolerance condition.

POSSIBLE IMPACT:

The internal power supplies, which are regulated and not affected by small input power fluctuations, provide reference voltage throughout the star tracker and may affect any part of star tracker operation.

The focal plane power supplies, which are also regulated and not affected by small input power fluctuations, provide reference voltages to the CCD. If any focal plane voltage degrades, the CCD performs slower and the star tracker will have problems tracking very bright stars. Tracking of average magnitude targets should not be affected. Performing a self-test will not indicate the star tracker magnitude degradation, since the BITE star's magnitude is low enough to reflect no operational impacts. On the other hand, if any focal plane voltage completely fails, the star tracker will be inoperable.

COMMENTS:

Power supply failure indication may have been a transient (-Z Tracker on MN A - O14, -Y Tracker on MN B - O15).
The \pm HORIZ, \pm VERT, ± 15 VA and \pm VDC voltages supply power to the CCD data drivers. The data drivers control the horizontal, vertical and magnitude shift registers. If the voltage level degrades, the

CCD performs slower which will cause the magnitude shift registers to overflow when very bright objects are being tracked. If this occurs, part of the magnitude signal will be lost.

Only a Power Supply Fail, RAM/ROM Fail, and a CCD Temp fail will cause the Tracker GOOD bit to be false outside of self-test (and the fourth EEPROM failure).

STAR TRACKER: IDT and SSST

BITE: Transmission Word Failure

TYPE: Continuously Monitored BITE

ONBOARD ANNUNCIATION:

SPEC 22: BITE Indication
Continuous or intermittent failure to acquire stars.

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
BIT COUNT ERROR or MANCHESTER FAIL or PARITY ERROR	V71X5053B		(5553)
	V71X5054B		(5554)
	V71X5055B		(5555)
H/W DATA WD 1 (MODE/STAT WD) 1st hex char = 8 3rd bit (bit 2) = 0 8 = 1000 = TRKR GOOD, NO TGT SUP, <u>TRANS WD NG</u> , SHUTTER OP This character is nominally = A = 1010 (IF THE TRANS WD IS GOOD)	V71M5020P		(5520)
(IDT only) H/W DATA WD 2 (HORIZ WD) 4th hex char = 8, 4 or 2 (or any combination) BITS 12, 13, and/or 14 set equal to 1 8 = 1000 = <u>BIT CNT ER</u> , NO MANCH FL, NO PAR ER, NO PRES FL 4 = 0100 = NO BIT CNT ER, <u>MANCH FL</u> , NO PAR ER, NO PRES FL 2 = 0010 = NO BIT CNT ER, NO MANCH FL, <u>PAR ER</u> , NO PRES FL This character is nominally = 0 = 0000 (IF NO BIT COUNT ERRORS, NO MANCHESTER FAILS, NO PARITY ERRORS, AND NO PRESSURE FAILS EXISTS).	V71M5040P		(5540)

CAUSE:

A transmission word failure results from one of the following three conditions: bit count error, manchester fail and/or parity error. Should any of these bits be set by the star tracker hardware, the OR gate in the star tracker software will result in a Transmission Word Fail indication (H/W Data Word 1, bit 2 set to zero).

POSSIBLE IMPACT:

The operational impact could be continuous or intermittent failure of the star tracker to acquire stars. The accuracy of the completed measurements may or may not be degraded.

1. Bit count error results from data dropouts in the received signal. Continued dropouts indicate a signal interface problem which would interfere with star tracker use.
2. Manchester fail results when an improperly coded signal is received from the MDM. Continued coding problems would interfere with star tracker use and cast doubt on star angle measurements.
3. Parity error results from excessive noise in the received signal and would interfere with star tracker use if the problem continued.

COMMENTS:

The transmission word tested is the one from the MDM to the star tracker (-Z Tracker on MDM FF1, -Y Tracker on MDM FF3). Each time the star tracker interface adapter unit (IAU) receives a message from the MDM, it tests the transmission word failure logic and identifies any errors during the reception of commands.

The Sighting Data Filter (DATA_FILR) module in the star tracker SOP, calculates an average horizontal and vertical offset angle from 21 consecutive data samples (6.25 Hz). While accumulating the 21 data samples, if there is no star present indication, or if a bad data point is sampled, the DATA_FILR module stops processing until the next time the STAR_TRACK or TARGET_TRACK modules requires DATA_FILR to be processed. This is why an intermittent Transmission Word Failure should not degrade tracker performance.

The transmission word failure appeared several times during flights. The majority of these have been caused by manchester fails, which appear to be primarily caused by timing problems between the MDM and the star tracker. A hardware change to the star tracker was not justified since the problem corrects itself on the next cycle without impacting star tracker operation.

A master alarm for this failure was disabled after STS-2 based on flight experience and postflight analysis indicating that this type of failure indication should not wake up the crew since it is a momentary failure (1 or more cycles) which should not impact star tracker operation.

For the SSST, MCC will have no insight into whether a bit count error, a manchester fail, or a parity error caused the transmission word failure since these bits have been replaced by the EEPROM, RAM/ROM and Watchdog time-out bits.

STAR TRACKER: SSST

BITE: Charge-Coupled Device (CCD) Temperature Failure

TYPE: Continuously Monitored BITE

ONBOARD ANNUNCIATION:

SPEC 22: BITE Indication

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
CCD TEMP MSB	V71X5027B		(5527)
and CCD TEMP LSB	V71X5028B		(5528)
H/W DATA WD 1 (MODE/STAT WD)	V71M5020P		(5520)
2nd hex char = 3 if star is <u>not</u> present			
2nd hex char = 7 if star <u>is</u> present			
3rd and 4th bit (bit 6 and 7) = 1			
3 = 0011 = NO SELF-TEST, NO STAR PRES, <u>CCD TEMP FL</u>			
7 = 0111 = NO SELF-TEST, STAR PRES, <u>CCD TEMP FL</u>			
This character is nominally 4 = 0100 (IF STAR PRES & NO CCD TEMP FL)			
0 = 0000 (IF NO STAR PRES & NO CCD TEMP FL)			

CAUSE:

Any failure in the Thermoelectric cooler (TEC) which disrupts its cooling capability, would be detected by the charge-coupled device (CCD) temperature sensors which will set the appropriate data bits as follows:

<u>ZONE</u>	<u>TEMP RANGE</u>	<u>MSB</u>	<u>LSB</u>
0	<3°C	0	0
1	3-11°C	0	1
2	11-23°C	1	0
3	>23°C	1	1

A star tracker fail is annunciated when CCD Temp Zone 3 is entered.

POSSIBLE IMPACT:

If the temperature of the CCD exceeds 23°C, excessive noise/error will degrade the position and magnitude data. Perform self-test to determine the magnitude of the noise/error by comparing the vertical/horizontal positions and (reference SCP 3.2 S TRKR SELF TEST) against the factory preset angles in the Star Tracker Self-Test SCP. Repeat the self-test for verification of the results. Track stars and take data points to provide data to evaluate star tracker performance. The star tracker will continue to operate but is not dependable. Single star tracker aligns may be required. Calibrate the CDR HUD per GNC Flight Rule A8-108.

COMMENTS:

When the CCD temperature gets above 23°C, the SSST is effectively uncalibrated. The star tracker position and magnitude values will not be accurate. The star tracker will see magnitudes higher than the actual target's magnitude. A magnitude bias will not make the tracker inoperable. On the other hand, if the position bias is large enough (determined from self-test), the star tracker will be inoperable. The CCD should eventually reach a steady state temperature, which will be reflected in the relatively constant position and magnitude biases recorded during self-test.

Only a power supply failure, RAM/ROM failure and CCD Temperature out-of-tolerance will cause the star tracker good bit to be false outside of self-test (and the fourth EEPROM failure).

STAR TRACKER: SSST

BITE: EEPROM

TYPE: Continuously Monitored BITE

ONBOARD ANNUNCIATION:

SPEC 22: BITE Indication

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
EEPROM FAIL	V71X5053B		(5553)
H/W DATA WD 2 (HORIZ WD) 4th hex char = 8 1st bit (bit 12) = 1 8 = 1000 = <u>EEPROM FL</u> , NO RAM/ROM FL, NO WATCH-DOG FL, NO PRES FL This character is nominally 0 = 0000	V71M5040P		(5540)

CAUSE:

An EEPROM fail BITE during self-test indicates an error in one or more I-Loaded values in the first, second or third EEPROM location. An EEPROM fail BITE during nominal operation indicates an error in one or more I-Loaded values in the fourth (default) EEPROM location. Cyclic redundancy check (CRC) is used to detect any change in the EEPROM values. Every 21 msec, a CRC value is calculated from the I-Loads in EEPROM and compared to the predetermined CRC word stored as the last value in EEPROM. If the two CRC words do not match, an error has occurred.

POSSIBLE IMPACT:

The first three EEPROM failures will only set the star tracker good bit to bad and display BITE on SPEC 22 during self-test. The star tracker may temporarily process bad data (for ~1 cycle), but it should continue to operate nominally.

The fourth and final EEPROM failure will be annunciated continuously on CRANS GNC ORBIT STATUS display. The star tracker good bit will be set to bad and BITE displayed on SPEC 22, the star tracker does not have to be in self-test. The star tracker may still pick-up stars and track targets, but not to its specified accuracy (± 60 arcsec). The exact operational impact depends on what value(s) is in error; therefore the star tracker may or may not be useable. Perform self-test to determine the magnitude of the error by comparing the vertical/horizontal positions and magnitude (reference SCP 3.2 S TRKR SELF TEST) against the factory preset angles in the star tracker Self-Test SCP 3.2. Track stars and take data points to provide data to evaluate star tracker performance.

COMMENTS:

The data stored in EEPROM includes the following:
1 - SSST calibration data,

- 2 - BITE star location and intensity,
- 3 - Self-test offset mode position command,
- 4 - CCD temperature threshold zones,
- 5 - Pressure fail threshold,
- 6 - Focal plane voltages, and
- 7 - CRC word (used during RAM/ROM & EEPROM checks).

I-Loads (1 thru 6) are processed to calculate a CRC word. This calculated word is then compared to the I-Loaded CRC word (7). Prior to delivery, this I-Loaded CRC word is calculated and written to EEPROM and is different for each star tracker.

Radiation degrades various parameters of electrical components altering the circuit performance & possibly making it inoperable. To reduce the probability of this causing a star tracker failure from erroneous I-Loads, each value in EEPROM is stored in four locations. The star tracker will use only one location until a failure in that location is detected.

EEPROM BITE software is kept in two parts of the CPU; the housekeeping software and the self-test software. The housekeeping software uses CRC to check EEPROM. If an EEPROM failure is detected, software will use the next location and will not set the EEPROM fail bit nor the star tracker good bit to bad (except for the fourth failure). When the last EEPROM location goes bad, the housekeeping software will announce an EEPROM failure and will set the star tracker good bit to bad (BITE will be displayed on SPEC 22).

The self-test software also uses CRC to evaluate EEPROM; however, when an EEPROM failure is detected during self-test, the EEPROM fail bit will be set for the appropriate amount of time (see table below) and the star tracker good bit will be set to bad.

<u>FAILURE NUMBER</u>	<u>SELF-TEST BITE ANNUNCIATION</u>
	<u>TIME</u>
1st	3 sec
2nd	6 sec
3rd	9 sec
4th	continuous

The fourth and last to be used EEPROM location is called the default location. Once the cyclic redundancy check has detected an error in the default location the EEPROM FL BITE will be announced continuously, before, during and after self-test.

STAR TRACKER: IDT and SSST

BITE: Position Bias and/or Magnitude Error

TYPE: Self-Test BITE

ONBOARD ANNUNCIATION:

SPEC 22: BITE and ST FAIL Indication

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
ST ANG ERROR	V71X5073B		(5573)
ST MAG ERROR	V71X5074B		(5574)
STR TRK STAT = FAIL = 1	V95J4929C		(4930)
H/W DATA WD 3 (VERT WD)	V71M5060P		(5560)

The 4th hex character of Data WD 3 will identify if the BITE was a position and/or magnitude BITE.

<u>4th hex character</u>	<u>BITE indication</u>
0, 1, 2, or 3	= no BITE
4, 5, 6, or 7	= MAG BITE
8, 9, A, or B	= POS BITE
C, D, E, or F	= MAG & POS BITE

CAUSE:

A position bias will cause a BITE annunciation if the BITE star is not within a specified tolerance (± 16 counts = ± 0.04 degrees = ± 140 arc sec) of the factory preset angle. Remember that a Position BITE annunciation is expected in the second part of the self-test.

A magnitude error will cause a BITE annunciation when the BITE star magnitude is not within a specified tolerance range (16 counts = 12.5 percent = 2.26 M) of the factory preset value.

POSSIBLE IMPACT:

If a position bias exists, determine the magnitude of the bias by checking the vertical and horizontal positions (reference SCP 3.2 S TRKR SELF TEST) against the factory preset angles in the star tracker Self-Test SCP. Repeat the self-test for verification of the results. Track stars and take data points to provide data to evaluate star tracker performance. The star tracker is probably not useable. Single star tracker aligns will be required. Calibrate the CDR HUD per GNC Flight Rule A8-108.

If a Magnitude BITE is suspected, the star tracker should still be useable. Failure of the LED or BITE circuitry does not necessarily degrade star tracker performance.

COMMENTS:

The following summarizes possible causes of position and/or magnitude BITES.

<u>OPTICAL FAILURES</u>	<u>POSSIBLE BITE INDICATION</u>
1. Window degradation (distortion, cracks, or breakage)	POSN and/or MAG
2. Lens degradation (distortion or transmission loss)	POSN and/or MAG
<u>MECHANICAL FAILURES</u>	
1. Mounting alignment shift (high temp, mech stress, or vibration)	POSN
2. Optical component shift (high temp, mech stress, or vibration)	POSN
<u>BITE STAR LED FAILURES</u>	
1. Artificial star (AS) LED degradation (caused by drift in LED characteristics or drift in driver output)	MAG
<u>IMAGE DISSECTOR TUBE (IDT) FAILURES</u>	
1. Photocathode degradation.	MAG
2. Multiplier degradation (gain or loss).	MAG
3. Catastrophic IDT failures (Tracker failed) (lead/conductor breakage or tube fracture)	POSN and MAG
<u>FOCUS FIELD CIRCUIT FAILURES (IDT ONLY)</u>	
1. Focus coil fail open (loses the electron image)	POSN and MAG
2. Focus coil shorted (depends on the number of turns shorted)	POSN
3. Focus coil misalignment	POSN and/or MAG
4. Focus current regulator failure	POSN and/or MAG
<u>DEFLECTION CIRCUIT FAILURES (IDT ONLY)</u>	
1. Deflection coil open circuit (Tracker failed)	POSN and MAG
2. Deflection coil short circuit (decrease in deflection, resulting in a smaller FOV, depends on the number of turns shorted)	POSN and/or MAG
3. Coil misalignment	POSN and/or MAG
<u>ELECTRONICS FAILURES</u>	POSN and/or MAG
<u>STAR TRACKER: SSST</u>	

BITE: RAM/ROM Failure

TYPE: Power-on and Self-Test BITE

ONBOARD ANNUNCIATION:

SPEC 22: BITE Indication

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
RAM/ROM FAIL	V71X5054B		(5554)
H/W DATA WD 2 (HORIZ WD) 4th hex char = 4 2nd bit (bit 13) = 1 4 = 0100 = NO EEPROM FL, <u>RAM/ROM FL</u> , NO WATCHDOG FL, NO PRES FL This character is nominally 0 = 0000	V71M5040P		(5540)

CAUSE:

At self-test and power-on, two bit patterns are written to every RAM address actually used and then read back. One bit pattern sets the odd bits equal to one and the even bits equal to zero. The other bit pattern does the opposite. If any one address is read back incorrectly, the RAM test is failed and the RAM/ROM FAIL bit is set.

Also at self-test and power-on, a 16 bit cyclic redundancy check (CRC) word that is recomputed by the processor is compared to the CRC word stored in EEPROM. If the two CRC words miscompare, the ROM test is failed and the RAM/ROM FAIL bit is set.

POSSIBLE IMPACT:

The CCD calibration data are temporarily stored in RAM. Any problem with RAM would result in bad data being used by the processor. This failure would result in erroneous position and/or magnitude values.

The permanent S/W (program code) is stored in ROM. Any problem with ROM would cause the star tracker to not operate nominally. This failure would result in inconsistent position and magnitude data, or result in the inability to acquire and track stars (including the BITE star).

A RAM/ROM failure at power-on and during self-test will set the star tracker good bit to bad and BITE will be displayed on SPEC 22.

Perform self-test again, to verify the position and magnitude results. The star tracker is probably not useable. Single star tracker aligns may be required. Calibrate CDR HUD per GNC Flight Rule A8-108.

COMMENTS:

If the CPU gets out of sync during self-test, a RAM/ROM BITE may be annunciated. The Watchdog timer will reset and clear the CPU problem. If another self-test is then performed, the RAM/ROM BITE should not be annunciated. If the failure is in the RAM/ROM, the BITE will be re-annunciated with each self-test and star tracker performance will degrade.

Only a power supply failure, RAM/ROM failure, or CCD temperature out-of-tolerance will cause the star tracker good bit to be false outside of self-test (and the fourth EEPROM failure).

STAR TRACKER: SSST

BITE: Watch-dog Time-out Failure

TYPE: Reset Initiation BITE

ONBOARD ANNUNCIATION:

SPEC 22: BITE Indication

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
Watch-dog FAIL	V71X5055B		(5555)
H/W DATA WD 2 (HORIZ WD) 4th hex char = 2 3rd bit (bit 14) = 1 2 = 0010 = NO EEPROM FL, NO RAM/ROM FL, <u>WATCH-DOG FL</u> , NO PRES FL This character is nominally 0 = 0000 (IF NO EEPROM FAILS, NO RAM/ROM FAILS, NO WATCHDOG TIME-OUT ERRORS, AND NO PRESSURE FAILS EXISTS.)	V71M5040P		(5540)

CAUSE:

The CPU is required to send a Watchdog timer (WDT) reset command every 270 msec to demonstrate that it is functioning properly. If the Watchdog timer does not receive the reset command after 270 msec, the WDT counter overflows and issues a reboot command to the CPU. This reboot is intended to clear the CPU problem which prevented it from sending a reset command to the WDT. In addition to rebooting the CPU, the WDT also writes a unique value in RAM. After the CPU reboots, it checks this location in RAM to determine if the reboot was caused by the WDT. If the value present is the unique value, then the processor must have been reset by the WDT. The Watchdog Time-out Fail bit will be set for approximately 2 sec.

POSSIBLE IMPACT:

An intermittent or transient CPU failure will cause the processor to temporarily use bad data. The Watchdog timer will reset the CPU and the problem will be corrected. This should not impact star tracker performance.

If there is a real CPU failure, the star tracker will no longer operate, and self-test cannot be performed. Single star tracker aligns will be required. Calibrate the CDR HUD per GNC Flight Rule A8-108.

COMMENTS:

When the watchdog timer is reset, the SSST outputs all zeroes for up to 2 seconds followed by good data, then the WDT fail bit is set for 1 to 2 seconds. The output of all zeroes for up to 2 seconds may cause simultaneous Star Tracker Fail, Transmission Word Fail, and Power Supply Fail indications.

If a CPU problem exists for ≥ 270 msec, the processor is reset and the Watch-dog Time-out BITE will be annunciated. This should clear any transient failures so the star tracker will continue to operate

nominally. If the failure is permanent, the processor will be reset repeatedly and the CPU will output all zeroes and cause continuous Tracker Fail, Transmission Word Fail, and Power Supply Fail indications. The star tracker will no longer operate because the processor will never get to the instruction S/W to track and acquire stars. A Watchdog Time-out BITE can only be monitored on CRANS GNC ORBIT STATUS display or a UDD. The star tracker good bit will be set to false and BITE displayed on SPEC 22 only if the WDT fails during self-test.

STAR TRACKER: IDT

FAILURE: Shutter/Bright Object Sensor Failure

TYPE: Failure Mode Identified By Self-Test Indications

ONBOARD ANNUNCIATION:

SPEC 22: BITE and ST FAIL Indication
Shutter position unchanged for self-test

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
SHUTTER POSITION (unchanged)	V71X5024B		(5524)
BRIGHT OBJECT - ALERT	V71X5076B		(5576)
SHUTTER POSITION (unchanged)	V71X5024P		(5524)
STR TRK STAT = FAIL = 1	V95J4929C		(4930)

CAUSE:

1. Shutter circuitry failure
2. Bright object sensor (BOS) failure
3. Bright object LED failure, or degraded output
4. Self-test command not accepted (BITE circuitry failure)

POSSIBLE IMPACT:

In shutter fail open cases, damage studies for the IDT star trackers indicate that brief exposure to a bright object, such as a scan of the Sun, will permanently damage the star tracker. Direct exposure to the Sun results in a permanently damaged photocathode. For exposure to the Moon or Sun-lit Earth, the concern is for reduced tube sensitivity resulting from permanently damaged dynodes. The amount of sensitivity degradation from other bright objects depends on the source geometry, brightness level, duration of exposure and individual tube characteristics. Damage to the dynodes can be permanent or temporary depending on the factors mentioned above.

Failure of the BOS will lose the automatic closing and opening function of the protective shutter when the Sun or Sun-lit Earth is passing through the field of view (FOV). Backup protection is provided by the target suppress (TS).

Early in the STS program (IDT trackers), the TS signal closed and latched the shutter, requiring the crew to make a keyboard entry on SPEC 22 to reopen the shutter. This was corrected by a software fix which looks at Orbiter attitude and star tracker pointing direction to determine if the required star should be in the FOV and issues a shutter OPEN command.

Failure of only the self-test bright object LED does not affect star tracker operation. Failure to accept the self-test command (a BITE circuitry failure) also does not affect star tracker operation.

COMMENTS:

For a nominal self-test, the shutter will be open at the start of the test, close during the test, and then open when the self-test command is removed. If the self-test command is not accepted, the shutter will remain open.

Verify there is no bright object in the FOV before commanding self-test, this will also prevent execution of self-test.

Nominal self-test:

<u>Shutter Position</u>	<u>Self-Test Phase</u>
Open	At start of self-test
Closed	Part 1; offset mode test
Closed	Part 2; wrong offset posn test
Open	Part 3; return from self-test
Open	At the end of the test

Several options have been identified to avoid damage to the star tracker with a shutter/BOS failure:

1. The Orbiter could be maneuvered to an attitude which keeps the Sun and Sun-lit earth out-of the FOV.
2. The star tracker door could be closed to protect the star tracker until the entry align.
3. Power could be removed from the star tracker when viewing bright objects with a known shutter/BOS failure. Removing star tracker power closes the shutter. Star tracker warmup time is 15 minutes.

Remember that a shutter position OPEN indication tells you that power is applied to the motor to open the shutter. A shutter position CLOSED indication means that power to the shutter has been removed. There is no microswitch feedback indicating the actual position of the shutter.

STAR TRACKER: SSST

FAILURE: Shutter/Bright Object Sensor Failure

TYPE: Failure Mode Identified By Self-Test Indications

ONBOARD ANNUNCIATION:

SPEC 22: BITE and ST FAIL Indication
Shutter position unchanged for self-test

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
SHUTTER POSITION (unchanged)	V71X5024B		(5524)
BRIGHT OBJECT - ALERT	V71X5076B		(5576)
SHUTTER POSITION (unchanged)	V71X5024P		(5524)
STR TRK STAT = FAIL = 1	V95J4929C		(4930)

CAUSE:

1. Shutter circuitry failure
2. Bright object sensor (BOS) failure
3. Bright object LED failure, or degraded output
4. Self-test command not accepted (BITE circuitry failure)

POSSIBLE IMPACT:

In shutter fail open cases, damage studies for the SSST indicate that indefinite exposure to a bright object, such as the Sun, will not damage the star tracker or degrade performance. The star tracker thermal electric cooler (TEC) keeps the tracker within the required temperature limits so the Charged Coupler Device (CCD) continues to function nominally.

Failure of the BOS will lose the automatic closing and opening function of the protective shutter when the Sun or Sun-lit Earth is passing through the field of view (FOV). The CCD background charge will reach its saturation threshold level and the High Background Protection bit will be set and the shutter will be closed.

Failure of only the self-test bright object LED does not affect star tracker operation. Failure to accept the self-test command (a BITE circuitry failure) also does not affect star tracker operation.

COMMENTS:

For a nominal self-test, the shutter will be open at the start of the test, close during the test, and then open when the self-test command is removed. If the self-test command is not accepted, the shutter will remain open.

Verify there is no bright object in the FOV before commanding self-test, this will also prevent execution of self-test.

Nominal self-test:

<u>Shutter Position</u>	<u>Self-Test Phase</u>
Open	At start of self-test
Closed	Part 1; offset mode test
Closed	Part 2; wrong offset posn test
Open	Part 3; return from self-test
Open	At the end of the test

Exposure to the sun or sun lit earth, due to a shutter/BOS failure, should not damage the SSST.

Remember that a shutter position OPEN indication tells you that power is applied to the motor to open the shutter. A shutter position CLOSED indication means that power to the shutter has been removed. There is no microswitch feedback indicating the actual position of the shutter.

STAR TRACKER: IDT and SSST

FAILURE: BITE Star Not Acquired

TYPE: Failure Mode Identified By Self-Test Indications

ONBOARD ANNUNCIATION:

SPEC 22: BITE and ST FAIL Indication
NO STAR PRES asterisk during self-test

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
ST ANG ERR	V71X5073B		(5573)
ST MAG ERR	V71X5074B		(5574)
No STAR PRES indication	V71M5026P		(5526)
H/W DATA WD 3 (VERT WD) The 4th hex character of Data WD 3 will be set to C, D, E, or F indicating a POS and MAG BITE.	V71M5060P		(5560)
VERT POS CYCLES Negative to zero to positive Negative to zero to positive, etc.	V71H5061B		(5561)
STR TRK STAT = FAIL = 1	V95J4929C		(4930)

CAUSE:

The BITE star LED could have lost brightness and is below the star tracker sensitivity or a large position bias exists.

POSSIBLE IMPACT:

Failure of BITE star LED does not degrade star tracker performance; however, a large position bias would affect star tracker operation.

COMMENTS

The star tracker gives itself two scan frames (2.4 seconds) to acquire and track the BITE star. If the BITE star is not acquired, Star Present (SP = 0), the position and magnitude error signals cause the star tracker to fail self-test. The vertical star angle will cycle from negative through zero to positive, flip back to negative, and continue cycling. Track stars and take data points to provide data to evaluate tracker performance. If performance is okay, the star tracker may be operated normally.

STAR TRACKER: IDT and SSST

FAILURE: Failure To Accept Self-Test Command

TYPE: Failure Mode Identified By Self-Test Indications

ONBOARD ANNUNCIATION:

SPEC 22: BITE and ST FAIL Indication
No SELF TEST asterisk
NO STAR PRES asterisk
SHUTTER OPEN throughout self-test

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
SHUTTER CLOSE = OP	V71X5024B		(5524)
SELF TEST CMD = ST indication	V71K5322B		(5822)
No SELF TEST ENG indication	V71X5025B		(5525)
SHUTTER POS = OP	V71X5024B		(5524)
STR TRK STAT = FAIL = 1	V95J4929C		(4930)

CAUSE:

Failure of BITE circuitry.

POSSIBLE IMPACT:

Failure of the BITE circuitry does not necessarily degrade star tracker performance.

COMMENTS

For a self-test, the shutter will be open at the start of the test. The shutter will remain open if the self-test command is not accepted. Verify there is no BOA prior to commanding self-test. A BOA will prevent the self-test from engaging and a "NO TARGET" message will be displayed on SPEC 22.

Nominal self-test:

<u>Shutter Position</u>	<u>Self-Test Phase</u>
Open	At start of self-test
Closed	Part 1; offset mode test
Closed	Part 2; wrong offset posn test
Open	Part 3; return from self-test
Open	At the end of the test

Track stars to verify proper operation and if okay, the star tracker may be operated normally.

STAR TRACKER: IDT and SSST

FAILURE: Failure to Return From Self-Test Mode

TYPE: Failure Mode Identified By Self-Test Indications

ONBOARD ANNUNCIATION:

SPEC 22: BITE and ST FAIL Indication
The star tracker does not go from self-test mode to term/idle.

MCC (GNC) ANNUNCIATION:

	<u>MSID</u>	<u>-Z</u>	<u>(-Y)</u>
No SELF TEST CMD indication	V71K5322B		(5822)
SELF TEST ENG = ST indication	V71X5025B		(5525)
STR TRK STAT = FAIL = 1	V95J4929C		(4930)

CAUSE:

Failure of BITE circuitry.

POSSIBLE IMPACT:

Failure of the star tracker to return from self-test mode and/or failure of the shutter to open makes the star tracker unusable. Single star tracker aligns will be required. The CDR HUD should be calibrated per GNC Flight Rule A8-108.

COMMENTS

Nominal self-test:

<u>Shutter Position</u>	<u>Self-Test Phase</u>
Open	At start of self-test
Closed	Part 1; offset mode test
Closed	Part 2; wrong offset posn test
Open	Part 3; return from self-test
Open	At the end of the test

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SCP 1.3 - GNC Hex Words
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TITLE

STAR TRACKER SELF-TEST DATA COLLECTION AND ANALYSIS

PURPOSE

This SCP describes the hardware and software details of self-test, collection of self-test data, analysis of these data, hardware characteristics and peculiarities, and how the SMS models the star trackers and self-test.

BACKGROUND

A star tracker self-test is performed to check the integrity of the LRU. When self-test is initiated (GNC SPEC 22, ITEM 1 or 2 EXEC), two light emitting diodes (LED's) are illuminated. One causes a bright object alert (BOA) which forces the shutter to be closed. A self-test cannot be engaged if an externally caused BOA is present since this prevents the bright object sensor (BOS) from being tested. Light from the second LED is reflected into the image dissecting tube (IDT) of the IDT Star Tracker by a small dot of silvering on the objective lens. A simulated IDT built-in-test equipment (BITE) star is thus created. For the Solid State Star Tracker (SSST), the second LED generates a star image through a pin hole that is reflected by a prism backwards through the objective lens. The image is then reflected by a mirrored spot on the protective window assembly, back through the lens and onto the CCD imager. This image on the CCD simulates a BITE star. The location of the BITE star is then measured. The measured horizontal and vertical locations are checked against a range of acceptable values coded into the PROM of the self-test circuitry. Likewise, the magnitude of the BITE star is measured and checked against a range of acceptable values. A summary of the Self-test software sequence is in shown in Figure 3.2-1. For a more detailed description of Self-test reference GNC SCP 3.1 "Star Tracker BITE".

At one time, a self-test of each star tracker was performed in the post insertion star tracker power up procedures. The nominal self-test was removed from the procedures after flight experience indicated that they were very reliable and the self-test itself was not very reliable. There were more good star trackers failing than passing self-test. The unreliability of the self-test has generated the need for the flight controller to analyze the self-test data to determine the true self-test result. The final star tracker health is determined by evaluating star tracker and IMU data after tracking stars.

DATA COLLECTION

Star Tracker Self-test data can be collected by using a history tab in real time or by retrieving ODRC data with MEWS. When using a history tab, snap the data approximately every second during the self-test (should collect from 10 to 15 snaps of data). The measured intensity and horizontal and vertical positions of the BITE star can be checked against the acceptable values listed in Tables 3.2-I for the SMS and 3.2-II for the flight hardware. The latest hardware data in Table 3.2-II can be verified by checking in the Star Tracker database on the Boeing KSC GNC web site.

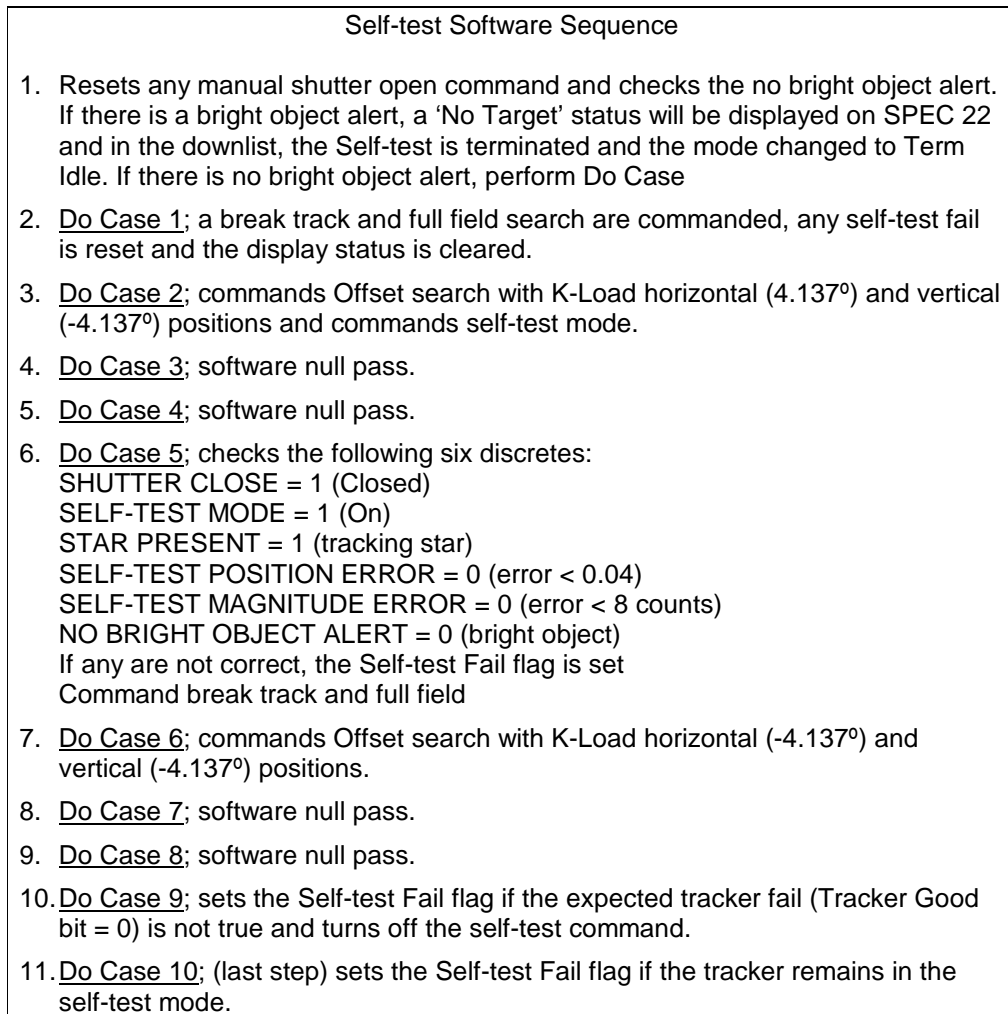


Figure 3.2-1 Summary of Self-test Software Sequence

DATA ANALYSIS

Flight data from STS-47 for IDT S/N 003 will be used to aid in the discussion of how to analysis the self-test. This tracker failed self-test several times during the flight because of a early check for the position and magnitude of the BITE star. A more detailed discussion of this hardware peculiarity can be found in the next section. Figures 3.2-2 through 3.2-5 show the results of two self-test in the format of a MEWS tab and a history tab.

Using the history tab of a good self-test in Figure 3.2-2 below, the steps of evaluating the self-test will be covered. Column A is the beginning of self-test, indicated by the self-test feedback (row 5) equal 1. Columns B and C indicate the tracking of the BITE star by the star present

discrete (row 8) equal 1. The position and magnitude data in these columns should be verified against past history found in Table 3.2-II. From the table IDT S/N 003 had the following: horizontal position of 4.38 degrees, vertical position of -4.46 degrees and magnitude of 12 counts (C hex). They agree very well. Note that the magnitude is the last two hex characters in the mode status word (row 1). Columns D and E show the expect position and magnitude errors for the second part of self-test (rows 6 & 7). Also note that the first hex character of the mode status word changed from B to 3 indicating that the first bit (Tracker Good) went to 0 meaning Tracker Fail. Column F is the end of self-test (row 5) and all error flags clear (rows 6 & 7). The last column G has the star tracker status indication (row 4) equal to 2 which means Self-test Pass. This same data in a MEWS tab format is in Figure 3.2-4.

STS-47									
	263/ 03: 06: 33	263/ 03: 06: 32	263/ 03: 06: 31	263/ 03: 06: 30	263/ 03: 06: 29	263/ 03: 06: 28	263/ 03: 06: 27	263/ 03: 06: 26	263/ 03: 06: 25
NAME									
-Z_ST_MODE_STATUS_WD1	A200	A200	3A00	3A00	BA00	BA00	BD0C	BD0D	BA00
-Z_ST_HOR_POS	5.081	-3.768	-3.765	-3.765	-3.765	4.977	4.365	4.365	4.487
-Z_ST_VERT_POS	0.752	-4.281	-4.088	-4.154	-3.918	-3.687	-4.454	-4.451	-3.994
-Z_ST_STATUS_INDICATION	2	0	0	0	0	0	0	0	0
-Z_ST_SELF_TEST	0	0	1	1	1	1	1	1	1
-Z_ST_ANGLE_ERR	0	0	1	1	0	0	0	0	0
-Z_ST_MAGTD_ERR	0	0	1	1	0	0	0	0	0
-Z_ST_STAR_PRESENT	0	0	0	0	0	0	1	1	0
-Z_ST_BRT_OBJECT_OFF	1	1	0	0	0	0	0	0	0
-Z_ST_SHUTTER_CLOSED	0	0	1	1	1	1	1	1	1
	G	F	E	D			C	B	A

ANALYSIS:
IDT S/N 003
A = first snap of tracker in self-test mode
B&C = check for star present bit and verify good positions and magnitude (magnitude is last two hex characters in mode status word)
D&E = note expected position and magnitude errors
F = self-test, position and magnitude errors clear
G = note status (1 = self-test fail and 2 = self-test pass)

Figure 3.2-2 History Tab and Analysis of Good Self-test

Now an example of a failed self-test will be discussed using the history tab in Figure 3.2-3. Again begin by looking for the start of self-test which is column A row 5. Column B has both the position and magnitude error flags set (rows 6 & 7) with no star present discrete set. The next second of data in column C has the star present discrete set and the position and magnitude data in this column agrees well with the history data in Table 3.2-II. Since the error flags were set in the first part of self-test and remain set until cleared at the end of self-test (column D), the second part of self-test can not be evaluated. Column E row 4 has the star tracker status equal to 1 which means Self-test Fail. However since the data in column C indicates that the star tracker did track the BITE star correctly, the star tracker is considered good and the failure is a failure of the self-test circuitry. Figure 3.2-5 shows this same self-test in the form of a MEWS tab of ODRC data.

STS-47									
	263/	263/	263/	263/	263/	263/	263/	263/	263/
	03:	03:	03:	03:	03:	03:	03:	03:	03:
	06:	06:	05:	05:	05:	05:	05:	05:	05:
NAME	01	00	59	58	57	56	55	54	53
-Z_ST_MODE_STATUS_WD1	A200	A200	3A00	3A00	3A00	3D0C	3A00	BA08	A200
-Z_ST_HOR_POS	5.081	-3.763	-3.768	-3.765	5.06	4.365	4.494	4.469	5.083
-Z_ST_VERT_POS	0.419	-4.583	-4.408	-4.471	-3.088	-4.451	-4.596	-4.532	-0.328
-Z_ST_STATUS_INDICATION	1	0	0	0	0	0	0	0	0
-Z_ST_SELF_TEST	0	0	1	1	1	1	1	1	0
-Z_ST_ANGLE_ERR	0	0	1	1	1	1	1	0	0
-Z_ST_MAGTD_ERR	0	0	1	1	1	1	1	0	0
-Z_ST_STAR_PRESENT	0	0	0	0	0	1	0	0	0
-Z_ST_BRT_OBJECT_OFF	1	1	0	0	0	0	0	0	1
-Z_ST_SHUTTER_CLOSED	0	0	1	1	1	1	1	1	0
	E	D				C	B	A	

ANALYSIS:
 IDT S/N 003
 A = first snap of tracker in self-test mode
 B = self-test fail with no star present (both position and magnitude fails)
 C = note the star present bit, verify good positions (from Table 3.2-II, horizontal = 4.38 and vertical = -4.46) and magnitude (magnitude is last two hex characters in mode status word = 0C hex = 12 decimal count)
 D = self-test, position and magnitude errors clear
 E = note status is 1 = self-test fail (however star tracker is good, self-test failed due to known staircase threshold signal problem that causes an early check of position and magnitude before bite star has been acquired)

Figure 3.2-3 History Tab and Analysis of Failed Self-test

HARDWARE CHARACTERISTICS/PECULIARITIES

During the manufacturing of each star tracker at the vendor (Ball Aerospace, Boulder, Colo.), the BITE star intensity and position (horizontal and vertical) are measured in terms of PCM counts. A tolerance around each position value of ±16 or ±17 counts is then established. For the intensity, the tolerance range is 16 counts and biased toward dimmer values. This prevents small, natural decreases in tracker sensitivity from causing self-test failures. The horizontal, vertical and intensity tolerances are then coded into the PROM of the self-test circuitry. Table 3.2-II lists these tolerances for each tracker currently on a vehicle.

The granularity for each position measurement is 9.14 arcsec (0.00254°) per PCM count. The equation to convert from PCM counts to S-20 intensity is $M = 5.25 - 2.5 (\log_{10}(\text{counts}))$. S-20 specifies that the intensity measurement is made in the visual part of the electromagnetic spectrum from 0.3 to 0.7 μm.

Many of the trackers have unique characteristics. Several of these are worth mentioning because of their operational impact. It is important to note that these characteristics are associated with the self-test circuitry and should not have an impact on the performance of the star trackers. Be careful to analyze the data from the self-test to ensure that the tracker failed as a result of a known self-test problem and not due to any real system failures.

Since star tracker self-test data can be evaluated by MCC, self-tests should be scheduled over ground coverage so MCC can determine the validity of the star tracker data should a failure occur. By comparing measured position and magnitude data to the known position and

magnitude data, MCC can determine if a real failure has occurred. Should ground coverage not be available, the crew should inspect the star table for anomalous indications before performing an IMU alignment with a suspect star tracker.

All IDT star trackers can fail self-test because of a generic glitch on the tracker Staircase Threshold signal. This glitch causes double triggering of a counter circuit, causing the premature comparison of the self-test position and magnitude data to the expected values. The self-test data should show that the BITE star was acquired before the 2.4 second hardware time-out limit, but the position and magnitude check was already performed and the failure declared. The magnitude data is loaded into the Data Word register 1 before the horizontal and vertical position data. If the magnitude data is loaded prior to the early comparison, the magnitude BITE will not be annunciated. Since the Staircase Threshold circuit is only used during self-test, the star tracker normal operations should not be affected.

All SSST have an 8% chance of annunciating a star tracker BITE for 2 sec during part one of self-test. Immediately after self-test is commanded, star tracker data words are erroneously set to zero for approximately 200 msec. The star tracker SOP is executed at 6.25 Hz and has an 8% chance of processing the bad data words. If the erroneous data words are processed, a BITE message may be annunciated on SPEC 22 for no more than two seconds.

Serial Number 2 (IDT loss on OV102) failed self-test because the BITE star magnitude built up too slowly. The hardware comparison to the factory set value occurred before the magnitude had built up to its peak value. A waiver was written during factory acceptance test because of this anomaly, which also reoccurred in SAIL and was verified using Ground Support Equipment (GSE).

Serial number 7 (IDT), which was lost during STS 51-L, had a problem in that it had fewer scan lines in its IDT than other trackers. This coupled with the particular location of the BITE star caused SN 7 to fail self-test about 50% of the time. What caused the failure was that during the first half of the test, the tracker did not acquire the star on the first scan through the 1° square offset search window. The hardware self-test timed out before the tracker acquired the star on a subsequent scan. The BITE star, however, was always acquired before the offset command was changed at 4 seconds into the test. The data from a failed self-test of this tracker had to be analyzed to determine the exact cause of the failure. A check of measured position and intensity values immediately after the star present discrete was set was required. If they were within tolerance, the failure was due to the timing/scan line problem. This was further verified by the fact that bit 1 of the mode status word was set to 0 (bad) before bit 6 of this word (star present) was set to 1.

Serial number 8 (IDT) has a BITE star that is located outside the 1° square offset search window. The hardware test times out and self-test always fails on this unit. Self-tests are conducted at KSC during flight turnaround of a vehicle. The software used for these tests differs from the flight location so as to include the SN 8 BITE star. During ground conducted self-tests, serial number 8 always passes.

Serial number 9 (IDT) has an unusually bright LED that produces the BITE star image. When the tracker was tested at Ball, BITE star intensities of 18 to 20 PCM counts were measured (the limit is 23 counts). Slight changes in the electronics of the self-test circuitry can occur which can cause the measured BITE star intensity to increase. A waiver was written against this tracker for an overbright BITE star. On STS 51-I, this tracker actually failed self-test due to a BITE star intensity of 24 PCM counts. A second test passed with a measured intensity of 23 counts.

SMS UNIQUE CHARACTERISTICS

The SMS uses a math model to simulate the star trackers. The model is identical for both trackers. The BITE star is at an approximate horizontal location of 4.13° (1627 counts, 656 hex) and a vertical location of -4.13° (-1627 counts, 9A5 hex). The nominal brightness is $M = (0 \text{ counts}, 00 \text{ hex})$.

When a self-test is requested, the trackers are commanded to offset search about the location of the BITE star. If the test is to pass, the star will be found at exactly that value given above. In other words, the math model has no randomness built into it. If the test is to fail, either one of the measured positions will be in error by at least 16 counts (0.04°) or the intensity will be in error by at least eight counts.

Another unique fact about the SMS model warrants mention; however it is not related strictly to self-test. The NAV base to star tracker transformation matrix is unique for each tracker on each vehicle. However, the SMS uses only two transformations (one for each tracker) independent of vehicle/flight software load. These transformations are within a tenth of a degree for OV-104. The transformations for OV-103 (Discovery) differ from those for the SMS by $\approx 0.3^\circ$. The transformations for OV-105 (Endeavour) differ from those for the SMS by $\approx 0.5^\circ$. For simulations with OV-103 and 105, a software patch containing the correct NAV base to star tracker transformation matrices must be loaded into the SMS model. If the patch is not loaded, the star data acquired by the trackers will be degraded with error reflected in the ΔANG and ANG ERR measurements. Transformation matrix differences can cause discrepancies between predictions made with the MCC supersighter program. Supersighter uses only the old OV-102 or SMS transformation. In the past, this has resulted in differences of several tenths of a degree in the predicted star position within a tracker FOV.

TRACKER COORDINATE SYSTEM

This section provides a discussion of the star trackers (IDT and SSST) coordinate systems and their orientations to the Orbiter body axes (X_b , Y_b , Z_b). Figure 3.2-6 depicts the tracker field-of-views (FOV's) as seen from inside the vehicle looking out. The $-Z$ boresight is rotated 3° from the $-Z_b$ axis in a plane rotated 41° from the $+X_b$ axis toward the $-Y$ axis. The $-Y$ boresight is parallel to the X_b - Y_b plane and is rotated 10.6° toward the $+X_b$.

In Figure 3.2-6, H (horizontal) and V (vertical) represent displacements of an object in the FOV when the tracker (vehicle) is rotated about one of its primary axes. For the $-Y$ tracker, the V rotation axis is parallel to $-Z_b$ and to the H displacement axis and perpendicular to the V displacement axis. Positive rotation (right-hand rule) of the tracker about the V axis (negative vehicle yaw) causes the tracker FOV to pan toward the tail ($-X_b$). This causes an object within the FOV to have an apparent motion toward the nose ($+X_b$) and thus a displacement in the $+V$ direction. The other primary axis, H, of the $-Y$ tracker is parallel to the X_b - Y_b plane and nearly parallel to X_b (skewed 10.6°). Positive rotation about this axis (negative vehicle roll) causes the FOV to pan downward toward $+Z_b$ and thus a displacement in the $+H$ direction.

Coordinate system conventions for the $-Z$ tracker are very similar to the $-Y$. Both the V and H rotation axes are parallel to the X_b - Y_b plane. Positive rotation about the V axis (positive vehicle roll) causes the tracker FOV to pan toward the starboard wing ($+Y_b$). An object within the FOV would appear to move toward the port wing, a $+V$ displacement. Positive rotation about the H axis (positive vehicle pitch) causes the FOV to pan toward the tail ($-X_b$). An object within the FOV would appear to move toward the nose ($+X_b$), a $+H$ displacement.

The effect of vehicle rotation about the three body axes is shown in Figure 3.2-6 by the crosses with arrowheads pointing to plus or minus signs. Vehicle roll, pitch and yaw rotations are designated by the letters R, P and Y, respectively. It is important to remember that the arrows indicate the apparent motion of the object, which is opposite to the motion of the vehicle.

REFERENCES

1. Level C FSSR, GN&C Part E, Star Tracker SOP, Par. 4.66.4.2.
2. Star Tracker Subsystem Manager.
3. STS Flight Software I-LOAD.

Flight/Test: STS-047 Title:		TDF: Data:						
Measurement ID	MODE STATUS	HORZ POS	VERT POS	STATUS WORD	SELF TEST ENGAGED	POSITION ERROR	MAG ERROR	STAR PRESENT
Units	V71M5020P	V71H5041B	V71H5061B	V95J4929C	V71X5025B	V71X5073B	V71X5074B	V71X5026B
Rate Sec/Sample DAY HR MN SEC								
263:03:06:25.094	A200	5.081	-0.574	0	0	0	0	0
263:03:06:25.173			-0.317					
263:03:06:25.373			-0.193					
263:03:06:25.494		4.487						
263:03:06:25.573			-3.994					
263:03:06:25.613	BA00				1			
263:03:06:25.694		4.481						
263:03:06:25.773			-3.864					
263:03:06:25.894		4.494						
263:03:06:25.973			-3.674					
263:03:06:26.173		4.357						
263:03:06:26.294			-4.448					
263:03:06:26.373		4.365						
263:03:06:26.494			-4.451					
263:03:06:26.573	BD0D	4.36						1
263:03:06:26.613			-4.454					
263:03:06:27.094		4.362						
263:03:06:27.173			-4.448					
263:03:06:27.294		4.365						
263:03:06:27.373			-4.454					
263:03:06:27.494			-4.451					
263:03:06:27.573	BD0C							
263:03:06:27.613			-4.451					
263:03:06:27.773			-3.816					
263:03:06:28.373		4.977						
263:03:06:28.494			-3.687					
263:03:06:28.573	BA00							0
263:03:06:28.613		5.05						
263:03:06:28.694			-3.56					
263:03:06:28.773			-3.433					
263:03:06:28.973		5.045						
263:03:06:29.094			-3.054					
263:03:06:29.173			-3.054					
263:03:06:29.294		5.06						
263:03:06:29.373			-4.055					
263:03:06:29.494		-3.765						
263:03:06:29.573			-3.918					
263:03:06:29.773			-3.806					
263:03:06:29.973			-4.52			1	1	
263:03:06:30.094		-3.768						
263:03:06:30.173			-4.408					
263:03:06:30.294		-3.765						
263:03:06:30.373			-4.281					
263:03:06:30.573			-4.154					
263:03:06:30.613	3A00							
263:03:06:30.773			-3.788					
263:03:06:30.973			-3.661					
263:03:06:31.094		-3.768						
263:03:06:31.173			-4.583					
263:03:06:31.294		-3.765						
263:03:06:31.373			-4.474					
263:03:06:31.573			-4.088					
263:03:06:31.773			-3.963					
263:03:06:31.973			-3.852					
263:03:06:32.094		-3.763						
263:03:06:32.173			-3.725					
263:03:06:32.294		-3.768						
263:03:06:32.373			-4.408			0	0	
263:03:06:32.573			-4.281					
263:03:06:32.613	A200				0			
263:03:06:32.694		-3.765						
263:03:06:32.773			-4.151					
263:03:06:32.973			-4.024					
263:03:06:33.173			0.503					
263:03:06:33.293				2				
263:03:06:33.294		4.464						
263:03:06:33.373			0.627					
263:03:06:33.494		5.081						
263:03:06:33.573			0.752					
263:03:06:33.773			0.879					

Figure 3.2-4 IDT S/N 003 ODRC Data of Self-test Passed

Flight/Test: STS-047 Title:		TDF: Data:						
Measurement ID	MODE STATUS	HORZ POS	VERT POS	STATUS WORD	SELF TEST ENGAGED	POSITION ERROR	MAG ERROR	STAR PRESENT
Units	V71M5020P	V71H5041B	V71H5061B	V95J4929C	V71X5025B	V71X5073B	V71X5074B	V71X5026B
Rate Sec/Sample DAY HR MN SEC								
263:03:05:53.094	A610	5.081	-0.967	4	0	0	0	1
263:03:05:53.173			-0.711					
263:03:05:53.293				0				
263:03:05:53.373			-0.584					
263:03:05:53.494		5.083	-0.328					
263:03:05:53.573	A200							0
263:03:05:53.613		5.081	-0.203					
263:03:05:53.694		4.53	-3.92					
263:03:05:53.773		4.481	-3.801					
263:03:05:53.894		4.494	-4.659					
263:03:05:54.094		4.469	-4.532					
263:03:05:54.173								
263:03:05:54.294								
263:03:05:54.373								
263:03:05:54.494								
263:03:05:54.573	BA08				1			
263:03:05:54.613		4.451	-4.283					
263:03:05:54.694		4.481	-4.156					
263:03:05:54.773			-4.029					
263:03:05:54.894			-3.903					
263:03:05:54.973		4.494						
263:03:05:55.094								
263:03:05:55.173								
263:03:05:55.294								
263:03:05:55.373								
263:03:05:55.494								
263:03:05:55.573	3A00		-4.596			1	1	
263:03:05:55.613								
263:03:05:55.694		4.367	-4.464					
263:03:05:55.773								
263:03:05:55.894			-4.451					
263:03:05:56.094		4.365						
263:03:05:56.173		4.362						
263:03:05:56.294		4.365						
263:03:05:56.373	3D0C							1
263:03:05:56.494		5.045						
263:03:05:56.573			-3.819					
263:03:05:56.613		5.048	-3.72					
263:03:05:56.694								
263:03:05:56.773		5.045	-3.336					
263:03:05:56.894		5.05	-3.214					
263:03:05:57.094								
263:03:05:57.173		5.06	-3.088					
263:03:05:57.294	3A00							0
263:03:05:57.373		-3.765						
263:03:05:57.494			-3.991					
263:03:05:57.573			-3.745					
263:03:05:57.613			-3.671					
263:03:05:57.694								
263:03:05:57.773		-3.768						
263:03:05:57.894			-4.583					
263:03:05:58.094		-3.765						
263:03:05:58.173			-4.471					
263:03:05:58.294			-4.09					
263:03:05:58.373			-3.961					
263:03:05:58.494								
263:03:05:58.573		-3.763						
263:03:05:58.613			-3.852					
263:03:05:58.694			-3.725					
263:03:05:58.773		-3.768						
263:03:05:58.894			-4.408					
263:03:05:59.094			-4.281					
263:03:05:59.173		-3.765						
263:03:05:59.294			-4.154					
263:03:05:59.373			-4.027					
263:03:05:59.494			-3.661					
263:03:06:00.094		-3.763						
263:03:06:00.173			-4.583					
263:03:06:00.294	A200				0	0	0	
263:03:06:00.373		-3.765						
263:03:06:00.494			-4.471					
263:03:06:00.573			-4.344					
263:03:06:00.613			-3.961					
263:03:06:00.694								
263:03:06:00.773			-3.849					
263:03:06:00.894		5.081	0.419					
263:03:06:01.094		5.086	0.561					
263:03:06:01.173		5.081	0.942					
263:03:06:01.293								
263:03:06:01.373								
263:03:06:01.494								
263:03:06:01.573								
263:03:06:01.694								
263:03:06:01.773								
263:03:06:01.894								
263:03:06:01.973								

Figure 3.2-5 IDT S/N 003 ODRC Data of Self-test Failed

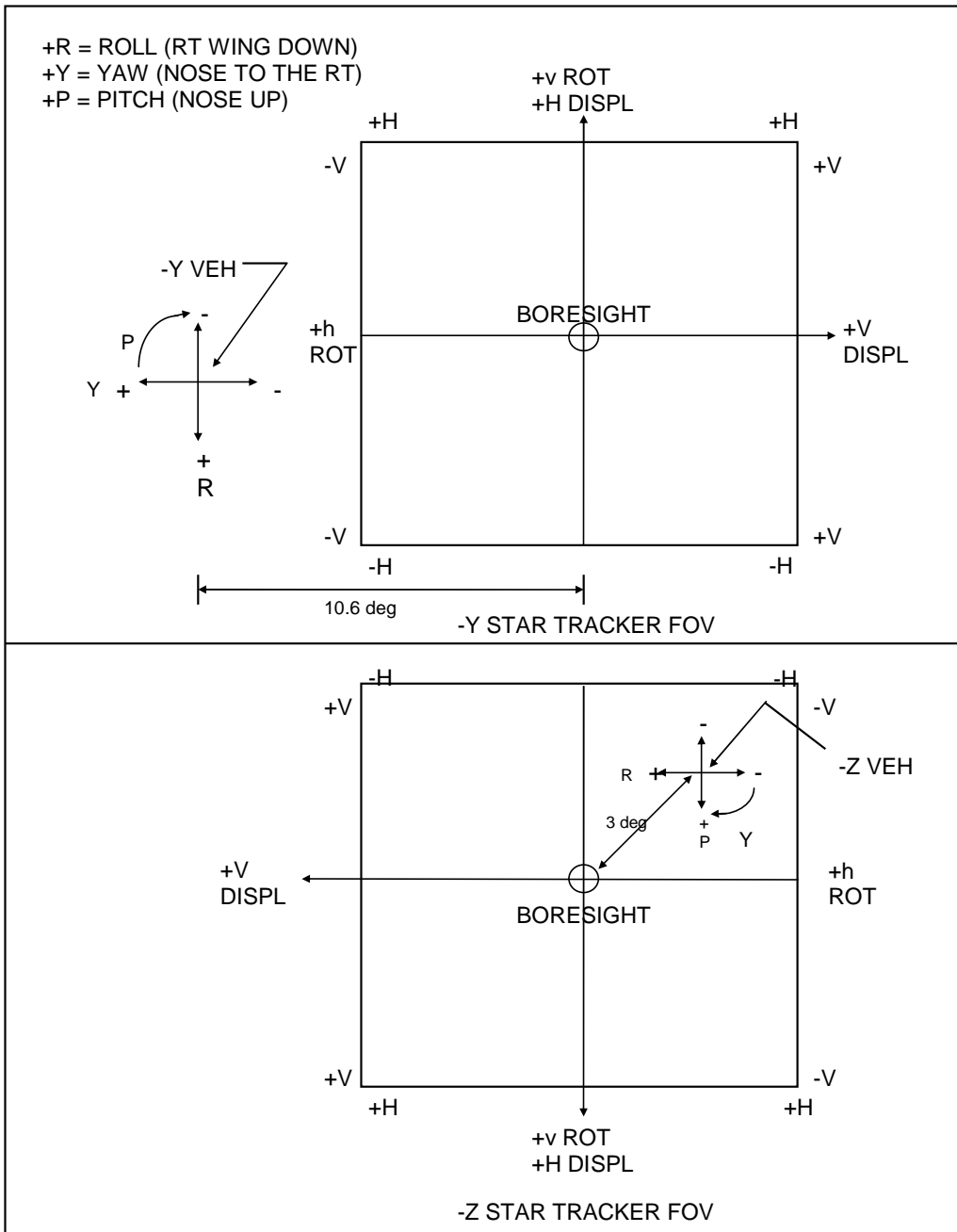


Figure 3.2-6. - Star tracker/Shuttle coordinate systems relationships (arrows show object motion for given vehicle rotation, view looking out).

TABLE 3.2-I. - BITE STAR TOLERANCES FOR THE SMS TRACKERS

Horizontal			Vertical			Intensity		
Counts	HEX	Deg	Counts	HEX	Deg	Counts	HEX	MAG
1611	64B	4.090	-1611	9B5	-4.090			
1612	64C	4.093	-1612	9B4	-4.093			
1613	64D	4.095	-1613	9B3	-4.095			
1614	64E	4.098	-1614	9B2	-4.098			
1615	64F	4.100	-1615	9B1	-4.100			
1616	650	4.103	-1616	9B0	-4.103			
1617	651	4.105	-1617	9AF	-4.105			
1618	652	4.108	-1618	9AE	-4.108			
1619	653	4.110	-1619	9AD	-4.110			
1620	654	4.113	-1620	9AC	-4.113			
1621	655	4.116	-1621	9AB	-4.116			
1622	656	4.008	-1622	9AA	-4.008	0*	00*	∞*
1623	657	4.121	-1623	9A9	-4.121	1	01	5.25
1624	658	4.123	-1624	9A8	-4.123	2	02	4.50
1625	659	4.126	-1625	9A7	-4.126	3	03	4.06
1626	65A	4.128	-1626	9A6	-4.128	4	04	3.75
1627*	65B*	4.131*	-1627*	9A5*	-4.131*	5	05	3.50
1628	65C	4.133	-1628	9A4	-4.133	6	06	3.31
1629	65D	4.136	-1629	9A3	-4.136	7	07	3.14
1630	65E	4.138	-1630	9A2	-4.138	8	08	2.99
1631	65F	4.141	-1631	9A1	-4.141			
1632	660	4.144	-1632	9A0	-4.144			
1633	661	4.146	-1633	99F	-4.146			
1634	662	4.149	-1634	99E	-4.149			
1635	663	4.151	-1635	99D	-4.151			
1636	664	4.154	-1636	99C	-4.154			
1637	665	4.156	-1637	99B	-4.156			
1638	666	4.159	-1638	99A	-4.159			
1639	667	4.161	-1639	999	-4.161			
1640	668	4.164	-1640	998	-4.164			
1641	669	4.166	-1641	997	-4.166			
1642	66A	4.169	-1642	996	-4.169			
1643	66B	4.171	-1643	995	-4.171			

TABLE 3.2-II. - BITE STAR TOLERANCES

IDT TRACKERS

IDT S/N	H HORIZONTAL POSITION				V VERTICAL POSITION			
	RANGE		*TEST POSN		RANGE		*TEST POSN	
	COUNTS	DEGREES	CNTS	DEG	COUNTS	DEGREES	CNTS	DEG
003	1719 (-16,+16)	4.36 (4.32,4.41)	1724	4.38	-1751 (-16,+16)	-4.45(-4.49,-4.41)	-1755	-4.46
005	1807 (-16,+16)	4.59 (4.55,4.63)	1801	4.57	-1753 (-16,+17)	-4.45(-4.49,-4.41)	-1759	-4.47
006	1640 (-16,+17)	4.16 (4.12,4.21)	1626	4.13	-1857 (-16,+17)	-4.71(-4.76,-4.67)	-1853	-4.70
008	1872 (-16,+17)	4.75 (4.71,4.80)	1869	4.75	-1636 (-16,+17)	-4.15(-4.19,-4.11)	-1632	-4.14
009	1757 (-16,+16)	4.46 (4.42,4.50)	1758	4.46	-1687 (-16,+16)	-4.28(-4.32,-4.24)	-1687	-4.28
011	1508 (-16,+17)	3.83 (3.79,3.87)	1503	3.82	-1808 (-16,+16)	-4.59(-4.63,-4.55)	-1813	-4.60
012	1614 (-16,+17)	4.10 (4.06,4.14)	1614	4.10	-1762 (-16,+17)	-4.47(-4.51,-4.43)	-1762	-4.47
013	1686 (-16,+17)	4.28 (4.24,4.32)	1672	4.25	-1665 (-16,+17)	-4.23(-4.27,-4.18)	-1668	-4.23

IDT S/N	I INTENSITY		
	RANGE	*TEST VALUE	
	(CNTS)	CNTS	MAG
003	12 (-4,+4)	12	2.55
005	15 (-9,+8)	21	1.95
006	13 (-9,+8)	15	2.31
008	15 (-9,+8)	15	2.31
009	15 (-8,+8)	13	2.47
011	15 (-9,+8)	14	2.39
012	15 (-9,+8)	15	2.31
013	15 (-9,+8)	22	1.89

SOLID STATE TRACKERS

SSST S/N	H HORIZONTAL POSITION				V VERTICAL POSITION			
	RANGE		*TEST POSN		RANGE		*TEST POSN	
	COUNTS	DEGREES	CNTS	DEG	COUNTS	DEGREES	CNTS	DEG
002	1628 (-17,+17)	4.13 (4.09,4.18)	1632	4.14	-1739 (-16,+17)	-4.42(-4.46,-4.37)	-1738	-4.41
003	1615 (-17,+17)	4.10 (4.06,4.14)	1616	4.10	-1789 (-16,+17)	-4.54(-4.58,-4.50)	-1793	-4.55
004	1594 (-16,+17)	4.05 (4.01,4.09)	1595	4.05	-1782 (-16,+17)	-4.52(-4.57,-4.48)	-1789	-4.54
005	1638 (-16,+17)	4.16 (4.12,4.20)	1638	4.16	-1883 (-16,+17)	-4.78(-4.82,-4.74)	-1884	-4.78
007	1558 (-16,+16)	3.96 (3.92,4.00)	1556	3.95	-1768 (-16,+16)	-4.49(-4.53,-4.45)	-1771	-4.50

SSST S/N	I INTENSITY		
	RANGE	*TEST VALUE	
	(CNTS)	CNTS	MAG
002	15 (-9,+8)	20	2.00
003	15 (-9,+8)	14	2.39
004	15 (-9,+8)	17	2.17
005	15 (-9,+8)	15	2.31
007	15 (-9,+8)	15	2.31

* - Test position reflects the data from KSC turnaround self-test (as of 7/2003).

Note: Position conversion: 9.1402 arcsec/count

Magnitude conversion: 2.50 log₁₀ (126/counts)

TITLE

STAR TRACKER MISALIGNMENT DETERMINATION

PURPOSE

To determine the good star tracker for use in alignment.

BACKGROUND

For all star alignments, one criterion for ensuring the validity of the data is to check the ANG ERR reading. The ANG ERR is a calculation of the error between the catalogued angular difference between the star pair and the measured angular difference between the line-of-sight vectors.

When the ANG ERR $> 0.08^\circ$, the data are considered suspect and the trackers must be evaluated. If the star tracker self-test cannot isolate a failure in one of the star trackers, this procedure should be used to determine the good tracker.

The crew will not have this procedure available in any of their Flight Data File (FDF) books; it can be sent to them via uplinked message. The procedure is complete, including all required ITEM entry numbers and explanatory notes.

This procedure assumes that an alignment attempt has been made that resulted in an ANG ERR $> 0.08^\circ$. By using one star tracker to track a single star from the star pairs pad twice, the good tracker can be identified. The star is acquired by one tracker in two attitudes, rotated 180 degrees from each other about the star's line of sight. This causes the position error to occur on opposite sides of the line of sight. As a result, the calculated ANG ERR and ANG DIFF will be twice the actual error (very small if the good tracker is being used).

This procedure also assumes that the error is a bias, and is the same value over the full tracker FOV. Depending on the geometry of the star pair, a scale factor error (where measurements taken at the center of the FOV will have no error) may not be detected by this procedure. A more general procedure would be to use UNIV PTG to track any catalog star twice in a corner of the FOV ($H \sim \pm 3.5$, $V \sim \pm 3.5$), using any two convenient omicron angles 180 degrees apart.

PROCEDURE

GNC 22 S TRK/COAS CNTL

S TRK CNTL - Y: TERM/IDLE, ITEM 9 EXEC (*)
S TRK CNTL - Z: TERM/IDLE, ITEM 10 EXEC (*)

A. Test -Z S TRK:

CRT S TABLE CLR: ITEM 20 EXEC

Use star pairs pad (Orbit Operations Checklist Flight Supplement) to track star pair for alignment. Using Dual S TRK Attitude (set 1 or set 2), MNVR to locate the star in -Z S TRK FOV tracking -Z star only.

When in attitude:

CRT S TRK - Z: REQ'D ID, ITEM 12 + __ EXEC
S TRK CNTL - Z: STAR TRK, ITEM 4 EXEC (*)
√ S TRK - Z: STATUS - (NO BITE)
√ SHUTTER - OP
√ DATA ACCEPTED IN STAR TABLE

Use alternate Single S TRK Attitude (set 2 or set 1) to track same star with -Z S TRK a second time (this is a 180° MNVR about the star LOS).

When in attitude:

CRT S TRK - Z: REQ'D ID, ITEM 12 + __ EXEC
S TRK CNTL - Z: STAR TRK, ITEM 4 EXEC (*)
√ S TRK - Z: STATUS - (NO BITE)
√ SHUTTER - OP
√ STAR TABLE: TRK ID 1, 2 - (REQ'D ID)
√ ANG ERR 1 - (≤ 0.16) Rcd __. __

If data is accepted into the star table, -Z S TRK is good (to within 0.1 degrees). If data not acceptable, or table clears when star tracked second time, -Z S TRK is bad.

TITLE

HUD/COAS CALIBRATION COORDINATION AND ANALYSIS

PURPOSE

The purpose of this SCP is twofold. The first is to explain the rationale, coordination effort, and proper setup for obtaining Head Up Display (HUD) or Crew Optical Alignment Sight (COAS) calibration data. The second is to describe the logic behind and procedures for analyzing these data.

BACKGROUND

During some Orbiter flights, it will be necessary to have a calibrated HUD/COAS device. Should the HUD/COAS be required to support a star alignment, it must first be accurately calibrated. There is a calibration vector stored onboard as an I-Load. This vector is predetermined by data from prior flights of the vehicle or by ground analysis results. The I-Load for the +X position was originally determined to support +X COAS calibrations. Flight data has shown that the +X COAS is not adequately repeatable during a mission, especially on OV-103. Many HUD calibration DTO's were performed and the CDR HUD was found to have an excellent repeatable line of sight (LOS) vector, and is now the primary backup to the star trackers for IMU alignments. The I-Load values have been updated to support CDR HUD calibrations at 14.7 psi. Since flight experience has shown that the actual line-of-sight may shift, a crewmember manually sights on a star and calibrates (or verifies) the HUD/COAS real time (in +X/-Z positions, respectively). By the use of the attitude reference pushbutton, the crew member may "mark" on a star, and by making an item entry on SPEC 22 (S TRK/COAS CNTL), an update can be performed which overwrites the I-Load with the last mark. Flight data suggest that the CDR HUD may experience less body bending effects than the COAS and the I-Load may therefore not require updating. The final updated mark is the current reference vector the S/W will use for alignments. The crew member may take several marks, both before and after an update to ensure the accuracy and repeatability of the reference vector.

HUD/COAS vector parameters are contained in the GNC downlist (OI-21 & subs). These data appear in decimal form on the HUD/COAS CAL display and on the COAS_CAL History Tab. This data is only available in the GNC high data rate downlist. If the calibration is done during GNC low data rate downlist, the variable parameter downlist must be used to obtain this data. See USING THE VARIABLE PARAMETER DOWNLIST section for information on gathering the data by this method. Though desirable, it is not necessary to monitor a calibration in real time. ODRC data can be requested to cover the entire cal data period. It is recommended that hardcopies or history tabs be made of each mark and update if the procedure is seen in real time.

The data collected from the calibration can be processed using a PC spreadsheet. There is a template spreadsheet to be used to evaluate the calibration and separate spreadsheet for each vehicle which contains it's history of calibrations. The evaluation of a calibration entails simply looking at the grouping of the marks with respect to each other and the I-Load or update to insure the reference pointing vector is accurate. This is done by computing the

vector separation angles and the horizontal and vertical angles which describe the vectors position relative to the +X or -Z body axis. The horizontal and vertical angles are presented on a plot to be used to make this engineering judgment.

PROCEDURE

- A. Prior to the HUD/COAS calibration, verify the normalized REFSMMATs are uplinked and rolled into the current REFSMMAT slot with an IMU alignment (ref. SCP 2.10), and check the data on the HUD/COAS CAL display to verify the data represents the I-Load or the previously stored update.
- B. Verify that high data rate GNC downlist will be available at the time of the calibration. If not, proceed to the USING THE VARIABLE PARAMETER DOWNLIST section of this SCP for gathering the mark vectors.
- C. During the calibration, monitor the HUD/COAS CAL display for changes in the mark decimal data for X, Y, Z and take history tab snapshots to ensure that every mark is correctly noted. Note when the mark is updated (when the update vector matches the mark vector). A hardcopy of the display can be taken for each mark as well.
- D. After the calibration is completed, pull ODRC data to ensure all marks are accounted for.
- E. Procedure for using the PC spreadsheet to obtain a plot of the calibration marks.
 1. Obtain a copy of the spreadsheet from the DF62 Private directory. Rename the file appropriately, such as, "Hud91" for a HUD calibration on STS-91.
 2. Edit the LABEL with the flight and position being calibrated. Select the vehicle and station being used in the boxes on the right side of the spreadsheet.
 3. Verify the I-Load LOS vector on the downlist is same as on the spreadsheet.
 4. Copy the I-Load vector and use Paste Special to paste only the values into the REF vector location. If an update is made later, you may want to paste the update vector into the REF vector location. Change the REF label to note which vector you have selected as the REF vector.
 5. Enter the vectors for each mark. There is room for up to 20 marks on the template spreadsheet. This should be enough for most cases, some editing of the spreadsheet may be required if more marks are taken.
 6. Check the UPDATE box to for the appropriate mark or marks.
 7. The horizontal and vertical angles for each mark are computed. The separation angle of each mark from a reference vector is also computed. The normal reference vector is the I-Load vector. If an update has been performed, the reference vector may be changed to the update vector. If this is done, change the reference vector label as well.

8. The horizontal and vertical angles will be shown on the plot. A detailed description of the spreadsheet with editing aids is given in the DETAILED WORKSHEET DESCRIPTION section.

DESCRIPTION OF EQUATIONS

The decimal coordinates for all LOS vectors from the HUD/COAS CAL display are used to determine the separation angle (α) between each vector pair. The formula is shown below for two vectors A and B.

$$\alpha = \arccos \frac{A \cdot B}{|A| * |B|}$$

Recall that the dot product between two vectors is

$$A \cdot B = |A| * |B| * \cos \alpha = (X_A * X_B + Y_A * Y_B + Z_A * Z_B)$$

Remember that, onboard, the vectors are considered to be unit vectors and the PASS assumes $|A| = |B| = 1$. Hence,

$$\alpha = \arccos (X_A * X_B + Y_A * Y_B + Z_A * Z_B)$$

In actuality, the onboard vectors are not unitized. Therefore the onboard separation angle will have a small error. The spreadsheet calculates the true angular separation using the following equation.

$$\alpha = \arccos \frac{X_A * X_B + Y_A * Y_B + Z_A * Z_B}{|A| * |B|}$$

The horizontal (H) and vertical (V) angles can be extracted only after the LOS vectors have been transformed from the navigation base to the body coordinate system. The transformation matrix for the appropriate Orbiter vehicle is an I-Load with FSSR names TNBBODY (1,1) through TNBBODY (3,3) and MSIDs V96U7096C through V96U7104C. The equations to transform a vector A and then calculate H and V follow.

$$A_{\text{BODY}} = T_{\text{NAV}}^{\text{BODY}} * A_{\text{NAV}}$$

Now, from the body vector's components A_x , A_y , and A_z , H and V for the -Z COAS is:

$$H = \arctan2 \frac{-A_y}{-A_z} \text{ and } V = \arctan2 \frac{A_x}{-A_z}$$

For the HUD or +X axis:

$$H = \arctan2 \frac{A_y}{A_x} \text{ and } V = \arctan2 \frac{-A_z}{A_x}$$

An arbitrary sign convention has been chosen for H and V. It is oriented such that when both coordinates are positive, the intersection point is located in the upper right-hand quadrant of the plane perpendicular to the body vector associated with a HUD/COAS mounting position. In other words, at the forward position, +V and +H are in the directions of the -Z and +Y body axes, respectively. At the aft position, +V and +H are in the directions of the +X and -Y body axes, respectively. H&V are defined (by DF62) as the angles of the HUD/COAS centerline from the ideal body axis (+X/-Z).

USING THE VARIABLE PARAMETER DOWNLIST

If the -Z COAS or CDR HUD calibration is scheduled to be performed during GNC low data rate periods, MCC can use the variable parameter (VP) downlist. These data appear in hexadecimal form. Each X, Y, Z vector coordinate is represented by two halfword locations plus one halfword update location (9 VP locations total).

The VP downlist memory locations should be given to the DPS Officer (using the variable parameter display request form) as early as possible to ensure the data are available when needed. The DPS Officer can build the load real-time, but prefers to know the locations prior to flight so that they can be prebuilt and loaded on to their workstations.

The hexadecimal data may be converted to floating point decimal using the off line conversion program, htd, location on the PC.

1. Check HALSTAT listings for current addresses for CGYV_I_CO (mark vector) and CGYS_I_COAS (update vector). Look up the addresses in MEMORY MAP and the I-Load will be noted in its hex format. The first six halfwords represent -Z (X, Y, Z) followed by the six +X (X, Y, Z) coordinates.
2. An electronic version of the variable parameter display request can be obtained from the DPS officer. Build the variable downlist format as desired, one example format is as follows:

HAL NAME	ADDRESS	VP Scaling			SLOT
		K	BIAS	TYPE	
CGYV_I_CO (MARK X HALFWORD 1)	BA64				
CGYV_I_CO (MARK X HALFWORD 2)	BA65				
CGYS_I_COAS (UPDATE X HALFWORD 2)	498F				
CGYV_I_CO (MARK Y HALFWORD 1)	BA66				
CGYV_I_CO (MARK Y HALFWORD 2)	BA67				
CGYS_I_COAS (UPDATE Y HALFWORD 2)	4991				
CGYV_I_CO (MARK Z HALFWORD 1)	BA68				
CGYV_I_CO (MARK Z HALFWORD 2)	BA69				
CGYS_I_COAS (UPDATE Z HALFWORD 2)	4993				

NOTE: Use the entire mark address (I_CO) and the least significant halfword (LSHW) of the update (I_COAS) in order to see each mark and recognize each update made (as the LSHW of I_CO and I_COAS will be identical when the mark has been updated). No VP scaling is required, as the downlisted data in HEX will be used.

3. Give the completed form to the DPS officer (two copies for them, retain one for a record) as soon as possible prior to the HUD/COAS calibration so that the VP load can be uplinked prior to the calibration.
4. Prior to the COAS/HUD calibration, verify REFSMMATs are normalized, uplinked, and rolled into the current REFSMMAT slot with an IMU alignment (Ref SCP 2.10), and check the variable parameter downlist on the DPS Variable Parameter display when the VP uplink is accomplished to verify the locations. (The hex data should represent the I-Load or the previously stored update).
5. During the calibration, take hardcopies of the DPS Variable Parameter display for a record of the I_CO (mark) HEX data for X, Y, & Z. Note when the mark is updated (by I_COAS data matching I_CO).
6. When the calibration is complete, inform the DPS Officer to return to the normal set of Variable parameter downlist.
7. Convert the hexadecimal coordinates to floating point decimal representation using the GNC off line HTOD program located on the PC. In case this cannot be accomplished, the conversion is outlined in the HEX to Decimal Conversion SCP (Reference SCP 10.6).
8. Once the decimal coordinates for all LOS vectors have been determined, the remaining steps for using the PC spreadsheet are the same as those listed in part E of the PROCEDURE section of this SCP.

DETAILED WORKSHEET DESCRIPTION

The blank spreadsheets are located on the S: drive (S:\Divisions\DF\Private\DF62\hud_coas\) and available on floppy diskette in the GNC supply cabinet. They are read only files that

should be copied to a working area before using to do an analysis. The spreadsheet is protected against inadvertent changes to all cells except those intended to be inputs.

The spreadsheet is shaded to help identify the input cells which have no shading. Figure 3.4-1 shows the Input section of the Mark Analysis worksheet before any selections have been made. This spreadsheet has room for 20 marks plus the I-Load to be plotted and analyzed.

LABEL as the name implies is where the flight and type of calibration can be noted. This label plus the selected vehicle will be the title of the plot.

The Vehicle and the Station being calibrated must be selected in the windows on the right side of the worksheet. These selections will place the correct I-Load LOS vector on the page, selects the correct NAV Base to Body transformation matrix for the calculations as well as selects the appropriate H and V equations for the selected station.

The REF VECTOR is the vector from which the separation angles are measured. This normally should be the I-Load LOS vector. It could also be the update mark LOS vector. The easiest method of putting this vector in is to highlight the I-Load or mark vector desired and do a copy. Place the cursor in the first cell for REF VECTOR and select Paste Special and then under Paste select Values. For the I-Load vector, the normal Paste will copy equations and shading which will provide incorrect numbers. The cell to the right of REF VECTOR IS allows for the user to define which vector he has chosen.

The LOS vector for each mark is placed in the appropriate cells and the mark or marks that are used to do the update are checked in the UPDATE box. This places an UPDATE label below the appropriate H and V values.

Figure 3.4-2 shows a portion of the results of the above inputs for the STS-68 HUD calibration. In this example note that the I-Load is for the +X COAS and not the HUD. This is the reason the large separation angles between the marks and the I-Load.

The intermediate calculations as well as the data used to generate the plot are shown in Figure 3.4-3. The H_{ave} and V_{ave} are the average H and V of the marks. These equations will require editing to remove all cells in the equation that have no associated mark data. The first column of the plot data has the data labels for the plot. These can be edited as desired in cases where other marks from previous flights might be plotted for comparison.

Figure 3.4-4 has the I-Load constants for the NAV Base to Body transformation matrix and the LOS vectors for the +X and -Z positions.

The Plot tab on the spreadsheet has the plotted marks and I-Load. Although the data is plotted automatically, the scaling will have to be changed to get the desired view of the data. Figure 3.4-5 shows the initial plot with the default scaling.

Now lets go through the thought process of changing these scales. For this example, the STS-68 I-Load is not applicable since it was for the +X COAS. Therefore looking at the marks select a V axis range to cover the marks, such as from -4.5 to -4.7 and pick an appropriate Major Unit value such as 0.05. Double click on the V axis to pop up a format box to change the scale as note above. Put the value for the x axis crossing to match the bottom of the scale, in this case -4.7. Now we must pick a range for the H axis to make the plot square. By square we want the lengths between Major Units on both axes to be equal when measured on a printout of the plot. This can be approximated by making the H range equal to 1.7 times the

V range and making the Major Unit values the same. So for this example the V range was 0.2, so the H range should be 0.34. If this range will cover all the desired marks, double click on the H axis to pop up the format box to change the scale. For this example make the Minimum equal to 1.0 and the Maximum equal to 1.34 with the same Major Unit of 0.05. Place the value for the y axis crossing as the value to place axis on the left side of the plot, in the case 1.0. The resultant plot is shown in Figure 3.4-6. Note that the label for mark 3 was edited to show it as the update mark.

LABEL		STS-XX HUD CALIBRATION				OV102 ▲	
VEHICLE		NO VEHICLE				OV103	
STATION		NO STATION				OV104	
						OV105 ▼	
		REF VECTOR IS I-LOAD				STATION	
I-LOAD	X	0.0000000000	H	#DIV/0! deg	0.0000000000	<input type="radio"/> + X	
	Y	0.0000000000	V	#DIV/0! deg	0.0000000000	<input type="radio"/> - Z	
	Z	0.0000000000			0.0000000000		
		SEP ANGLE FROM REF VECTOR					
MARK #1	X		H	#VALUE! deg	#DIV/0! deg		
<input type="checkbox"/> UPDATE	Y		V	#VALUE! deg			
	Z						
MARK #2	X		H	#VALUE! deg	#DIV/0! deg		
<input type="checkbox"/> UPDATE	Y		V	#VALUE! deg			
	Z						
MARK #3	X		H	#VALUE! deg	#DIV/0! deg		
<input type="checkbox"/> UPDATE	Y		V	#VALUE! deg			
	Z						

Figure 3.4-1 HUD/COAS Spreadsheet Input Page

LABEL		STS-68 HUD CAL				OV102 ▲	
VEHICLE		OV105				OV103	
STATION		+ X				OV104	
						OV105 ▼	
		REF VECTOR IS I-LOAD				STATION	
I-LOAD	X	0.983470559	H	-0.000985 deg	0.994078994	<input checked="" type="radio"/> + X	
	Y	0.002123276	V	-0.273147 deg	0.023145597	<input type="radio"/> - Z	
	Z	-0.181055486			-0.106165946		
		SEP ANGLE FROM REF VECTOR					
MARK #1	X	0.994113982	H	1.196533 deg	0.02518 deg		
<input type="checkbox"/> UPDATE	Y	0.022783797	V	-4.619951 deg			
	Z	-0.105918944					
MARK #2	X	0.994211972	H	1.216995 deg	0.07202 deg		
<input type="checkbox"/> UPDATE	Y	0.023135599	V	-4.677654 deg			
	Z	-0.104915977					
MARK #3	X	0.994078994	H	1.217278 deg	0.00000 deg		
<input checked="" type="checkbox"/> UPDATE	Y	0.023145597	V	-4.605614 deg			
	Z	-0.106165946	UPDATE				

Figure 3.4-2 Example of Inputs for STS-68 HUD Calibration

	Have	1.1965693 deg	1	4
	Vave	-4.631762 deg		
		TNB_B	0.9825962	0.0021508 -0.1857419
	0.999988542		-0.0017131	0.9999954 0.0025169
	-1.71968E-05		0.1857464	-0.0021549 0.9825953
	0.004767297			
		STS-68 HUD CAL	OV105	
#	0.99653516	OV102		H(+Y) V(-Z)
	0.020814105	OV103	I-LOAD	-0.0009853 -0.273147
	0.080528568	OV104	1	1.1965328 -4.6199506
		OV105	2	1.2169949 -4.6776538
#	0.996445908	SMS 102	3	1.2172779 -4.6056144
	0.021168261	SMS 103	4	1.1827649 -4.6434081
	0.081531522	SMS 104	5	1.1832133 -4.6220299
		SMS 105	6	1.1826322 -4.6219157
#	0.996547437		7	#VALUE! #VALUE!
	0.021175342		8	#VALUE! #VALUE!
	0.080278587		9	#VALUE! #VALUE!
			10	#VALUE! #VALUE!
#	0.996506383		11	#VALUE! #VALUE!
	0.020573945		12	#VALUE! #VALUE!
	0.080936902		13	#VALUE! #VALUE!
			14	#VALUE! #VALUE!
#	0.996537006		15	#VALUE! #VALUE!
	0.02058238		16	#VALUE! #VALUE!
	0.080565118		17	#VALUE! #VALUE!
			18	#VALUE! #VALUE!
#	0.996537361		19	#VALUE! #VALUE!
	0.020572275		20	#VALUE! #VALUE!
	0.080563149			
#	#VALUE!			
	#VALUE!			
	#VALUE!			
#	#VALUE!			
	#VALUE!			
	#VALUE!			

Figure 3.4-3 Intermediate Calculations & Plot Data

I-Loads			+X I-Load V99U5613C thru V99U5615C	
Nav Base to Body Matrix			-Z I-Load V99U5610C thru V99U5612C	
V96U7096C thru V96U7104C			+X I-LOAD	-Z I-LOAD
TNB_B	OV102		OV102	
0.9829565000	0.0004363300	-0.1838379000	0.99419611	-0.17497026
-0.0004529500	0.9999999000	-0.0000484000	0.023578673	0.000845611
0.1838379000	0.0001308500	0.9829566000	-0.10496675	-0.98457324
TNB_B	OV103		OV103	
0.9828661000	0.0001108162	-0.1843208600	0.99405318	-0.18395137
-0.0003560171	0.9999990400	-0.0012972000	0.025312617	0
0.1843205600	0.0013405955	0.9828652100	-0.10591268	-0.98293524
TNB_B	OV104		OV104	
0.9829423400	-0.0010151360	-0.1839108400	0.99424595	-0.18395137
0.0009305624	0.9999994000	-0.0005461669	0.025032	0
0.1839113200	0.0003657101	0.9829427500	-0.10415196	-0.98293524
TNB_B	OV105		OV105	
0.9825961500	0.0021507702	-0.1857419000	0.99422502	-0.18395137
-0.0017130849	0.9999953500	0.0025168766	0.024047922	0
0.1857464300	-0.0021548818	0.9825953200	-0.10458606	-0.98293524
TNB_B	SMS		Includes OI-28 HUD I-LOAD for OV104	
0.9829353491	0.0000000000	-0.1839513506		
0.0000000000	1.0000000000	0.0000000000		
0.1839513506	0.0000000000	0.9829353491		

Figure 3.4-4 I-Loads

STS-68 HUD CAL OV105

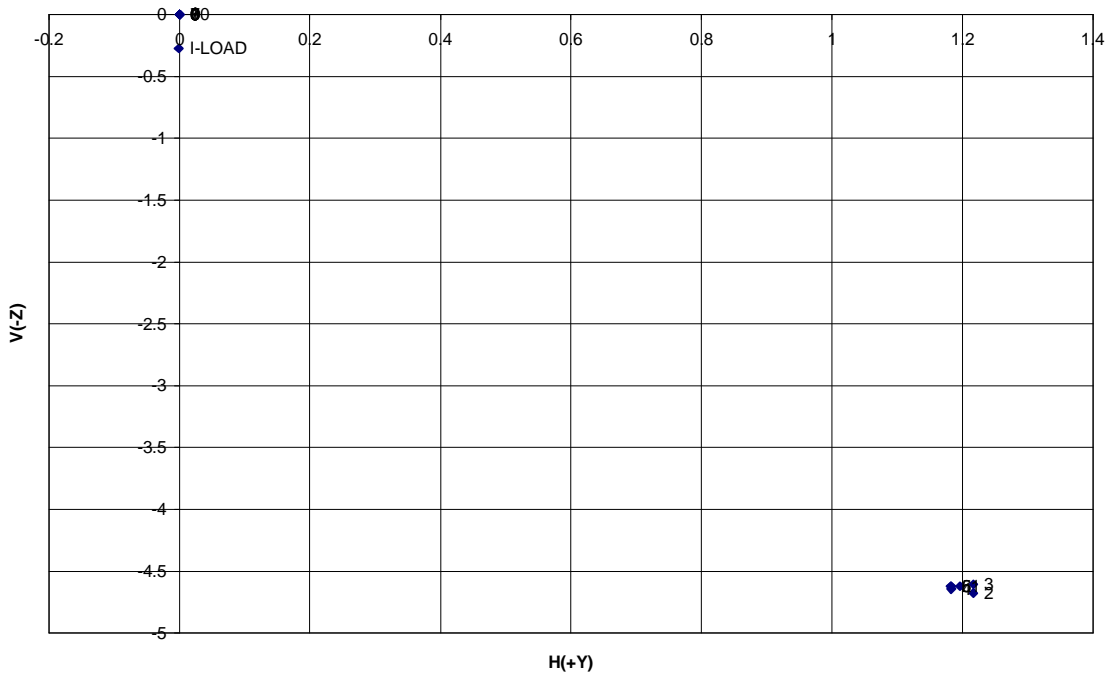


Figure 3.4-5 Example of initial plot data

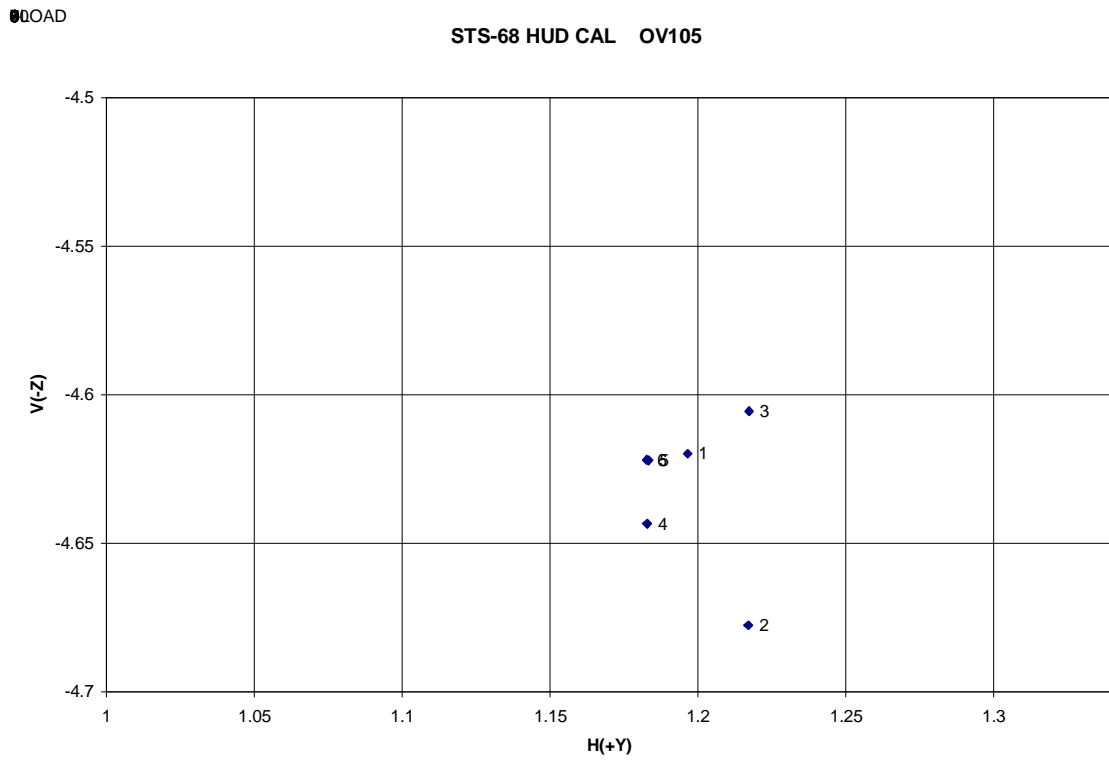


Figure 3.4-6 Example of Plot after scales are modified

TITLE

STAR CATALOG COMMAND WITH GCS

PURPOSE

The Orbiter onboard star catalog contains 100 stars of which the last ten (stars 101 through 110) can be changed via the Star Catalog Uplink command. This command consists of the position unit vectors for ten stars picked from an uplinkable star catalog of 849 stars. The uplinkable star catalog was provided by the engineering star tracker subsystem manager. It consists of stars to be used by the solid state star tracker which will be in the -Y location. This capability was developed primarily to support orbiter docked to the International Space Station.

General

WARNING: This procedure is governed by FCOH SOP 3.1 and 3.2.1, and cannot be modified without prior approval of the FOIG or the Flight Director (during real-time operations). Safety critical steps are marked by a box.

Restrictions:

OI Load: OI-26 and subsequent
OPS Mode : PASS (OPS 2 only) No BFS CMD
Major Function: GNC
Vehicles: all
Crew/MCC coordination: information only
Time Constraints: None
MCC Constraints: None

Hazardous: This load replaces the unit vectors for ten stars of the on-board star catalog. If the uplink causes erroneous unit vectors to be stored for these ten stars, the star tracker would not be able to track those stars. The remaining 90 stars in the on-board catalog would still be available for tracking for IMU alignments.

Require safing: no

PROCEDURES

A. BUILDING A STAR CATALOG UPLINK

Note: Before building the first star catalog uplink, the original I-loaded stars (101-110) should be built and stored, under DSM 43801, by following the part A procedure as follows.

1. Select the STAR UPLINK GCS program from the GNC DNAV MENU under Apps. The command build window is showed in Figure 3.5-1.

2. Under the FILE pull down menu, select NEW, or if retrieving a previously saved load, select OPEN and enter appropriate file name. If retrieving a previously saved load, all data should be verified per steps 3. through 8. below.
3. Enter a DSM Sequence number (1 through 50) in the DSM Sequence field.
4. Enter a title for the load in the title field. The title is limited to 21 characters and will be the title of the DSM when it is sent to the Command Server. It would be helpful to include the words 'Star Cat' in the title to help identify the load on the Command Tracking display when it is uplinked.
5. In each of the catalog slots 101 through 110, enter the desired star ID's. The program will search the uplinkable star catalog and display the position unit vector for each star as it is entered. Since the data file containing the position unit vectors is certified, verification of these vectors is not required. If desired, the selected star's position unit vectors can be verified by comparing them with Table 5.2-2 in the STS 83-0014V2 Level C FSSR Star Tracker SOP for OI-28 and subsequent releases.
6. When all entries are verified to be correct, save the load on the workstation using the save option on the pull down menu. Save the file in the MEDS directory under the flight specific directory with the file extension of ".gcs". This file will be retrieved using the Star Catalog Update command display for sending the load to the Command Server.
7. Obtain a hardcopy of the Star Command Build window.

Command Build Window

DSM Class = 438 OP Code = HEX 2F Major Function = GNC

DSM Sequence Title

Action Messages:

File Messages:

Star Table Data

Slot	Star ID	X	Y	Z
101	<input type="text"/>			
102	<input type="text"/>			
103	<input type="text"/>			
104	<input type="text"/>			
105	<input type="text"/>			
106	<input type="text"/>			
107	<input type="text"/>			
108	<input type="text"/>			
109	<input type="text"/>			
110	<input type="text"/>			

Figure 3.5-1 - Star Catalog Uplink Window

B. SENDING THE LOAD TO THE COMMAND SERVER

1. Verify a Command Manager is running on the workstation being used to submit the load to the Command Server. If required, start a Command Manager from the Master DNAV, Global Apps, Command Server menu.
2. Select the Star Catalog display from the GNC DNAV, Real Time, GNC GCS Display menu. Any previous stored load in the Command Server will be displayed. Retrieve the file built in step A.7. The Star Catalog Update Command display is shown in figure 3.5-2.
3. Select STORE to send the load to the Command Server. The Server feedback of the load will appear on the Star Catalog Update Command display.

NOTE: Command Display inputs are not allowed when the Command Server is in checkpoint.

4. Obtain a hardcopy of the new load.

File																																																																																																																																						
Star Catalog Update																																																																																																																																						
DSM #		DSM Title		GMT Gen																																																																																																																																		
43802		Star Cat 2		024:08:31:00																																																																																																																																		
<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;"></th> <th style="width: 10%; text-align: center;">hex</th> <th style="width: 15%;"></th> <th style="width: 15%;"></th> <th style="width: 10%;"></th> <th style="width: 10%; text-align: center;">hex</th> <th style="width: 10%;"></th> <th style="width: 10%;"></th> </tr> </thead> <tbody> <tr> <td>101 X</td> <td>40fe4920</td> <td>0.99330330</td> <td style="border: 1px solid black; text-align: center;">0.99330330</td> <td>106 X</td> <td>c07fa830</td> <td>-0.49866009</td> <td style="border: 1px solid black; text-align: center;">-0.49866009</td> </tr> <tr> <td>Y</td> <td>bf39b060</td> <td>-0.01408422</td> <td style="border: 1px solid black; text-align: center;">-0.01408422</td> <td>Y</td> <td>404d62c7</td> <td>0.30228847</td> <td style="border: 1px solid black; text-align: center;">0.30228847</td> </tr> <tr> <td>Z</td> <td>401dccf8</td> <td>0.11467410</td> <td style="border: 1px solid black; text-align: center;">0.11467410</td> <td>Z</td> <td>c0cff813</td> <td>-0.81237906</td> <td style="border: 1px solid black; text-align: center;">-0.81237906</td> </tr> <tr> <td>102 X</td> <td>406e16c3</td> <td>0.43003482</td> <td style="border: 1px solid black; text-align: center;">0.43003482</td> <td>107 X</td> <td>3e67bbd1</td> <td>0.00158285</td> <td style="border: 1px solid black; text-align: center;">0.00158285</td> </tr> <tr> <td>Y</td> <td>c02dccf8</td> <td>-0.17890881</td> <td style="border: 1px solid black; text-align: center;">-0.17890881</td> <td>Y</td> <td>40fc60d8</td> <td>0.98585272</td> <td style="border: 1px solid black; text-align: center;">0.98585272</td> </tr> <tr> <td>Z</td> <td>c0e28950</td> <td>-0.88490772</td> <td style="border: 1px solid black; text-align: center;">-0.88490772</td> <td>Z</td> <td>402ae83e</td> <td>0.16760626</td> <td style="border: 1px solid black; text-align: center;">0.16760626</td> </tr> <tr> <td>103 X</td> <td>4016246e</td> <td>0.08649335</td> <td style="border: 1px solid black; text-align: center;">0.08649335</td> <td>108 X</td> <td>4029d413</td> <td>0.16339225</td> <td style="border: 1px solid black; text-align: center;">0.16339225</td> </tr> <tr> <td>Y</td> <td>c0604867</td> <td>-0.37610680</td> <td style="border: 1px solid black; text-align: center;">-0.37610680</td> <td>Y</td> <td>40d1ca79</td> <td>0.81949574</td> <td style="border: 1px solid black; text-align: center;">0.81949574</td> </tr> <tr> <td>Z</td> <td>c0ec2b04</td> <td>-0.92253137</td> <td style="border: 1px solid black; text-align: center;">-0.92253137</td> <td>Z</td> <td>408c9ee0</td> <td>0.54929924</td> <td style="border: 1px solid black; text-align: center;">0.54929924</td> </tr> <tr> <td>104 X</td> <td>c0639016</td> <td>-0.38891733</td> <td style="border: 1px solid black; text-align: center;">-0.38891733</td> <td>109 X</td> <td>4036fa27</td> <td>0.21475452</td> <td style="border: 1px solid black; text-align: center;">0.21475452</td> </tr> <tr> <td>Y</td> <td>c0eba92a</td> <td>-0.92054999</td> <td style="border: 1px solid black; text-align: center;">-0.92054999</td> <td>Y</td> <td>3f5ba0e0</td> <td>0.02237022</td> <td style="border: 1px solid black; 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Figure 3.5-2 Star Catalog Update Command Display

C. VERIFYING A STAR CATALOG UPDATE LOAD

1. Verify the correct command has been loaded in the Command Server by comparing the server feedback from step B3 with the command built in step A7. Note that rounding in the hex to decimal conversion may cause a difference in the eighth decimal place.

D. NOTIFICATION AND APPROVAL

1. Advise the GNC FCR by DSM number that the load has been built, verified, and is ready for uplink.
2. The GNC FCR will verify that the load is correct.
3. The GNC FCR will obtain Flight Director approval for command uplink.
4. GNC coordinates with INCO on INCO Loop to uplink the command. Standard coordination shall include reading the DSM number, the MF, DSM title, and that the Flight Director has given a "Go" for uplink, as well as a read back by INCO of the information for verbal verification.
5. The GNC FCR will monitor the INCO loop until all command actions are completed. INCO will notify the GNC FCR when the actions are completed. GNC and GNC SPT will monitor the Command Tracking display to verify that the correct commands have been executed.

E. VERIFICATION OF UPLINK ONBOARD

1. When the uplink is complete, verify the new onboard star position unit vectors on UPLINKABLE STARS display.
2. GNC/GNC SPT will log the DSM# and uplink time in the Console Logs.
3. Once the load has been uplinked and Star Tracker performance has been verified, the original I-loaded stars (101-110) and the latest uplinked stars should remain stored in the Command Server. Other star uplink loads should be deleted.

F. INFORMING FAO AND POINTING

1. When the uplink is complete and verified, GNC will write an internal note informing FAO/POINTING on the configuration of the onboard star table.

TITLE

SMALL STAR SEPARATION ANGLE IMU ALIGNMENT

PURPOSE

The purpose of this SCP is to discuss how star pairs with small separation angle (less than 90°) can be used for IMU alignments.

PROCEDURE

In the past, star pairs with separation angles (θ) approaching 90° relative to the Orbiter have been used for IMU alignments. During periods when the orbiter is docked to the MIR spacecraft, however, such star pairs will most likely not be available; in addition, the orbiter will be less able to maneuver for the acquisition of stars. Therefore, star pairs separated by smaller angles, will need to be evaluated as possible alignment pairs.

Figure 1 shows the degradation of realignment uncertainty as a function of star pair separation angle. Figure 1 is the graph of the tabular data in Table 1. The figure shows that as the separation angle decreases to 50°, the uncertainty increases slowly. Beyond 50°, the uncertainty increases rapidly, but is still acceptable for alignments down to 10° (uncertainty of 0.1°). Separation angles below 7°- 10° are probably not desirable for alignment, however, a separation as small as 2° can be used to determine the position of a lost platform to within 1° or to determine drift trends.

To supplement our new-found knowledge in the selection of appropriate small angled pairs, we now attempt to explain how the attitude accuracy becomes diluted; however, several definitions must first be established. Refer to Figures 2-3 for an overall perspective of the basic elements.

Celestial Sphere: a convenient sphere of infinite radius, whose center is defined as the position of the star tracker, and whose primary axis is defined as the line between the star tracker position and the position of the primary star. For the discussion in this SCP, we may consider a sphere of finite radius "r".

Primary Star: the star whose position along with the star tracker position, defines the primary axis of the celestial sphere.

Secondary Star: the star whose position is anywhere in the celestial sphere and which defines the azimuth angle of attitude.

Equatorial Plane: that plane which contains the star tracker and which is perpendicular to the primary axis of the celestial sphere.

Secondary Plane: that plane which contains the secondary star, and which is perpendicular to the primary axis passing through its center.

Instrument Error: measurement errors unique to individual star trackers which essentially remain constant.

For illustration purposes, the celestial sphere will be defined with an arbitrary radius, "r". Referring to Figure 2, we see the celestial sphere and the primary axis. We assume that we have sighted three stars, all of which lie on the surface of the celestial sphere. The first star (star 1) also lies on the primary axis. The second star (star 2) also lies on the equatorial plane. The third star (star 3) lies along the same azimuth as the first two stars, but is not on the equatorial plane or on the primary axis.

We assume that the star tracker determines the position of the primary star without error. We further assume that all of the star tracker error is incurred in the positioning of the secondary star. It should also be noted that the difference in instrument error from one star tracker to another is negligible.

As shown in Figure 3, the instrument error defines a "band" with constant arc length widthwise along the meridian containing the primary and secondary stars. This error appears as an azimuth error in the final attitude.

Since we have assigned an arbitrary radius "r" to the celestial sphere, r happens to be the perpendicular distance from the primary axis to star 2. And since star 2 lies on the surface of the celestial sphere, it falls on an arc with circumference $2\pi r$, transcribed by the celestial sphere and the equatorial plane. We will call this arc C1.

Star 3, although not in the equatorial plane, can be thought of as contained in a second plane parallel to and elevated away from the equatorial plane. We note that the perpendicular distance from star 3 to the primary axis is $r \sin \theta$. And since star 3 lies on the surface of the celestial sphere, it falls on an arc with circumference $2\pi r \sin \theta$, transcribed by the celestial sphere and the "secondary" plane. We will call this arc C2.

Since the instrument error is constant along the azimuth, we see that the error associated with the positioning star 2 and 3 is distributed over two different arcs, C1, and C2. For star 2 the instrument error is distributed over the larger arc, C1. For star 3, the instrument error is distributed over a smaller arc C2 ($\sin \theta < 1$). The smaller the arc, the less precise the measurement, because the error consumes a larger proportion of the arc containing that star. Therefore, as Figure 1 illustrates, as the separation angle decreases, the resolution of measurement also decreases.

To further illustrate this concept, we consider the following. For a given star tracker, let the instrument error be $\pm 1^\circ$. Let a secondary star be sighted in the equatorial plane, i.e., 90° from the primary star. The azimuth angle will have an error of $\pm 1^\circ$. Now let a third star be sighted with a separation angle of 1° relative to the primary star. For the second pair, the error would be $\pm 180^\circ$ because the third star lies exactly on the edge of the "band" of instrument error.

FIGURES & TABLES

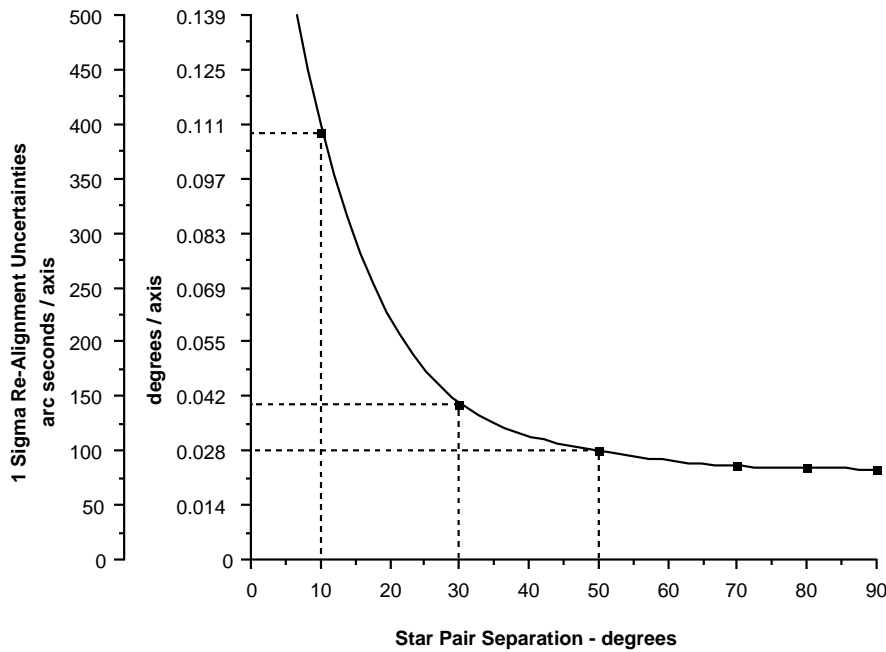


Figure 1 - On-Orbit Star Tracker / IMU Realignment Uncertainties as a Function of Star Pair Separation for all Random Errors

Star Pair Separation degrees	1 σ Realignment Uncertainties	
	arc seconds / axis	degrees / axis
10	392	0.109
30	143	0.040
50	100	0.028
70	86	0.024
90	82	0.023
110	86	0.024
130	100	0.028
150	143	0.040

Source: SODB Section 4.5.1, Table 4.5.1-19

TABLE 1 - ON-ORBIT STAR TRACKER / IMU REALIGNMENT UNCERTAINTIES AS A FUNCTION OF STAR PAIR SEPARATION FOR ALL RANDOM ERRORS

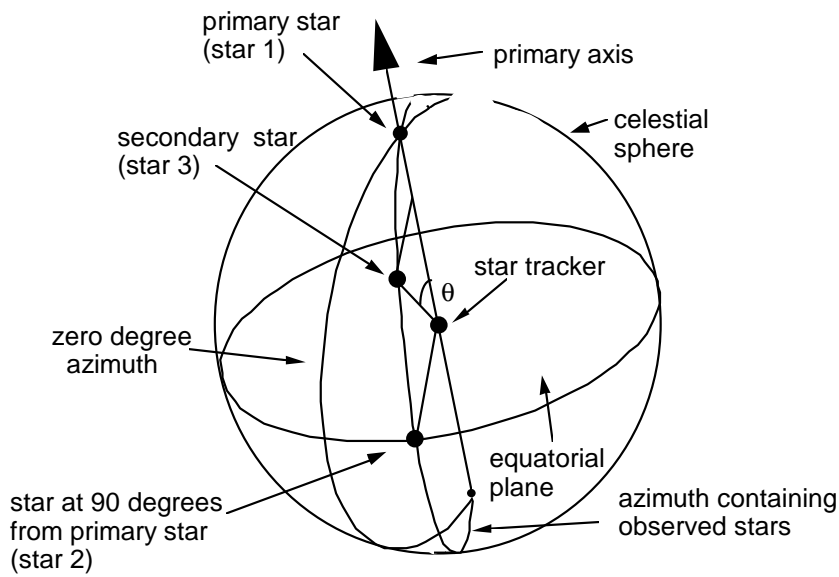


Figure 2 - Celestial Sphere relative to Star Tracker

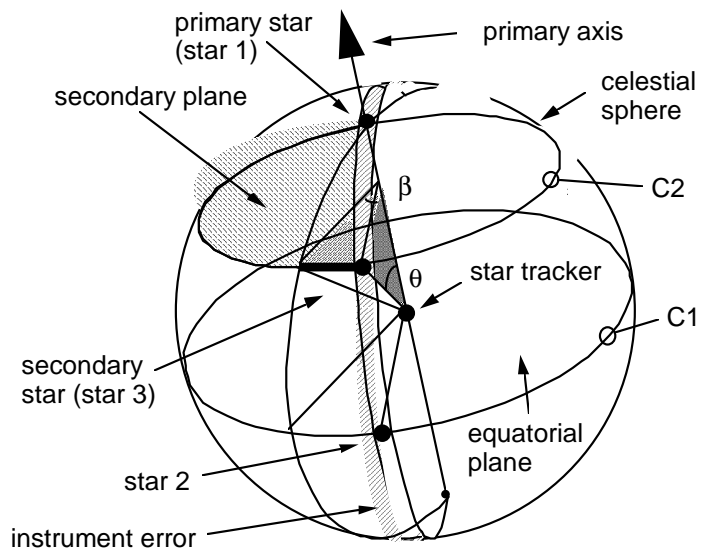


Figure 3 - Relationship of Instrument Error to Celestial Sphere

Error Source	1 σ Error Magnitude, arc seconds/axis
Initialization measurement errors (bench initialization) Star Tracker	14
Inertial Measurement Unit	14
Line replacement unit reinstallation errors (no measurements) Star Tracker	20
Inertial Measurement Unit	20
Navigation base Thermal Bending (Star Tracker to IMU)	<15
IMU Stable Member errors Pitch to Outer Roll gimbal non-orthogonality	30
Case to Outer Roll gimbal misalignment	28
Resolver errors	44
Star Tracker error (line of sight with respect to case)	42
RSS 1 σ / axis / star measurement (budget total)	82

Source: SODB Section 4.5.1.2.3, Table 4.5.1-20

Table 2 - Error Budget for Star Tracking / IMU Realignment

TITLE

SINGLE STAR TRACKER DOOR CLOSURE

PURPOSE

This SCP provides procedures for closing a single star tracker door when required by Flight Rule 8-109: Star Tracker System Management.

BACKGROUND

The star tracker doors are closed prior to entry to prevent plasma flow through the orbiter, which could result in damage to the airframe, navigation base, and/or crew cabin. If the doors are subject to one failure that would fail them both in the open position, Flight Rule 8-109B requires that one of them be closed, to preclude a possibly catastrophic entry should this next failure occur.

Closing a star tracker door with the star tracker powered on causes two door motor control opstats to remain powered after the door control system is turned off. For example, the -Y star tracker is powered on with the door close. On SSSH drawing 9.6 zone O8, the FMCA1 K13 relay will be powered on. The star tracker is powered on (a "1") and the door is not open (a "0"), thus the inverted AND logic operator will output a "1" energizing the relay. This is the logic that prevents the door from opening if the star tracker is turned off. The other FMCA1 relay logics incorporate the star tracker door control switch output and will not energize with the door control off. For the same reasoning, the FMCA2 K3 relay will also be energized in this configuration. These relays cause the FMCA1 Forward Opstat1 and FMCA2 Forward Opstat 2 respectively to remain powered. It is preferable not to leave relays energized. Therefore if a star tracker door will be closed for an extended duration, the corresponding star tracker should be turned off.

PROCEDURE

Assess door motor health via the following sources of information:

- motor operation duration during post insertion tracker door opening (MET~2 hrs) (7 seconds for both motors operating, 14 seconds for one).
- orbiter systems failure impacts from SSSH drawing 9.6, sheet 1. External malfunctions affecting motor function are all control buses, main buses, and FPC/FMC/AC(multi-phase) sub-buses.
- Orbiter star tracker door status from the CRANS GNC ORBIT STATUS and SENSORS PELAUNCH Displays

Determine if current conditions place the orbiter in one of the following cases:

- A) Loss of both trackers' door motor 1
- B) One tracker door failed open due to one of the following:
 - 1. Loss of both motors on one tracker door
 - 2. One star tracker door mechanically stuck open
- C) Loss of one star tracker and one of its motors

Cases A and B require door closure per Flight Rule 8-109. Case C does not, because the orbiter is not one failure from both doors stuck open. However, a closure of the failed tracker's door is recommended because the next failure could cause the failed tracker's door to be failed open, requiring closure of the good tracker's door (resulting in loss of both star trackers).

A) LOSS OF BOTH TRACKERS DOOR MOTOR 1 (DOOR CLOSURE REQUIRED)

In this case, a subsequent loss of MN B/FPC2/FMC2/AC2 or CNTL BC1, BC2, or BC3 will fail both doors in the open position. To preclude this, one tracker door must be closed by performing the following procedure:

- Turn off -Y(-Z) star tracker (one with door to be closed):
 - O6 -Y(-Z) STAR TRKR PWR - OFF
 - O15(14) cb STAR TRKR -Y(-Z) - op
- Close -Y(-Z) star tracker door:
 - O6 STAR TRKR DR CNTL SYS 2(1) - CL
 - √-Y(-Z) STAR TRKR DR POS tb - bp (start timer)
 - When both tb - CL (8-24 sec), or tb - bp for > 24 sec,
 - DR CNTL SYS 2(1) - OFF

B) ONE TRACKER DOOR FAILED OPEN (DOOR CLOSURE REQUIRED)

In this case, one tracker door is failed in the open position, and a single mechanical failure can fail the second tracker door in the open position. Thus, the tracker door with the only remaining motor must be closed with the following procedure:

- Turn off -Y(-Z) star tracker (one with door to be closed):
 - O6 -Y(-Z) STAR TRKR PWR - OFF
 - O15(14) cb STAR TRKR -Y(-Z) - op
- Close -Y(-Z) star tracker door
 - O6 STAR TRKR DR CNTL SYS(two) - CL
 - √-Y(-Z) STAR TRKR DR POS tb - bp (start timer)
 - When tb - CL (8-24 sec), or tb - bp for > 24 sec,
 - DR CNTL SYS(two) - OFF

C) LOSS OF ONE TRACKER AND ONE OF ITS DOOR MOTORS (DOOR CLOSURE RECOMMENDED)

In this case, two options exist to get one star tracker door closed. Both tracker doors can be closed and only the good tracker's door re-opened, or if it is undesirable to close both doors temporarily, the closure of one of the doors can be inhibited by unpowering the associated

electrical bus (via a FMCA logic circuit breaker). The latter procedure avoids the risk (albeit small) of the good tracker's door mechanically jamming closed (resulting in the loss of both trackers), but the crew must open and close a circuit breaker on the middeck.

To close both doors and re-open one:

- Turn off -Y(-Z) star tracker (one with door to be closed):
O6 -Y(-Z) STAR TRKR PWR - OFF
O15(14) cb STAR TRKR -Y(-Z) - op
- Close both star tracker doors:
O6 STAR TRKR DR CNTL SYS(two) - CL
√POS tb(two) - bp (start timer)
When both tb - CL (8-24 sec), or either tb - bp for > 24 sec,
DR CNTL SYS(two) - OFF
- Open door of -Z(-Y) (good) star tracker:
O6 STAR TRKR DR CNTL SYS (two) - OP
√-Z(-Y) STAR TRKR DR POS tb - bp (start timer)
When tb - OP (8-24 sec), or tb - bp for > 24 sec,
DR CNTL SYS (two) - OFF

To close only the -Y(-Z) failed tracker door with its motor 1 failed:

- Disable motor on -Z(-Y) tracker:
MA73C:C MCA LOGIC MCA PWR AC3(1) 3Ø FWD 3(1) - op
- Turn off -Y(-Z) star tracker (one with door to be closed):
O6 -Y(-Z) STAR TRKR PWR - OFF
O15(14) cb STAR TRKR -Y(-Z) - op
- Close -Y(-Z) star tracker door:
O6 STAR TRKR DR CNTL SYS 2(1) - CL
√-Y(-Z) STAR TRKR DR POS tb - bp (start timer)
When tb - CL (8-24 sec), or tb - bp for > 24 sec,
DR CNTL SYS 2(1) - OFF
- Recover power:
MA73C:C MCA LOGIC MCA PWR AC3(1) 3Ø FWD 3(1) - cl

To close only the -Y(-Z) failed tracker door with its motor 2 failed:

- Disable motor on -Z(-Y) tracker (not required if motor 2 lost due to bus failure):
MA73C:C MCA LOGIC MCA PWR AC2 3Ø FWD 2 - op
- Turn off -Y(-Z) star tracker (one with door to be closed)::
O6 -Y(-Z) STAR TRKR PWR - OFF
O15(14) cb STAR TRKR -Y(-Z) - op
- Close -Y(-Z) star tracker door:
O6 STAR TRKR DR CNTL SYS 1(2) - CL
-Y(-Z) STAR TRKR DR POS tb - bp (start timer)
When tb - CL (8-24 sec), or tb - bp for > 24 sec,
DR CNTL SYS 1(2) - OFF
- Recover power:
MA73C:C MCA LOGIC MCA PWR AC2 3Ø FWD 2 - cl

REFERENCES

1. Space Shuttle Systems Handbook, drawing 9.6 (star tracker), sheets 1-2
2. STS Operational Flight Rules, Volume I, All Flights, Jan. 20, 1989, PCN-22, Rule A8-109

TITLE

BACKUP HUD/COAS CALIBRATION USING MISALIGNED IMU

PURPOSE

The purpose of this SCP is to explain the principle involved, document the ground procedure, and describe the coordination required between the crew and the MCC.

BACKGROUND

Reference SCP 3.4 for the explanation for the need for HUD/COAS calibration for each flight. This SCP addresses the technique by which a calibration may be performed using a misaligned IMU. Redundancy for IMU alignment is normally recovered following loss of a star tracker by performing a nominal calibration (or verification) within 24 hours. However, since calibration cannot be performed while docked to ISS, and, because undocking early to perform a HUD calibration carries a high cost to the program, it is likely that the calibration will be delayed increasing the window of exposure to a second star tracker failure. A second star tracker failure before calibrating the HUD leaves us without a calibrated instrument to perform the required IMU alignment immediately before the nominal calibration procedure. This procedure provides a method for calibrating the HUD without first performing an IMU alignment. The procedure may also be used for the non-docked multiple failure case where a second star tracker fails before the required calibration can be performed.

The procedure relies on the crew performing a maneuver that constitutes a rotation about the HUD boresight and recording the onboard calculated attitudes at the two endpoints of the maneuver. The ideal rotation (it does not matter if the actual rotation does not match the ideal during the maneuver) between the two endpoints is a rotation about the boresight because the crewman has verified that the boresight was pointed directly at the same star at both ends of the maneuver. It does not matter that the IMU may be misaligned producing an absolute error in the attitudes because when the two attitudes are used to calculate the change in attitude the IMU attitude reference cancels out of the equations. Stated another way, the error in both attitudes is the same (assuming the IMU does not drift significantly while the maneuver is being performed) and therefore does not affect the difference between the two attitudes. The mathematically ideal rotation magnitude is 180 degrees (comparable to a 90 degree star separation for an IMU alignment). There is no data to quantify the gain, but anything above 30 degrees is probably fully adequate. A selection of 60 degrees was made to give a comfortable margin for roll wander (roll wander will be especially bad if marks are taken in pulse as they must be if on primary jets) in both attitudes while still staying above 30 degrees. If there were some genuine reason why this procedure had to be done with only a 10 degree attitude change, the results would likely still be fully acceptable and would certainly be better than foregoing the calibration altogether. A detailed error analysis might support an even smaller angle, but flying to a very small angle could lead to taking the two marks (considering roll wander) in essentially the same attitude. Taking marks in essentially the same attitude would definitely lead to a bad result. The cost of a detailed error analysis hardly seems justified by the small potential benefit of reducing the "engineering judgment" target attitude change from 60 degrees to something less than 60 but greater than 20 degrees. 20 degrees is an "engineering judgment" of the point

at which roll wander could become a problem. There is not likely to be a measurable propellant benefit from a smaller angle and the time benefit is no more than about 3 minutes.

The flight procedure directs the crewman to maneuver to place a star of his choice (it need not be identified; it need not even be a nav star) near the HUD marker (boresight) in a manner similar the normal calibration procedure (SCP 3.4) except that the FSW is not placed in COAS CAL or SIGHT mode. The crewman then centers the marker and takes marks until he is satisfied that he has taken a good one. There will be no feedback for the crewman to assess the quality of his marks (no Delta Bias) because the FSW is not in CAL mode. The feedback in this situation would be of very little value even if the FSW were in CAL mode due to the effect of IMU misalignment on the calculated delta bias. Not being in CAL mode has the advantage that the attitude data stored when the ATT REF pb is pressed (QM50_REF) is on telemetry and therefore readily available to the MCC. In CAL mode the attitude data stored when the ATT REF pb is pressed consists of nine matrix values rather than four quaternion values. Because this data is not on telemetry the only way to get it on the ground is via variable parameter downlink. Since a maximum of five floating point numbers can be downlinked by variable parameters at one time, two loads would be required for each of the two marks along with a hex to decimal conversion for each value. Furthermore, incorporating these values into a workstation application working directly from telemetry would be much more complex than using the telemetered quaternion values.

After a good mark (crewman's judgement, made sure ATT REF pb pushed with object in "P") has been made the crewman rolls the vehicle keeping the star near the boresight until the ADI (REF) roll bug moves approximately +/- 60 degrees. After the MCC has confirmed that the data has been recorded another mark is taken on the same star. As with the first mark, the crewman repeats his marks until he is satisfied that a good one has been taken. This attitude difference between the two marks represents a pure rotation about the sighting device line of sight. The vector about which the ideal rotation occurred can be calculated from the two attitudes and is the calibration vector of the HUD. Any error in the attitude reference (neglecting drift that occurs during the maneuver) has no effect because the attitudes at the start and at the end of the maneuver are in error by the same amount, thus the reference frame and errors in it drop out of the attitude difference equation. Just as the attitude reference frame does not have to be known, the identity of the star does not have to be known; it is necessary only that the same star be used for the mark taken before the roll maneuver and the mark taken after the roll maneuver.

Once the proper calibration vector has been determined it must be entered into the FSW. Two methods are available: 1) GMEM write, and 2) maneuvering the vehicle to an attitude (it is a fictitious attitude in the sense that there is an unknown IMU error) such that a mark taken in COAS Calibration Mode will cause the proper vector to be stored. The GMEM write method contains no additional costs other than the slight risk associated with any GMEM write. **The GMEM write method may be preferred for very low propellant margins and it is required for loss of VERNS PRI jets cannot hold a sufficiently tight deadband to produce an acceptably accurate result using the fictitious attitude method. Any attempt to use PRI (or ALT) would consume very large amounts of propellant and would almost certainly produce an unacceptable result.** The fictitious attitude method produces some additional error and it requires the expenditure of additional propellant and crew time even using VERNS. The method consists of using Universal Pointing to track the point in the celestial sphere where, as determined by the IMU, the selected nav star or celestial target should be and taking a mark (in COAS CAL mode) when the total attitude errors are very small. The advantage of the celestial target option over a nearby star is that this target corresponds exactly to the point in

inertial space where the boresight was pointed when the final second attitude mark was taken. Since the orbiter has been holding attitude in DAP A while awaiting MCC calculations, no maneuver will be required prior to collapsing to DAP B deadbands. The fictitious attitude does not require that the star or celestial target be above the horizon. It requires only that the total errors are within deadband for roll and as near zero as possible for pitch and yaw while Universal Pointing is tracking the point where the star or target should be as determined by the IMU.

MCC PROCEDURE

A workstation application using telemetered data is not yet available. The following MCC Procedure uses a PC spreadsheet to perform the necessary calculations. Because there is no nominally flown crew procedure (this procedure is expected to be a seldom used workaround), the crew procedure given at the end of the SCP must be uplinked.

A. Data Collection and Vector calculation

NOTE: If at the 3 level with IMUs, deselect an IMU before beginning procedure to avoid the possibility of IMU switching.

1. Upon crew report that a good first attitude mark has been taken, record the values of QM50_REF as QM50_REF1.
2. When the data has been recorded give the crew a go to take the second attitude mark.
3. Enter the first attitude data into the spreadsheet.
4. Upon crew report that a good second attitude mark has been taken, record QM50_REF as QM50_REF2.
5. If it has been decided to use the GMEM write option to enter the calibration data into the FSW, give the crew a go to proceed to the cleanup step (STEP 9) of the flight procedure.
6. Enter the second attitude data into the spreadsheet.
7. Proceed to step B if fictitious attitude is to be used or step C if GMEM Write is to be used.

B. Attitude Method for Loading the Calibration Vector into FSW (Fictitious Attitude)

1. The spreadsheet calculates Pitch/Yaw to be used for the Universal Pointing track option and right ascension/declination for a celestial target corresponding to the second attitude. Using these values (a star whose catalog vector is near the current attitude may be used instead of the celestial target) give the crew the fictitious track attitude for Universal Pointing. Two axis maneuver may be used unless there is an identified need to specify omicron. If using celestial target, then the SPEC 22 ITEM 21 REQD ID is 5 and the Universal Pointing ITEM 8 TGT ID is 5.
2. The spreadsheet will be used for two purposes:

(1) It will calculate the delta angle between the Nav Base(NB) vector and the I-Load vector. You will need to record the two marks that were taken by the crew (QM50_REF1 and QM50_REF2) and also record the Original Onboard Vector before any updates are made. The Onboard Vector can be found on the HUD_COAS CAL display ("UPDATE"). Once all this data is entered into the spreadsheet the results are calculated and displayed under "ONBOARD/DES DELTA ANG".

NOTE: If the delta calculated here is $\leq 1^\circ$ then there is no need to continue with the update.

(2) If you are not using the GMEM write method to get the vector into the FSW, the spreadsheet can also calculate the delta angle between the mark vector and the desired vector. Since we will be in CAL mode (Step 4 of crew procedure), the crew will take a mark and the data will be seen in the HUD/COAS CAL display. The crew's mark will be recorded in the spreadsheet under the cell labeled "Vector". All other inputs will remain the same.

3. Upon crew report that a good mark has been taken (total errors within deadband for roll and as near zero as possible for pitch and yaw) in the fictitious attitude, record the mark vector from telemetry and enter it into the spreadsheet as mentioned above "Vector". As previously stated, this is the delta angle between the mark vector and the desired vector.
4. If the calculated delta between the mark vector and the desired vector is satisfactory (~ 0.05 degree) give the crew a go to ACCEPT the calibration (SPEC 22) and go to the cleanup step (STEP 7). If the mark is not satisfactory give a go to repeat the mark (STEP 5). The limit of 0.05 degree was determined by "engineering judgement"; a smaller limit value would greatly increase the probability of having to repeat the procedure and a larger limit value would significantly degrade the accuracy of the calibration. The 0.05 degree limit is reasonably achievable on VERNs, but it is not reasonable to expect even 0.1 degree on PRI (and at great propellant cost). For this reason the fictitious attitude method should not be attempted on PRI. The GMEM option will introduce no additional error.

C. GMEM Write Method for Loading the Calibration Vector into FSW

1. Convert the calibration vector components (three numbers) to hexadecimal floating point.
2. Perform memory write FCOH SOP 3.3.3 GPC MEMORY READ/WRITE to HALNAME CGYS_COAS. CGYS_COAS is a two-dimension array consisting of 12 halfwords, the first six halfwords are the -Z calibration vector and the last six are the +X calibration vector.

DETAILED WORKSHEET DESCRIPTION

The blank spreadsheet will be placed on the MCC PC MENU. It is also located on the S: drive (S:\Divisions\DF\Private\DF62\hud_coas\CONTCAL\contcal.xls) and is available on floppy diskette in the GNC supply cabinet. It is a read only file; it must be copied to a working area and that copy used to perform the calculations. The spreadsheet is protected against inadvertent changes to all cells except those intended to be inputs.

Color shading is used to identify types of blocks: inputs are shaded yellow; results are shaded blue; critical evaluation data is shaded red and “nice to know” data is shaded green. Figure 1 is a copy of the main sheet (page 1) containing test data. In this black and white only SCP the shading is in levels of gray.

Vehicle ID must be entered; it is used to select the correct nav base to body transformation (TNB_B). Options are: SMS,,OV103, OV104, OV105, and VAR. VAR allows for an off nominal TNB_B; the input for VAR is shaded yellow on page 2 (Figure 2) of the spreadsheet. Most intermediate calculations are performed on page 2.

FLIGHT is not required for correct calculations; it is provided only as a means for recording the flight from which the data comes.

ADI sense must be input. It is used to make the necessary adjustments in case the aft station COAS or some contingency sighting device is being calibrated. FWD is always the correct input for HUD calibration. The other options are AFT -Z and AFT -X.

The red shaded area to the right of ERROR MSG= can display either of two error messages and the red shaded area just below the error message error can display one info type message. These possible messages will be discussed later.

QM50_REF1 and QM50_REF2 are the quaternion inputs for the marks in the two different attitudes and are entered exactly as they appear on telemetry (QM50-REF). The spreadsheet then conjugates QM50_REF1 and performs the multiplication $QREF1_M50 * QM50_REF2$ resulting in QREF1_REF2 from which an eigen vector extraction yields the vector of interest.

The red shaded cells just below the input and intermediate calculation quaternions should be very nearly unity. FSW quaternions sometimes are slightly non-unity, with the error appearing in the sixth or seventh decimal place. An error in the fifth place suggests an input error. Non-unity for any of the intermediate calculations to the right of the input quaternions indicates that the spreadsheet calculations have been corrupted. If either of the input quaternions is different from unity by an amount exceeding a threshold of $4e-6$ a message will be displayed in the error message cell as a reminder to check the inputs. The threshold can be changed on page two (to be described later).

Under **** RESULTS **** :

The NB VECTOR is the final result of the calibration. If GMEM Write is to be used these numbers must be converted to hexadecimal (GNC SCP 10.6) for the memory write.

The PITCH and YAW values are the Universal Pointing body vector to be used in the fictitious attitude method of entering the calibration vector into the FSW.

ROTATION is the eigen angle (the total angle) between the two attitudes. This should be about 60 degrees. BODY VECTOR is the actual eigen axis between the two attitudes and is a “nice to know” intermediate value.

ONBOARD VECTOR is an input which is taken from telemetry and is used initially to calculate the ONBOARD/DES delta bias between the spreadsheet calculated calibration vector (NB VECTOR) and the I-LOAD vector. After the new vector has been placed onboard by either the “fictitious attitude” method or the GMEM Write method, the new telemetry value can be entered

into the spreadsheet to calculate the residual delta bias between the desired value and the one that resulted from the procedure (of course the residual should be extremely small if GMEM Write is used). If the residual is too large (generally above 0.05) the “fictitious attitude” procedure should be repeated. If propellant or time do not permit a repeat of the procedure a real time decision can be made either to accept a larger error or to use the GMEM write method.

The RA (right ascension) and DEC (declination) values can be used instead of randomly selecting a star. Using these values for the Universal Pointing Celestial object to be tracked results in the “fictitious attitude” being the attitude in which the last mark was taken. Because this is essentially the attitude the orbiter is holding while awaiting the results of the MCC calculations it avoids an arbitrary attitude maneuver. If the IMU error is small Pointing can provide a nearby star but even that is likely to require a small maneuver.

Page 2 contains intermediate calculations and constants plus three contingency input parameters. The VAR TNB_B and quaternion non-unity tolerances were described earlier. The other contingency input is a manual vector correction input. The process for extracting a vector from a quaternion actually extracts an axis which is represented equally well by a vector or by the negative of the vector. The spreadsheet has a calculation which determines whether the extraction process has yielded the desired vector or its negative using the ADI SENSE input as an indication of the approximate direction of the calibration. This calculation is expected to work properly for any device which can sight through the forward, overhead, or payload bay windows. Contingency situations where the calculation may not work properly include: (1) sighting through either side window where the device line of sight is actually aft of the Y axis, and (2) taking marks where the sighting device line of sight does not correspond to the ADI SENSE input. Situation 2 could result from system failures. The ADI SENSE input to the spreadsheet must agree with the actual ADI SENSE and ATT REF pb used by the crew. For example: If the forward ATT REF pb is used, but sighting is actually made through the overhead or payload bay window the ADI SENSE input to the spreadsheet must be FWD and if the AFT ATT REF pb is used in -Z sense, but sighting is made through the forward window the ADI SENSE input must be -Z. In such failure driven situations where the ADI SENSE does not correspond with the actual window used the automatic vector correction calculation may fail. If for any of the above reasons, or for some other unanticipated reason, the calibration vector calculated is opposite to the direction expected, the manual vector correction can be used to reverse the direction by making an input of -1. The manual vector correction parameter must always be exactly unity, +1 to accept the automatic correction or -1 to reverse the automatic correction. If a non-unity input is made an error message is displayed on page 1 to the right of ERROR MSG=. If the reversal is requested by inputting -1 a message indicating that manual vector correction is enabled will be displayed in the cell below the page 1 error message cell.

HUD/COAS CONTINGENCY CALIBRATION CALCULATIONS (QM50_REF)

INPUTS		RESULTS	CRITICAL EVALUATION DATA		USEFUL INFO
VEHICLE =		SMS	FLIGHT =		GEN
ERROR MSG =		NONE			ADI SENSE = FWD
Sense options: FWD, AFT -Z, AFT -X					
(CONJUGATED)					
INPUT (May be scaled)		NORMALIZED		NORMALIZED	
QM50_REF1	QM50_REF2	QREF1_M50	QM50_REF2	PRODUCT	
-0.76109454	-0.55792702	-0.76109605	-0.55792925	QREF1_M50*QM50_REF2	
-0.17328636	-0.57781226	0.17328670	-0.57781457	0.8235557	
0.11742976	0.43892532	-0.11742999	0.43892708	0.5652707	
0.61393258	0.40272447	-0.61393380	0.40272608	0.0164048	
0.99999801	0.99999600	1.00000000	1.00000000	0.0442259	
				1.00000000	

***** *** RESULTS *** *****

ADI SENSE =	FWD	BODY VECTOR		NB VECTOR	ONBOARD VEC	ONBOARD/DES DELTA ANG
PITCH=	355.53	0.99653634	0.99387301	0.99450000	0.882	
YAW=	1.66	0.02892059	0.02892059	0.01381000		
ROTATION=	69.115	0.07796738	-0.10667731	-0.10381000		
		1.00000000	1.00000000	0.99999874		
RA =	282.323					
DEC =	2.810					

FIGURE 1

HUD/COAS CONTINGENCY CALIBRATION CALCULATIONS (QM50_REF)

VEHICLE = SMS FLIGHT= GEN

CONSTANTS AND INTERMEDIATE CALCULATIONS

				TNB_B	SMS		
				0.9829353	0.0000000	-0.1839514	
				0.0000000	1.0000000	0.0000000	
Product vector length				0.1839514	0.0000000	0.9829353	
0.56723542							

			TNB_B		TNB_B	OV102	
			0.9829353	0.0000000	-0.1839514	0.9829565	0.0004363
			0.0000000	1.0000000	0.0000000	-0.0004530	0.9999999
			0.1839514	0.0000000	0.9829353	0.1838379	0.0001309
							0.9829566

Correct for -X or -Z sense if AFT Station						TNB_B	OV103	
Q+X_+X	Q+X_-Z	Q+X_-X				0.9828661	0.0001108	-0.1843209
1.0000000	0.0000000	0.0000000				-0.0003560	0.9999990	-0.0012972
0.0000000	0.7071068	0.0000000				0.1843206	0.0013406	0.9828652
0.0000000	0.0000000	0.0000000						
0.0000000	-0.7071068	-1.0000000						

						TNB_B	OV104	
						0.9829423	-0.0010151	-0.1839109
1.0000000	0.0000000	0.0000000	1.0000000	0.0000000	0.0009306	0.9999994	-0.0005462	
0.0000000	0.9965363	0.9965363	0.0000000	0.9965363	0.1839113	0.0003657	0.9829428	
0.0000000	0.0289206	0.0289206	0.0000000	0.0289206				
0.0000000	0.0779674	0.0779674	0.0000000	0.0779674				

						TNB_B	OV105	
						0.9825962	0.0021508	-0.1857419
						-0.0017131	0.9999954	0.0025169
						0.1857464	-0.0021549	0.9825953

Auto Vector Correction 1
 Manual Vector Correction 1 1
 Quaternion non-unity tol 0.000004

			TNB_B	VAR	
			1.0000000	0.0000000	0.0000000
			0.0000000	1.0000000	0.0000000
			0.0000000	0.0000000	1.0000000

Calculate RA DEC of CAL Vector in curent attitude

QM50_REF2	QSENSE_+X		Vector			
-0.5579293	1.0000000	-0.5579293	0.0000000	0.5317197	-0.5579293	0.0000000
-0.5778146	0.0000000	-0.5778146	0.9965363	-0.5334219	0.5778146	0.2131577
0.4389271	0.0000000	0.4389271	0.0289206	0.4302462	-0.4389271	-0.9757868
0.4027261	0.0000000	0.4027261	0.0779674	-0.4976178	-0.4027261	0.0490289
					RA =	-77.68
					DEC =	2.81

MESSAGES
 BAD Manual Vector Correction!!!
 Input Quaternion NON-UNITY!!!

FIGURE 2

CONTINGENCY HUD CALIBRATION, GNC 201

1. HUD PREP
Remove L(R) HUD Cover

F3 L(R) HUD PWR - ON
F6U(F8U) MODE - TEST

Wait ~ 15 sec for final symbology of test mode
display (Refer to ORB OPS CL, p. 7-12)
Final test mode display symbology

* If final test mode symbology not in *
* agreement with diagram, notify MCC *

L(R) HUD BRT - MAN NIGHT
MAN BRT - as reqd

C3 DAP: A/AUTO/VERN(PRI)
Change DAP A,B to A1,B5

NOTE

Do NOT activate COAS CAL or SIGHT Mode

O14,O15, cb DDU L(R) (two) - cl
O16:E

F6(F8) FLT CNTLR PWR - ON

NOTE: If 3 IMUs, check MCC on IMU for DES

2. MARK STAR in FIRST ATTITUDE
Select any star or planet (not necessarily a nav
star)

F6(F8) DAP: A1/INRTL(FREE)/VERN(PRI) (for COARSE CNTL)
ADI SEL - REF
Mnvr to locate star

DAP: B5/INRTL(FREE)/VERN(PRI) (for FINE CNTL)

Mnvr to center star in HUD boresight:
('P' in 'COMPLETE', refer to ORB OPS CL, p. 7-12)

F6(F8) ATT REF pb - push (ADI will go to 0,0,0)

NOTE

Repeat marks as necessary. Notify MCC when a good
mark has been made.

DAP: A/INRTL/VERN(PRI)

3. MARK STAR in SECOND attitude

Mnvr ~ Roll 60 degrees (ref ADI ROLL) about star
line of sight keeping star near HUD boresight

On MCC go

DAP: B5/INRTL(FREE)/VERN(PRI) (for FINE CNTL)

Mnvr to center star in HUD boresight:

F6(F8) ATT REF pb - push (ADI will go to 0,0,0)

NOTE

Repeat marks as necessary maintaining ADI ROLL near
0 degrees. Notify MCC when a good mark has been made.

DAP: A/INRTL/VERN(PRI)

Notify MCC that a good mark has been made

On MCC call go to step 7 or continue to step 4.

4. Load and execute MCC provided UNIV PTG attitude

UNIV PTG

CRT

ERR TOT ITEM 23 EXEC
TGT ID ITEM 8+___EXEC
IF TGT ID 5
RA ITEM 9+___EXEC
DEC ITEM10+___EXEC
BODY VECT ITEM 14 +5 EXEC
P ITEM 15+___EXEC
Y ITEM 16+___EXEC
OM ITEM 17+___ EXEC (May use blank OM)
TRK ITEM 19 EXEC
DAP:AUTO

When in attitude

GNC 22 S TRK/COAS CNTL

CRT

COAS: REQD ID -ITEM 21+___EXEC
√POS +X - ITEM 26 EXEC(*)
CAL MODE - ITEM 24 EXEC(*)

5. MARK on FICTITIOUS STAR

DAP: B5/AUTO(FREE)/VERN (for FINE CNTL)

NOTE

Mark with att REF PB when ERR ROLL within DB
(0.033 VERN) and PITCH and YAW are
minimum.

Repeat marks as necessary. Notify MCC when a good mark has been made

DAP A/AUTO/VERN(PRI)

On MCC call proceed to step 6 or repeat step 5

6. Update HUD CALIBRATION

GNC 22 S TRK/COAS CNTL

UPDATE ITEM 28 EXEC

COAS: DES - ITEM 25 EXEC(*)

7. CLEANUP

F6U(F8U) HUD MODE - NORM
F3U HUD PWR - OFF
F7(F8) FLT CNTLR PWR - OFF

O14,O15, cb DDU L(R)(two) - as reqd
O16:E

Install L(R) HUD Cover

Reconfig to FLIGHT PLAN DAP

RELEVANT WORKSTATION DISPLAYS

Attitude Summary

COAS/HUD CAL

TITLE

TACAN DILEMMA RESOLUTION

PURPOSE

To describe the Mission Control Center (MCC) computations available to flight controllers, as well as recommended procedures, in resolving a TACAN range or bearing redundancy management (RM) dilemma.

ASSUMPTIONS

Commfaulted TACAN's or "loss-of-lock" parameters are not available as candidates to RM selection filtering or FDIR. Subsequent incorporation of data from a previously unlocked parameter should resolve the dilemma (declare a parameter/line replaceable unit (LRU) failed) based upon 3-level FDIR voting logic.

BACKGROUND

A TACAN dilemma is defined as a condition whereby range or bearing data from the two remaining LRU's eligible for selection filtering differs beyond the FDIR thresholds, and RM is unable to resolve this discrepancy. The crew may be unable to resolve the dilemma utilizing either the horizontal situation display (HSD), or the horizontal situation indicator (HSI). Flight controllers can assist the crew in resolving the dilemma by monitoring MCC computations which compare individual TACAN range and bearing against the corresponding values generated from ground radar measurements. The results of these computations appear on the ASCENT/ENTRY SENSORS- display, and can be plotted on RTPLOT. Console operators should be alerted to the data miscompare prior to a dilemma annunciation (fault summary message) via the TACAN vs. radar computations.

PROCEDURE

- A. When a data miscompare occurs, reference the AESP procedure for a TACAN dilemma, in the MS entry section of the book, behind the COMM/GNC tab, titled "RM DLMA TAC". A thorough understanding of each step in this procedure is required (Ref. Flight Procedures Handbook, Vol I/II for procedure rationale.)
- B. When a data miscompare occurs, the following CRANS element(s) will change state:

TAC 1 (2,3) SELF TEST
TACAN BRG DG BAD
TACAN RNG DG BAD

This would signify that there is a disagreement between two units and should correspond to the units in Self Test and/or a fault summary message (RM DLMA TAC).

- C. On the ASCENT/ENTRY SENSORS- display- Determine which TACAN ground radar comp [TAC 1/GND, 2/GND, 3/GND] is furthest from zero, and declare that LRU/parameter to be failed.
- D. Call up the appropriate RTPLOT corresponding to the parameter in dilemma. Verify failed unit/data is furthest from the zero axis.
- E. On the GPS COMPARES display, determine which unit has the largest miscompare with GPS. Verify that this is the failed unit.

NOTE: Manual deselection of a TACAN will remove both range and bearing data from RM. Following the dilemma resolution, the remaining TACAN should be monitored and assessed against ground radar computations.

TITLE

TACAN ONE LOCK

PURPOSE

To verify the acceptability of data from a single TACAN through evaluation of range and bearing data (applicable during OPS 304-305, 602-603).

BACKGROUND

Navigation nominally requires valid data from two TACAN's prior to acceptance of initial data (expected by approx. 155,000 ft). Should only one TACAN be available as late as 140,000 ft, the ground may elect to recommend that the data from this single TACAN be used to update the NAV state vector. It is the responsibility of the Guidance and Procedures Officer (GPO) to validate the data from the single locked-on TACAN.

PROCEDURE

- A. As data become available, scan the range/ground and bearing/ground RTPLOTS for adequate number of data points to ensure a solid TACAN lock-on.
- B. A digital display of these comps appears on the ASCENT/ENTRY SENSORS display.

Acceptability of TACAN data is coordinated between GNC and the Guidance and Procedures Officer (GPO). GPO compares the TACAN data with the state vector error. If the state vector is near perfect, then TACAN data may not be incorporated even if the range/ground and bearing/ground comps are small. Conversely, if the state vector error is large, then TACAN data may be incorporated even if the comps are large. This is a judgement call.

Flight Rules state that the desired selected error be less than 0.3 n. mi. in range, and less than 1.0 degree in bearing. If at the three level, and the selected TACAN data violates one or both of these limits, the alternate ground station should be selected (if available). If at the two level, and the selected TACAN data violates one or both of these limits, then the TACAN with the largest error should be deselected.

- C. Inform GNC on the status of TACAN range and bearing data.

NOTE: The two-lock requirement must be bypassed via crew deselection of the remaining RM candidate units (commfaulted or powered off LRUs do NOT need to be deselected).

RELATIVE MOC EDTE DISPLAYS

<u>EDTE</u>	<u>TITLE</u>
1416	GNC SENSORS ENTRY
1628	TACAN_STATUS
1632	TACAN_DELTA-TIMETAG
1630	TACAN

REFERENCES

1. Level C FSSR, GN&C Part D, Redundancy Management, table 4.5.4-2, p.4-189, June 1987.
2. STS Flight Software I-Load, JSC-19350, rev 2, vol. I, Feb. 1986.

TITLE

TACAN BLANKING PULSE MONITORING

PURPOSE

The purpose of this section is to define the procedures for verifying that the blanking pulse signals are operating properly for each of the TACAN's. A blanking pulse verification procedure is performed prelaunch as part of the OMI and is addressed by the LCC. This section will define a similar procedure to be performed shortly after entry interface.

BACKGROUND

In order to determine range information a TACAN sends an interrogation signal to a ground station and then in turn receives a reply signal back from the station. When a TACAN is transmitting an interrogation signal, it also sends a blanking pulse to its receiver. This blanking pulse tells the receiver not to lock on to the transmitted signal. Since the Orbiter has three TACAN's, the blanking pulse is also routed via coax cable between the TACAN's so that, when any TACAN is transmitting, all three TACAN receivers will receive the blanking pulse.

Mission Planning and Analysis Division (MPAD) analysis and SAIL testing have shown that, if a blanking pulse fails off (either internal to the TACAN or by disconnection of a coax cable), then the TACAN's ability to lock onto a ground station will be slightly degraded but not inhibited. The Collins TACAN will show only a slight delay and will lock on very close to nominal.

One other important point is that a failed off blanking pulse will only affect TACAN performance if an X mode ground station is being used. When operating in the Y mode, the TACAN will continue to operate nominally if the blanking pulse fails off. This has to do with the pulse pair spacing of the transmitted and received signals and is explained in the TACAN Systems Brief.

The proper operation of the blanking pulse only needs to be verified for a nominal end of mission to Edwards or any other site using an X mode station. It is not necessary for any of the aborts because it will have been performed prior to launch. Also, for nominal end of mission to Northrup or KSC, this procedure cannot be performed unless the alternate ground station is selected. The primary station for both of these sites uses a Y mode channel, but the alternate stations for these sites are X mode.

PROCEDURE

BLANKING PULSE FAIL OFF

Verification of proper operation of the blanking pulse for a Collins TACAN can very easily be accomplished upon transition to MM 304. To determine if the blanking pulse has failed off, the following conditions must exist:

- A. An X mode channel must be selected.
- B. The upper antennas must be selected. The lower antennas are spaced too far apart to readily identify this failure.
- C. The vehicle must be far enough away from the selected station that lock-on does not occur; i.e., the TACAN's must be in the search mode.

Upon transition to MM 304 the TACAN SOP will begin cycling the antennas in unison between upper and lower every 10 seconds. For a nominal end of mission into Edwards, channel 111X will be selected. At MM 304 transition, the Orbiter will not be within lock-on range of the station. When all three upper antennas are selected, observe the AGC signal on the Ascent/Entry Sensors display. If the AGC is greater than 4.9 volts, then the blanking pulses are working correctly.

If the AGC signals are less than 4.9 volts, then this is an indication that the TACAN's have locked on or are trying to lock on to a signal. If there are no TACAN ground stations using the same frequency within range of the Orbiter, then a failed-off blanking pulse has occurred. The Guidance officer can provide information on TACAN ground stations that are close to the Orbiter ground path and the frequencies that are used.

CORRECTIVE ACTION

If it is determined that a failed-off blanking pulse has occurred, then testing and analysis indicates that no action is required. The TACAN's should be monitored closely, however, in the event that actual performance does not agree with the analysis. The following procedure should be used:

- A. For a Collins TACAN expect very little delay.
If no lock-on by 120k feet, go to step B.
- B. Mode TACAN 1 to RCV, wait 5 seconds.
If TACAN's lock-on, go to step E.
- C. Mode TACAN 1 to GPC.
- D. Repeat steps B and C for TACAN's 2 and 3 until failed TACAN is isolated.
- E. Leave failed TACAN in RCV so that it can still process bearing data.

BLANKING PULSE FAIL ON

Each time a TACAN LRU transmits a range interrogation signal, it also sends a blanking pulse which prevents all receivers (including its own) from sensing the transmitted signal. If the blanking pulse fails ON, then all non-failed Collins TACANs will experience a late lock-on when using an X channel station and will be unaffected when locking onto a Y channel. A Collins TACAN with a failed ON blanking pulse will never lock on the ground station.

The Collins TACANs, which are susceptible to the internal blanking pulse failure, have additional protection in their input circuitry which prevents a blanking pulse failure in a neighboring TACAN from disabling its performance. The Collins units should only suffer a late lock-on condition only on the X channels.. If a TACAN blanking pulse fails ON for any TACAN, the following signature should be present in the MCC on the Ascent/Entry Sensors display:

- Bearing will frequently read 1.49 degrees. This signature will be repeated on one or more units every 2-3 seconds.
- Range will not lock on, even when the orbiter is close enough to the ground station that lock-on would nominally be expected.

CORRECTIVE ACTION

If the above signature is seen, it should be assumed that the blanking pulse on one of the TACANs is failed ON. In this case the following procedure should be voiced to the crew:

07 TACAN 1 - OFF

If failure signature continues, then:

07 TACAN 1 - GPC TACAN 2 - OFF

If failure signature continues, then:

07 TACAN 2 - GPC TACAN 3 - OFF

If failure signature continues, then:

07 TACAN 3 - GPC Conclusion: Blanking pulse failure was incorrect assumption.

TITLE

MLS DILEMMA RESOLUTION

PURPOSE

To establish a method to aid the crew in resolving microwave scan beam landing system redundancy management (MLS RM) dilemmas when in GNC 305.

ASSUMPTIONS

MLS's without commlock indications are considered deselected (i.e., data not available to RM) for the particular computer cycle that the commfault and/or loss-of-lock occurs.

BACKGROUND

The crew may be unable to identify the failed MLS by comparing NAV data on the horizontal situation indicator (HSI).

PROCEDURES

The initial analysis and monitoring of an MLS dilemma is broken down into the following steps.

- A. The crew does not have a published procedure in the onboard FDF for an MLS dilemma. If there is time, the crew will select each of the affected MLS LRUs (one at a time) as the source MLS on the HSI, and try to determine which LRU is failed. In any case, once the bad LRU is identified (by the crew or MCC) the crew should either power off the affected (bad) unit with the MLS power switch (panel 07), or they should take TACAN to FORCE on SPEC 50. Either option will inhibit MLS processing to navigation for that LRU, and clear the dilemma. Other considerations for MLS dilemmas are for whether to even work the MLS dilemma or not. These are :
 1. Is MLS required for landing on this day/nite, per the Rules? (The Sensors controller should generally be aware of this before this time in the entry, as there is little (or no) time in the window where MLS is processed to be asking questions.) If not, then *probably* no action is required, unless the crew is still on the HAC (i.e. there is more time).
 2. Has the crew called the "runway in sight"? If yes, *probably* no action is required.
 3. What are the cloud deck ceiling levels, and visibility conditions, etc.?
 4. General situational awareness goes a long way in this case to knowing whether or not MLS is *really* required on the given day. It should be important if it requires bothering the crew this late on the HAC, or on Final.

B. When a dilemma occurs, one of the following CRANS elements will change state:

MLS AZ (EL, RNG) DIS

An indication on any one of these would signify exceeding the RM limits between two units and would correspond to the eventual "RM DLMA MLS" fault message onboard.

C. Compare the AZ (EL, or RNG) parameter from each MLS unit with the respective ground radar computed parameter (Ref. ASCENT/ENTRY SENSORS display). The unit with the largest delta (from zero) will be the failed unit. This same data can be plotted on RTPLOT, and those respective plots can also be referenced, as required for determining which MLS unit is bad.

The GPS COMPARES display will also compare the MLS azimuth, elevation, and range to the GPS solution and may also be used to determine which LRU is bad and in what component

TITLE

ADTA DILEMMA RESOLUTION

PURPOSE

To define a method to aid the Flight Controller in resolving air data transducer assembly redundancy management (ADTA RM) dilemmas during Entry. It is assumed that the crew was unable to resolve the problem using Alpha Mach Indicator/Altitude Vertical Velocity Indicator (AMI/AVVI) air data, and H, Alpha, and M on OVERRIDE SPEC 051 display. During the dilemma, Guidance and Control Software is using NAV-derived air data and/or default air data parameters. After clearing the dilemma condition, Guidance and Control Software reverts back to the use of ADTA-derived air data parameters.

A call should be made to the crew to fly theta limits if the dilemma is still present by Mach 2.0 to ensure that the crew is flying theta limits no later than Mach 1.5. Also, the crew should fly pitch CSS when incorporating air data below $M = 2.5$ to avoid an Nz step (there's a potential for an Nz step caused by a change in Q-bar during the NAVdad-to-Air Data mode change).

If air data is not incorporated into G&C, flight control defaults to a fixed value of alpha (7.5 degrees). Q-bar is derived from an I-loaded table as a function of navigation ground relative velocity (V_{rel}). Since guidance no longer limits alpha by protecting the low Q-bar boundary, it is necessary for the crew to follow theta limits on the vertical situation display. In this situation, the displayed alpha is not reliable.

Keeping theta between the NOSE HI and NOSE LO region will ensure that the vehicle alpha is within acceptable limits. Allowing theta to exceed NOSE HI increases the chances of stall while allowing theta to fall below NOSE LO could cause Q-bar to increase to unacceptable limits. Keeping theta within limits also reduces energy dispersions. The NOSE HI and NOSE LO limits cross at a bank angle of 57 degrees which may stall or exceed Q-bar on the vehicle. Therefore, the crew is not to exceed a bank of 50 degrees to avoid this point.

Note that these procedures are not intended to be followed verbatim in real time situations but rather they should be understood and practiced as the controller progresses through the training flow. An eventual thorough understanding is required in order to effectively implement these steps as they apply to a variety of failure scenarios. Also, the controller may choose to implement the steps in whatever order seems appropriate, given the failure signature and other factors affecting the dilemma resolution.

PROCEDURES

- A. When a data mismatch occurs, reference the AESP procedure for an ADTA dilemma, in the MS entry section of the book, behind the COMM/GNC tab, titled "RM DLMA ADTA". A thorough understanding of each step in this procedure is required. (Ref. Flight Procedures Handbook, Vol I/II for procedure rationale.)
- B. Determine the ADTA causing dilemma:
1. An "RM DLMA ADTA" message displayed on the Onboard Fault Summary display(DPS controlled display).
 2. Use the ASCENT/ENTRY SENSORS display and CRANS elements to determine which ADTA's are available to RM.
 - a. ADTA probe not deployed (L ADP DPLY 1 and 2, R ADP DPLY 1 and 2). At least one DEPLOY discrete must be set true (and not commfaulted) and the corresponding STOW discrete must be set false (and not commfaulted), in order for the data from that probe to be considered by PASS RM.
 - b. ADTA failed (ADTA RM FAIL). Specific ADTA failed is determined by an "F" after ADTA 1 (2,3,4) on the Ascent/Entry Sensors display.
 - c. ADTA with a COMMFAULT (BYPASS FF1 ADTA, BYPASS FF2 ADTA, BYPASS FF3 ADTA, BYPASS FF4 ADTA).
- C. Verify that the ADTA pressures disagree by greater than the RM limit. If all ADTA pressures agree, then advise the crew to DESELECT/RESELECT any ADTA on SPEC 51, to reset the ADTA RM.
1. If the dilemma does not recur, a transient failure existed and the ADTA will continue to calculate air data parameters for Guidance and Control.
 2. If the dilemma recurs and ground-radar-derived altitude is present, go to step D; and if no ground radar, go to step E.
- D. Call up the ADTA plots on RTPLOT
1. Select the ADTA VS RDR1 and ADTA VS RDR2 plots.
 2. The ADTA 1, 2, 3, and 4 computed altitudes are plotted against the ground-radar-derived altitude. A diagonal guideline is drawn to represent the points of agreement between the GND RADAR and ADTA ALT. The delta altitude between radar and ADTA will be mainly affected by static pressure port or transducer failures, or failures that affect the overall operation of the entire ADTA.
 3. If GND ALT is available on the plot, the ADTA ALT furthest displaced from the diagonal guideline should be declared failed and deselected by the crew.

4. If not able to isolate failed ADTA, proceed to analysis of P α L, P α C, and P α U RTPLOT plots.
- E. Configure and select RTPLOT to display the ADTA 1, 2, 3, 4 altitudes plotted against the NAV-derived altitude. A diagonal guideline is drawn to represent the points of agreement between the NAV-derived and ADTA altitude
1. The ADTA ALT furthest displaced from the diagonal guideline should be declared failed and deselected by the crew.
 2. CAUTION: If NAV is currently using Air Data (i.e., the dilemma does not currently exist), this plot may be misleading. The individual NAV/ADTA deltas will not reflect true ADTA health, since NAV is using the ADTA data.
 3. If not able to isolate the failed ADTA, proceed to analysis of P α L and P α U RTPLOT plots.
- F. Use GPS COMPARES display to determine which ADTA or Air Data Probe is in error. GPS can only be used as a comparison to the ADTA altitude data. If an "RM DLMA ADTA" message is received and there is no apparent miscompare between the GPS altitudes, then analysis of the P α L, P α C, and P α U ADTA data must continue.
- G. Analysis of P α L, P α C, and P α U RTPLOT data
1. The P α L and P α U data are plotted against a guideline defined by flight data obtained from previous flights.
 2. The ADTA pressure furthest displaced from the guideline should be declared failed and deselected by the crew.
 3. If not able to isolate failed ADTA, proceed.
- H. Reasonableness test of ADTA pressures.
1. Compare ADTA 1 (2, 3, 4) pressures (PS, P α U, P α C, P α L) at a specific MACH or NAV ALT, as displayed on the ASCENT/ENTRY SENSORS display to the predicted data recorded in tables 4.6-II and 4.6-III.
 2. If one ADTA pressure involved in the dilemma is offset from the predicted pressure, declare it failed and have the crew deselect the ADTA.
 3. If the failed ADTA is not isolated by plots or pressure reasonableness test, go to step H to compare ADTA data with NAV digital data.
- I. On the ASCENT/ENTRY SENSORS display compare the NAV M, α , and H with the individual ADTA's M, α , and H. You can also compare the ADTA's to each other with this digital data.
1. Be sure that the crew has not deselected any of the ADTA's for which you are comparing data, since this would likely eliminate the dilemma. If the dilemma no longer exists and NAV is using Air Data, then the comparisons between the

individual ADTA's and NAV will yield misleading information concerning ADTA health.

2. If the failed ADTA is not isolated by this procedure, then an unresolvable dilemma situation exists and Guidance and Control will use NAV-derived and/or default Air Data parameters for vehicle control. The crew should fly theta limits below $M = 2.0$.

TABLE 4.6-II.- PREDICTED ADTA PRESS VS. NAV ALT/MACH

[STS-1 FLIGHT DATA]

V95H0175C NAV ALT	V90P4706C P	V90P4710C P α U	V90P4711C P α C	V90P4712C P α L	V95L3029C MACH
101457	1.23	3.73	6.65	4.50	3.57
95994	1.38	4.10	6.85	4.49	3.22
90235	1.56	4.41	7.07	4.52	2.85
85104	1.72	4.46	6.88	4.41	2.59
82070	1.80	4.41	6.39	3.96	2.23
77720	1.98	4.22	5.89	3.65	1.92
71351	2.35	4.35	5.81	3.60	1.67
64932	2.68	4.54	5.83	3.60	1.47
59292	3.60	4.53	5.72	3.54	1.19
53628	3.88	4.72	5.71	3.62	0.97
47895	4.62	5.21	6.48	4.45	0.88
43585	5.54	6.31	7.54	5.12	0.83
39245	6.74	7.71	9.07	6.16	0.80
34607	8.25	9.15	10.77	7.69	0.74
29903	10.08	11.08	12.58	9.35	0.68
25762	11.98	12.87	14.46	11.06	0.63
21795	13.94	15.09	16.73	12.83	0.61
18549	15.72	16.97	18.53	14.56	0.58
14263	18.54	20.13	21.51	16.86	0.56
10082	21.54	23.42	24.45	19.52	0.51
6248	24.73	26.59	27.57	22.75	0.48
2750	28.05	29.42	31.56	26.54	0.42
2124	28.10	28.62	30.18	27.62	0.36

TABLE 4.6-III.- PREDICTED ADTA PRESS VS. NAV ALT/MACH
[STS-26 FLIGHT DATA]

V95H0175C NAV ALT	V90P4706C P	V90P4710C P α U	V90P4711C P α C	V90P4712C P α L	V95L3029C MACH
115273	0.92	3.22	6.35	4.56	4.62
110234	1.12	3.60	6.77	4.65	4.30
105230	1.22	3.90	6.97	4.67	3.96
100011	1.30	4.17	7.09	4.57	3.54
95017	1.37	4.16	6.90	4.53	3.15
90151	1.48	4.19	6.77	4.35	2.85
85299	1.61	4.27	6.71	4.29	2.58
80279	1.75	4.23	6.45	4.15	2.36
75275	1.76	3.75	5.17	3.17	1.88
70300	2.09	3.75	5.02	3.11	1.63
65141	2.42	4.20	5.47	3.37	1.51
60673	2.83	4.58	5.81	3.54	1.38
55199	3.84	4.94	6.13	3.72	1.18
50191	4.40	5.41	6.48	4.03	0.98
45411	5.17	6.50	7.38	4.46	0.90
40289	6.49	7.91	9.08	5.74	0.86
35286	8.02	9.12	10.76	7.46	0.78
30322	9.92	11.08	12.81	9.18	0.72
25178	12.15	13.25	14.99	11.37	0.64
20201	14.73	15.76	17.59	13.92	0.59
15007	17.97	19.34	21.14	16.77	0.56
10241	21.29	23.50	24.43	19.12	0.53
7631	23.38	25.20	26.48	21.61	0.50
2469	27.97	29.29	31.09	26.69	0.45
2101	28.00	28.30	29.81	27.73	0.34

TITLE

SENSOR AA/RGA CALIBRATION

PURPOSE

To detect and differentiate between a rate gyro assembly/accelerometer assembly (RGA/AA) scale factor or bias error and to determine the bias or scale-factor correction required to retain the line replacement unit (LRU) in the redundancy management (RM) scheme. The bias error can be corrected by this command procedure. The scale factor error can be corrected by a General Memory read/write procedure (Reference SCP 11.19, G-MEM Read/Write Procedures).

GENERAL

WARNING: This procedure is governed by FCOH SOP 3.1, COMMAND POLICY FOR MOD, and cannot be modified without prior approval of the FOIG or the Flight Director (during real-time operations). Safety critical steps are marked by a box.

Restrictions:

OI Load: all

OPS Mode: PASS (MM 301 of OPS 3) No BFS CMD

Major Function: GNC

Vehicles: all

Crew/MCC coordination: information only

Time Constraints: none

Hazardous: An RGA/AA bias compensation is only performed in an attempt to improve the capabilities of an already degraded LRU. If erroneous bias terms are uplinked to an RGA/AA the LRU may become completely unusable. A successful second uplink attempt should be performed to achieve the desired onboard values.

Require safing: no

BACKGROUND

The Orbiter rate gyro/accelerometer assembly standard operating procedure (SOP) converts the body rates and accelerations to the appropriate engineering units by applying a scale factor and bias to each reading. The lateral accelerometer also has an additional misalignment compensation factor. An RM selection filtering process then reduces the multiple measurements into one source. The crew can select or deselect an LRU from RM in OPS 8 SPEC 40 and 41, or in OPS 3 SPEC 53.

PROCEDURES

A. RGA/AA COMPENSATION EQUATIONS

1. RGA/AA (I =1, 2, 3, 4)

$$CGPV_RGA_AA_{1,I} = CGBV_RGA_ROLL_RATE(I) CGPS_ROLL_SCALE_I + CGPS_ROLL_BIAS_I$$

$$CGPV_RGA_AA_{2,I} = CGBV_RGA_PITCH_RATE(I) CGPS_PITCH_SCALE_I + CGPS_PITCH_BIAS_I$$

$$CGPV_RGA_AA_{3,I} = CGBV_RGA_YAW_RATE(I) CGPS_YAW_SCALE_I + CGPS_YAW_BIAS_I$$

$$CGPV_RGA_AA_{4,I} = CGBV_NORM_ACCLRM_SIG(I) CGPS_NORM_ACC_SCALE_I + CGPS_NORM_ACC_BIAS_I$$

$$CGPV_RGA_AA_{5,I} = CGBV_LAT_ACCLRM_SIG(I) CGPS_LAT_ACC_SCALE_I + CGPS_LAT_ACC_BIAS_I$$

COMPENSATED DATA = (MEASURED DATA) (SCALE FACTOR) + BIAS

$$YC = (YM) (C) + K$$

2. NOMINAL VALUES	<u>SCALE FACTOR</u>	<u>BIAS</u>
ROLL	1.25 E-03 deg/sec/bit	0 deg/sec
PITCH	6.25 E-04 deg/sec/bit	0 deg/sec
YAW	6.25 E-04 deg/sec/bit	0 deg/sec
NORM_ACC	1.25 E-04 g/bit	0 g
LAT_ACC	3.125 E-05 g/bit	0 g

NOTE: CGPV RGA AA5 (AA LAT COMPENSATED) has an additional misalignment angle(s) compensation factor which is added to the calculation shown above. Since CGPS_LAT_ACC_MISALIGN_I is K-loaded to zero, this factor has no effect on the compensation. The complete calculation as shown in the HAL code is:

$$CGPV_RGA_AA_{5,I} = CGBV_LAT_ACCLRM_SIG(I) CGPS_LAT_ACC_SCALE_I + CGPS_LAT_ACC_BIAS_I + CGPV_RGA_AA_{4,I} CGPS_LAT_ACC_MISALIGN_I$$

NOTE: When scale factor and bias I-loads are loaded into the software, the units per volt are converted to units per bit as shown in item 2 above.

B. DETERMINATION OF BIAS CORRECTION TERM

1. A bias exists if one LRU shows a data readout, while other LRU readouts are at zero.
2. A bias exists if an LRU data output varies by a fixed amount from the other LRU readouts.
3. The bias correction term will be measured bias subtracted from the previous bias.

$$KC = Kp - KM$$

where: KC = corrected bias term

Kp = previous bias term

* KM = measured bias (bad LRU - good LRU readout)

* For AA's, the measured bias is displayed in FPS² and must be divided by 32.174, for conversion to g's.

C. LOADING THE COMMAND INTO THE COMMAND SERVER

NOTE: A Command Manager must be running on any workstation that runs command applications. Start or Stop a Command Manager from the Master DNAV, Global Apps, Command Server menu.

1. Select the Orbiter Rate Gyro Bias Update or the Accelerometer Assembly Bias Update Command display from the GNC DNAV. Any previous load in the command server will be displayed. The command displays are shown in Figures 4.7-1 and 2

NOTE: Command Display inputs are not allowed when the Command Server is in checkpoint.

2. Build DSM 43501 (RGA) or 43601 (AA) with I-load values (generally 0's) for all axes of all LRU's to preserve capability to remove bias(es) if necessary. Build DSM 43502 or DSM 43602 with the bias correction for the appropriate axis(es) and I-load values for all other axes. Each load must have a valid compensation value for each axis of each LRU. DSM's 43X03-43X50 are available if multiple bias corrections are required. Note that AA telemetry data is in units of feet per second per second and must be converted to units of G's by dividing by 32.174 before being entered on the command display. Note also that for both AA's and RGA's the compensation values are opposite in sign to the measured bias.
3. Select STORE to send the command to the Command Server.
4. Obtain a hardcopy of the new load.

File

Orbiter Rate Gyro Bias Update

DSM #		GMT Gen
<input style="width: 50px;" type="text" value="43502"/>	↕	<input style="width: 150px;" type="text" value="RGA load"/>
		<input style="width: 100px;" type="text" value="024:08:31:00"/>

	hex	deg/sec	deg/sec
RGA 1 Roll	40333333	0.20000000	<input style="width: 80px;" type="text" value="0.20000000"/>
Pitch	40266666	0.15000001	<input style="width: 80px;" type="text" value="0.15000001"/>
Yaw	c01c28f6	-0.11000000	<input style="width: 80px;" type="text" value="-0.11000000"/>
RGA 2 Roll	c04ccccd	-0.30000001	<input style="width: 80px;" type="text" value="-0.30000001"/>
Pitch	403d70a4	0.23999999	<input style="width: 80px;" type="text" value="0.23999999"/>
Yaw	c0333333	-0.20000000	<input style="width: 80px;" type="text" value="-0.20000000"/>
RGA 3 Roll	40400000	0.25000000	<input style="width: 80px;" type="text" value="0.25000000"/>
Pitch	c019999a	-0.10000000	<input style="width: 80px;" type="text" value="-0.10000000"/>
Yaw	402147ae	0.13000000	<input style="width: 80px;" type="text" value="0.13000000"/>
RGA 4 Roll	40666666	0.40000001	<input style="width: 80px;" type="text" value="0.40000001"/>
Pitch	c04ccccd	-0.30000001	<input style="width: 80px;" type="text" value="-0.30000001"/>
Yaw	40147ae1	0.08000000	<input style="width: 80px;" type="text" value="0.08000000"/>

<input style="width: 80px;" type="button" value="Store"/>	<input style="width: 80px;" type="button" value="Delete"/>	<input style="width: 80px;" type="button" value="Clear"/>	<input style="width: 80px;" type="button" value="Exit"/>
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Command Advisories

Figure 4.7-1 - Orbiter Rate Gyro Bias Update Command Display

File																																							
Accelerometer Assembly Bias Update																																							
DSM #		DSM Title	GMT Gen																																				
<input style="width: 100%;" type="text" value="43602"/>	↕	<input style="width: 100%;" type="text" value="AA BIAS load"/>	024:08:31:00																																				
<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 20%;"></th> <th style="width: 15%; text-align: center;">hex</th> <th style="width: 25%; text-align: center;">G's</th> <th style="width: 40%; text-align: center;">G's</th> </tr> </thead> <tbody> <tr> <td>Accel1 Lat</td> <td style="text-align: center;">3ff5c28f</td> <td style="text-align: center;">0.06000000</td> <td style="text-align: center;"><input style="width: 100%;" type="text" value="0.06000000"/></td> </tr> <tr> <td> Norm</td> <td style="text-align: center;">bfcccccdd</td> <td style="text-align: center;">-0.05000000</td> <td style="text-align: center;"><input style="width: 100%;" type="text" value="-0.05000000"/></td> </tr> <tr> <td>Accel2 Lat</td> <td style="text-align: center;">3fa3d70a</td> <td style="text-align: center;">0.04000000</td> <td style="text-align: center;"><input style="width: 100%;" type="text" value="0.04000000"/></td> </tr> <tr> <td> Norm</td> <td style="text-align: center;">bf51eb85</td> <td style="text-align: center;">-0.02000000</td> <td style="text-align: center;"><input style="width: 100%;" type="text" value="-0.02000000"/></td> </tr> <tr> <td>Accel3 Lat</td> <td style="text-align: center;">bf28f5c3</td> <td style="text-align: center;">-0.01000000</td> <td style="text-align: center;"><input style="width: 100%;" type="text" value="-0.01000000"/></td> </tr> <tr> <td> Norm</td> <td style="text-align: center;">bf7ae148</td> <td style="text-align: center;">-0.03000000</td> <td style="text-align: center;"><input style="width: 100%;" type="text" value="-0.03000000"/></td> </tr> <tr> <td>Accel4 Lat</td> <td style="text-align: center;">3f51eb85</td> <td style="text-align: center;">0.02000000</td> <td style="text-align: center;"><input style="width: 100%;" type="text" value="0.02000000"/></td> </tr> <tr> <td> Norm</td> <td style="text-align: center;">3f28f5c3</td> <td style="text-align: center;">0.01000000</td> <td style="text-align: center;"><input style="width: 100%;" type="text" value="0.01000000"/></td> </tr> </tbody> </table>					hex	G's	G's	Accel1 Lat	3ff5c28f	0.06000000	<input style="width: 100%;" type="text" value="0.06000000"/>	Norm	bfcccccdd	-0.05000000	<input style="width: 100%;" type="text" value="-0.05000000"/>	Accel2 Lat	3fa3d70a	0.04000000	<input style="width: 100%;" type="text" value="0.04000000"/>	Norm	bf51eb85	-0.02000000	<input style="width: 100%;" type="text" value="-0.02000000"/>	Accel3 Lat	bf28f5c3	-0.01000000	<input style="width: 100%;" type="text" value="-0.01000000"/>	Norm	bf7ae148	-0.03000000	<input style="width: 100%;" type="text" value="-0.03000000"/>	Accel4 Lat	3f51eb85	0.02000000	<input style="width: 100%;" type="text" value="0.02000000"/>	Norm	3f28f5c3	0.01000000	<input style="width: 100%;" type="text" value="0.01000000"/>
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Command Advisories																																							

Figure 4.7-2 - Accelerometer Assembly Bias Update Command Display

D. VERIFICATION OF COMMAND SERVER LOAD

1. Verify the correct command has been loaded in the Command Server by comparing the Server feedback on the command display for the correct DSM number and the data values for each axis and LRU.
2. Set up variable parameters to confirm the I-load value and the uplink. See Table 11.19-II for HAL name and array sequence.

E. NOTIFICATION AND APPROVAL

1. Advise the GNC FCR by DSM number that the load has been built, verified, and ready for uplink.
2. The GNC FCR will verify that the load is correct.
3. The GNC FCR will receive Flight Director approval to perform the uplink. The GNC FCR request to INCO for the uplink command will include a confirmation of Flight Director approval for uplink, the GPC major function destination, and the DSM number of the command.
4. The GNC FCR will monitor the INCO loop until all command actions are completed. INCO will notify the GNC FCR when the actions are completed. The GNC FCR will monitor Command Tracking displays to verify that the correct commands have been executed.

F. VERIFICATION OF UPLINK ONBOARD

1. Record uplink time in console log and verify with variable parameters correct value(s) for all axes and LRU's.

NOTE: If uplink causes erroneous onboard biases, request the previous DSM number to be uplinked to preserve capability.

2. Observe all LRU's to verify performance.

G. TRACKING OF LOADS BUILT

1. Once the load has been uplinked and RGA/AA performance has been verified, ensure that only the I-loaded and the most recent RGA/AA compensation loads remain stored in the Command Server.
2. Remember that these corrections are for the PASS only. The BFS cannot be corrected because it applies a scale factor and bias to the selected signal rather than to each LRU signal.

H. DETERMINATION OF SCALE-FACTOR CORRECTION TERM

1. A scale-factor error exists if the difference between an LRU and the remaining LRU's varies as a function of the sensed input.
2. The equations to be used in deriving the scale-factor correction are as follows.
 - a. The LRU hardware can be modeled by:

$$(IN + BIAS)SF = OUT \quad (1)$$

Where: IN = LRU input

BIAS = LRU bias

SF = hardware scale factor

OUT = LRU output

- b. The software then compensates this LRU output to reconstruct the input value.

$$CIN = (OUT)SCALE - K \quad (2)$$

Where: OUT = LRU output (from equation 1)

SCALE = scale-factor compensation

K = bias compensation

CIN = computed LRU input

- c. If a scale-factor error exists, the LRU output is erroneously scaled up or down depending on the type of hardware failure. Since the software compensation values remain the same as before the failure, the computed LRU input is therefore in error.

This error can be eliminated by computing a new software scale-factor correction as follows:

Compute the actual LRU output (OUT) from equation 2.

$$OUT = \frac{CIN + K}{SCALE} \quad (3)$$

where CIN is the computed LRU input of the bad LRU from telemetry. SCALE and K are I-loads.

- d. Compute the required scale-factor compensation (SCALE) required to generate the correct computed LRU input. Again using equation 2.

$$SCALE = \frac{CIN + K}{OUT} \quad (4)$$

where CIN is the computed LRU input of a good LRU from telemetry, K is an I-load and OUT was computed in equation 3 above.

- e. The corrected scale factor is then computed by substituting equation 3 into equation 4. This reduces to the final equation:

$$CORRECTED\ SCALE = \frac{TLM\ OUTPUT\ OF\ GOOD\ LRU + K}{TLM\ OUTPUT\ OF\ BAD\ LRU + K} \quad (I - LOAD\ SCALE)$$

3. For memory read/write procedure for Orbiter RGA/AA scale-factor correction, see RGA/AA scale-factor read/write in SCP 11.19, G-MEM Read/Write Procedures.

I. ADDITIONAL MEMORY READ/WRITE REQUIREMENTS

1. RGA/AA DES/SEL.

After bias or scale-factor correction has been made, the LRU may be reselected in OPS 3 on SPEC 53.

J. DATA COLLECTION

1. During ascent phase (OPS 1)
- a. Monitor real-time data for anomalies.
 - b. Hard copy the SENSORS ascent/entry display .
 - c. ODRC data over periods where AA/RGA were reading outputs.
 - d. Request and monitor playback data during orbital maneuvering system (OMS) burns to record variations in the AA/RGA outputs.
2. During orbit checkout phase (OPS 8)
- a. Sensor self-test per Orbit Operations Checklist.

- (1) Perform: FCS and dedicated display entry config setup

AA warm-up 5 min
RGA warm-up 2 min

(2) Perform:

Sensor test - MLS, TAC, RA, AA
Sensor test - RGA, ADTA

(3) Crew to monitor and record null bias, high test, and low test data failures for later transmission to the ground.

b. Procedure for generating rates/acceleration in OPS 8, if required to reconfirm a previous RGA/AA failure.

NOTE: For OPS 8 test, digital autopilot (DAP) must be configured while in OPS 2.

(1) Perform test in DAP A. (OPS 2)

GNC 20 DAP CONFIG

ITEM 13 + 1.00 EXEC

ITEM 17 + 1.00 EXEC

A/FREE/PRI

ROT - PULSE/PULSE/PULSE

TRANS - PULSE/PULSE/PULSE

(2) RGA/AA Test (OPS 8)

(a) Rotations (R,P,Y) - deflect rotational hand controller (RHC) as required and release (do not exceed soft-stop). Crew to record good and bad data for comparison by the ground.

(b) Translation (X,Y,Z) - deflect translational hand controller (THC) as required and release. Crew to record good and bad data for comparison by the ground.

(3) DAP RECONFIG (OPS 2)

GNC 20 DAP CONFIG

ITEM 13 + .1 EXEC

ITEM 17 + .1 EXEC

A/FREE/PRI

Reconfig DAP as required.

3. During entry phase (301,302)
 - a. Monitor real-time data for anomalies.
 - b. Procedure for generating rates/acceleration in OPS 3, if required to reconfirm a previous RGA/AA failure.
 - (1) DAP: FREE
ROT - DISC/DISC/DISC
TRANS: NORM/NORM/NORM
 - (2) Rotations - deflect RHC to hardstop for approximately 2 sec
 - (3) Translations - deflect THC for approximately 2 sec
 - c. Take hard copies of the Sensors Ascent/Entry display.
 - d. Pull ODRC data over periods where AA/RGA were reading outputs.

K. DATA INTERPRETATION

When monitoring data, it is important to note the Least Significant Bit (LSB) of the hardware data output to the GPC. While the data are truncated on crew displays SPEC 40 and 41 in OPS-8, the data on the MCC displays are rounded off. Variation in data is shown below:

ROLL RGA LSB 0.08° /SEC						
	VALUES SEEN					
ACTUAL VALUE	0	.08	.16	.24	.32	.4
CREW (TRUNCATED)	0	0	.1	.2	.3	.4
SNAPSHOT (LSB)	0	.08	.16	.24	.32	.4
MCC DISPLAY (ROUNDED)	0	.1	.2	.2	.3	.4

PITCH/YAW RGA LSB 0.04° /SEC											
	VALUES SEEN										
ACTUAL VALUE	0	.04	.08	.12	.16	.2	.24	.28	.32	.36	.4
CREW (TRUNCATED)	0	0	0	.1	.1	.2	.2	.2	.3	.3	.4
SNAPSHOT (LSB)	0	.04	.08	.12	.16	.2	.24	.28	.32	.36	.4
MCC DISPLAY (ROUNDED)	0	0	.1	.1	.2	.2	.2	.3	.3	.4	.4

LAT AA LSB 0.002Gs (0.064 FPS²)								
ACTUAL VALUE	VALUES SEEN							
	CREW (TRUNCATED)	0	.064	.128	.192	.256	.32	.384
SNAPSHOT (LSB)	0	0	.1	.1	.2	.3	.3	.4
MCC DISPLAY (ROUNDED)	0	.064	.128	.192	.256	.32	.384	.4
	0	.1	.1	.2	.3	.3	.4	.4

NORM AA LSB 0.008GS (0.2574 FPS²)						
ACTUAL VALUE	VALUES SEEN					
	CREW (TRUNCATED)	0	.2574	.5148	.7722	1.0296
SNAPSHOT (LSB)	0	.2	.5	.7	1.0	1.2
MCC DISPLAY (ROUNDED)	0	.2574	.5148	.7722	1.0296	1.2870
	0	.3	.5	.8	1.0	1.3

REFERENCES

1. I-Load Map - STS-26 Final, FSSR STS83-0015B, RGA - 4.40 (table 4.40-1) and AA - 4.42 (table 4.42-1).

TITLE

RGAs POWER LOSS DURING ASCENT/ENTRY

PURPOSE

The purpose of this SCP is to provide a quick reference that explains the impacts and possible actions necessary for electrical bus losses, with respect to the Rate Gyro Assemblies (RGAs), both for the Orbiter and the Solid Rocket Boosters (SRBs).

BACKGROUND

Flight rule A8-102 RGAs SYSTEM MANAGEMENT discusses actions necessary in the situation where a known failure condition exists such that one additional failure would cause two Orbiter RGAs to simultaneously lose power. The required action is to deselect one of the two exposed RGAs in the Backup Flight Software (BFS). When power is lost to an RGA or SRB RGA, the output from the electronics will spike and generate false rates. These rates eventually decrease to zero. The flight rule explains that the window of exposure is approximately 10 seconds, during which the false signature is output from the affected RGAs.

While it may appear that a number of bus failures would put GNC in a posture of invoking this flight rule, there are in fact only a few specific instances where this would be appropriate. These are noted in the first part of the table below, Table 4.8-1. The reason for the small number of cases is due to the fact that most of the bus loss scenarios would cause power to be lost to one of the FA MDMs associated with one of the failed RGAs. This would not allow the false signature to be throughput into the BFS. For example, the loss of CNTL AB1 would cause the loss of RGA 1 RPC A. The flight rule protects for the subsequent loss of APC 5, which would remove power from both RGA 1 and RGA 2. While this appears to be a case to invoke the flight rule, it is not. The loss of both CNTL AB1 and APC 5 takes power from MDM FA 1, which would not allow the false rates from RGA 1 to be input into the BFS.

There are only three electrical bus failures that would be cause for using the flight rule. While the first two bus failure scenarios are clear, the last is not quite as straightforward. The loss of MN A will take redundant power from two RGA RPCs, RGA 1 RPC A and RGA 4 RPC A. Although it appears the flight rule would allow the choice of deselecting any of the RGAs in the BFS, this is not the case. The loss of MN A will take redundant power to MDM FA 1. The deselection of RGAs 1 or 2 in the BFS is not necessary in this case because the single point failure the flight rule protects for, APC 5, would remove the remaining power on MDM FA 1. This situation does not arise with RGAs 3 and 4. Therefore the action to take when MN A is down: only deselect either RGA 3 or RGA 4 in the BFS.

The other case where invoking this flight rule would be appropriate is the failure of one of three of the Orbiter RGA's RPCs. The failure must be with the RPC itself and not an electrical bus associated with the RPC. These are also indicated at the top of the table.

There are a couple of situations that would also be cause for using the flight rule, but aren't as readily apparent. This is when either RGAs 1 or 4 indicate OFF for both the switch and RPC (A or C respectively). This case is similar to the previous RPC scenario only if CNTL bus AB1 or CA3 have not failed completely. There are two possible causes of this failure signature. There

is a chance that this problem can be caused by a partial loss of either CNTL AB1 or CNTL CA3. Coordination with the EGIL team is necessary for determining if there is a partial problem on the bus. If EGIL reports no problems with the busses, the problem is at the RGA power switch. This is a situation where invoking the flight rule would be appropriate to safe the BFS, as the redundant power to the FA MDMs are not affected by the first failure, the RGA power switch.

There are also cases that expose the BFS to this situation for a short duration. In these instances, the initial bus loss would have already taken power from one RGA and it would be outputting the false rates for 10 seconds. Then, there are single bus losses that will take another RGA; if this happens during this timeframe, the flight rule will also apply. While it does still apply, the small window of exposure does not warrant the application of the flight rule. It is improbable that the flight control team can assess the situation, make the proper call, the crew execute the item entry, while just having engaged the BFS within 10 seconds of the first bus failure. Because of this very short window of exposure, it is recommended that the flight rule not be applied.

While the BFS is protected from dual SRB RGA failures by the flight rule A8-56 BFS LRU REQUIREMENTS, the information regarding bus loss and their impacts to SRB RGAs are included for documentation purposes.

TABLE 4.8-1: BUS LOSS AND RGA FAILURES DURING ASCENT/ENTRY

BUS LOSS	NEXT WORST FAILURE	IMPACTS	ACTION
APC 1	APC 5	ORBITER RGA 1 & 2	Invoke FR A8-102
MPC 1	MPC 3	ORBITER RGA 3 & 4	
MAIN A	MPC 3	ORBITER RGA 3 & 4	

FAILURE			

ORB RGA 1 RPC A	APC 5	ORBITER RGA 1 & 2	
ORB RGA 4 RPC A	MPC 3	ORBITER RGA 3 & 4	
ORB RGA 4 RPC C	CNTL CA1	ORBITER RGA 3 & 4	

---INFORMATION ONLY---

APC 5	APC 1*	ORBITER RGA 1 & 2
MPC 3	MPC 1*	ORBITER RGA 3 & 4
CNTL BC1 or APC 5	MPC 3* or CNTL CA1*	ORBITER RGA 2 & 3
CNTL CA1	MPC 3*	ORBITER RGA 3 & 4
APC 3	APC 4	SRB RGA 2, 3, & 4
APC 4	APC 3	SRB RGA 2, 3, & 4

* These failures must occur within 10 seconds of the first bus failure to affect the RGAs in the BFS.

TITLE

BFS AIR DATA MANAGEMENT

PURPOSE

The purpose of this section is to provide information on the tools used by the crew to evaluate ADTA data in the BFS, the procedures they use in doing so, and what MCC calls are required to the crew.

BACKGROUND

The BFS Override Display (SPEC 51) does not display individual ADTA data, as does PASS SPEC 51, and the BFS downlist does not include these data either. This results in air data evaluation and incorporation being an onboard call which requires the crew to rely on means other than the use of SPEC 51. There are also other PASS/BFS differences which affect BFS air data evaluation. In the PASS, the Air Data select switch (Panel F6/F8) allows the AMI and AVVI tapes (or emulated tapes with the same functions in vehicles outfitted with MEDS, the Multifunction Electronic Display Subsystem) to be driven by either the left probe selected data or the right probe selected data if the switch is in either the LEFT or RIGHT position, respectively. If a probe is not considered deployed by probe RM, then OFF flags will appear on the tapes when that probe is selected. With the BFS engaged, if neither probe is deployed, NAV data is displayed on the tapes whether the CDR's switch is in the LEFT, RIGHT, or NAV position. It is important to note that only the left side select switch functions in the BFS; all of the dedicated displays, both left and right side, are slaved to that switch. The OFF flags are not driven by the BFS.

Another item of interest is the fact that BFS does NOT provide default switch position logic. This means that if an electrical bus has failed such that the left side source select switch is not operational, the BFS will not use the PASS default switch position logic (also referred to as "green dot" position). When the switch power is lost, the AMI/AVVI will show NAVDAD until one of the Air Data probes are deployed. Notice the condition is NOT Air Data incorporation, it is an Air Data probe being successfully deployed! This scenario is also possible if all the switch contacts lose connectivity, i.e., the center position reads "0", similar to an electrical failure. The BFS dedicated displays software only examines the center position for an "ON" or "OFF" condition to determine the state of the switch and therefore the data to display on the AMI/AVVI. After Air Data deploy, only when the switch is outputting an "ON" or "1" state will NAVDAD be displayed. If that switch output is "OFF" or "0", once the probes are deployed (nominally at Mach 5.0), the AMI/AVVI will display raw Air Data (this is the case when the switch is moved to LEFT or RIGHT). If there is a failure and the switch is still in NAV this can cause unexpected results on these displays until the Orbiter descends closer to the Air Data's calibrated region (~ M=3.5), whereupon the dedicated displays will behave normally (assuming good Air Data). Before Air Data deploy, the AMI/AVVI will display NAVDAD regardless of the switch position.

With one or both probes deployed the BFS will drive the tapes with the center selection filter's selected air data if the switch is in either the LEFT or RIGHT position. The center selection filter selects data from one or both probes depending upon availability of probe data. With only one probe deployed, that probe's lowest number ADTA data will be displayed (assuming no

BITEs or commfaults) and with both probes deployed the average of the left and right probe data will be displayed. Therefore, the air data probes are deployed one at a time when on the BFS in order to allow for evaluation of individual probe data. First, the left probe is deployed and its data are compared on the tapes to NAV by cycling the air data switch from LEFT (or RIGHT) to NAV. If the data are biased, the problem may be in either the probe or in ADTA 1 (in this discussion it is assumed NAV is perfect and does not itself contribute to any detected biases). The crew may then pull the ADTA 1 circuit breaker (cb) to display ADTA 3 data. If the left probe data then compare favorably with NAV, the problem was with ADTA 1. If there is not a good comparison with NAV, the left probe is biased and should be stowed.

If the left probe has good data and remains deployed, the right probe data will be averaged with the left probe (good data on left and unknown on right). If the tapes agree with NAV, then both probes are good. If there is a disagreement, then the ADTA 2 cb can be pulled so that the ADTA 4 data can be analyzed, or the right probe may be stowed.

The MCC can verify probe deployment via individual ADTA data good flags, which are "bad" (indicated by a red "F" on the BFS SENSORS display) if the probe is not deployed or the ADTA has a BITE or is commfaulted. If at least one flag shows "good" (absence of a red "F") then the probe is deployed. If both flags show "bad", then it is likely that the probe is not out.

Onboard, it is easy to determine that the first probe is deployed. The ADTA residual and ratio fields on BFS SPEC 50 will be blank until a probe is deployed. Another indication (though less reliable) is that with the switch selected to LEFT or RIGHT, the tapes may jump when the probe is deployed. This will depend upon the magnitude of the difference between the probe data and NAV data.

However, determining onboard whether the second probe is deployed is not so easy. When the second probe becomes deployed the selected data will change to an average of the two. If the two ADTAs (one on the left, one on the right) are in close agreement then there will be little change in the tapes or the residual and ratio numbers. If the probe does not deploy, no change will appear in the tapes or the residual and ratio numbers.

There are two options for the crew in determining the deploy status of the second probe if comm is not available. One is to re-stow the first probe and then deploy the second probe. The residual and ratio's will blank until the second probe is out. However, this is not a good option since it is not desirable to give up a probe if its data has been determined to be good and it may be difficult to verify that the left probe actually got back out. The other option is to open the circuit breaker on ADTA 4. This will cause a "RM FAIL ADTA" message, but only if the probe is considered deployed by RM. Therefore, if the message doesn't occur, then the probe is not deployed. This method is better than the first, although some crews may have trouble with it due to reach and visibility constraints.

Very little of the BFS ADTA procedures are included in the flown FDF due to a lack of room, however, they are included in the crew's Training Data File. The only steps contained in the flown FDF exist in the ASCENT/ENTRY SYSTEMS PROCEDURES (AESP) "POST BFS ENGAGE" procedure. Here the crew is instructed to inhibit air data to G&C in order to allow evaluation of the air data prior to incorporation (the BFS initializes air data incorporation in the Auto state). In addition, the crew is reminded to take air data to G&C by Mach 1.5 since default air data does not exist in the BFS. Remember that BFS ADTA safing steps exist in the AESP "RM FAIL ADTA" and "RM DLMA ADTA" procedures.

PROCEDURES

A. CREW TRAINING DATA FILE PROCEDURE

IF BFS ENGAGE PRE-DEPLOYMENT:

(probe deployment verification and data analysis):

1. Inhibit air data to G&C
2. Deploy left probe - look for resid/ratios on SPEC 50
3. Compare probe and NAV on tapes
4. If data bad, stow left probe or
 5. If time permits, ADTA 1 cb - pull, go to step 3
6. Deploy right probe, MCC verifies deploy or
 7. Pull ADTA 4 cb - expect "RM FAIL ADTA"
 8. If good deploy, ADTA 4 cb - IN, I/O RESET, else stow right probe , go to step 12.
9. Compare NAV and probes on tapes
10. If data bad, stow right probe or
 11. If time permits, ADTA 2 cb - pull, go to step 9
12. If data good, enable air data to G&C

IF BFS ENGAGE POST-DEPLOY

1. If already assessed in PASS >>
2. Compare probes with NAV
3. If bad data, inhibit air data to G&C and stow right probe (or pull ADTA 2 cb)
4. If bad data, redeploy right probe and stow left probe (or pull ADTA 1 cb)
5. If data good, enable air data to G&C

B. GROUND PROCEDURES

The ground has very limited insight into the status of the air data system in the BFS. All of the insight is on the "BFS SENSORS" display. The ADTA 1, 2, 3, 4 areas are the BFS software data good flags for each ADTA. These will show "GOOD" (i.e., blank) if the probe has a DEPLOY discrete set, there is power to the LRU, there are no commfaults or BITEs on that LRU. These "GOOD" and "BAD" indications do not assess the validity of the air data probe output measurements.

The only way to assess the quality of each individual probe/ADTA is to watch the NAV altitude residuals and the dynamic pressure difference between NAV and the air data system. From these data, large errors can be seen between the air data system and NAV (small errors may go undetected).

Information provided by the Engineering Directorate has shown that the ADTA BITE circuitry will only protect the system from unreasonable values of air data. There are "soft" failures that can affect the flight control system, and go unnoticed by BITE.

REFERENCES

1. Guidance and Control Systems Briefs, JSC-18863, Sec. 4.13, latest version.
2. Informal Note of Interest, BFS Air Data Management, DF6/P. Perkins, Nov. 1988.

TITLE

GPS SATELLITE CONSTELLATION MONITORING

PURPOSE

To aid GNC console operators in monitoring GPS satellites during ascent, orbit, and entry operations. The SCP discusses the following:

- Actions related to identifying a failed satellite
- Corrective actions to protect the orbiter navigation state vector from incorporating bad GPS data due to a problem satellite.
- NASA and Department of Defense (DoD) interaction with regard to the satellite constellation.
- MCC interactions between GNC and FDO/GPO with regard to GPS actions.
- GPS satellite lock during ascent.
- GPS satellite lock during orbiter maneuvers on-orbit.
- GPS satellite lock during entry, including antenna blockage effects due to the plasma region.

BACKGROUND

The global positioning system uses a constellation of 24 orbiting satellites at 10,980 nmi orbits to determine the position, velocity, and time of the orbiter. The DoD monitors the satellite constellation from ground terminals located around the globe with the main GPS monitoring station located at Falcon Air Force Base in Colorado.

The MAGR-S GPS is programmed to select the best GDOP (lowest) of the satellites in view every 15 seconds. To accomplish this the MAGR-S acquires information about the satellite health, determines if the satellite is at least 10 degrees above the horizon, and the receiver downloads the satellites ephemeris data. Once all of the information is acquired, the MAGR-S computes a GDOP for all of the possible 4 satellite combinations. Once all the possible GDOPs are computed, the MAGR-S “weighs” each set of GDOPs taking into account the previous track history of the satellites and the User Range Accuracy (contained in the navigation message) for each satellite. The MAGR-S then selects the satellites with the lowest weighted GDOP for tracking.

The MAGR-S internally manages the satellites by collecting the following information about each satellite:

- Ephemeris data when each satellite “rises” and after each GPS hour roll-over.
- Almanac data
- UTC offset
- Satellite health

A satellite may either declare itself failed via its own internal health status checks, or may be declared failed by Falcon AFB via command to the suspect satellite. In either case, the satellite is declared “unhealthy” and taken offline by the DoD. The satellite health word which is downloaded to the MAGR-S recognizes the bad health status, and will not use that satellite to compute a navigation state. As an additional level of protection, if the DoD corrective action cannot be accomplished in time to protect the shuttle entry phase, a satellite may be deselected in the GPC software to prevent the MAGR-S from tracking a suspect satellite.

PROCEDURE

FAILED SATELLITE - For a suspect satellite that is being used by the MAGR-S to compute the navigation state, deselect the satellite on SPEC 55 with an ITEM 43 through and ITEM 50. This will inhibit the MAGR-S from using the deselected satellite. MCC will be notified by 2 SOPS of failed satellites through the LSO, GPO, or FDO consoles depending on flight phase.

BAD GPS DATA - For a case where the GPS is computing a bad navigation state vector, the error should be caught by the QA1, QA2 and QA4 flight software checks. QA1 is the Figure of Merit (FOM) check which is made by the MAGR-S internally and shipped to the GPC. QA2 is the GPS to NAV compare made by the GPC. QA4 is the GPS to GPS compare made in the GPC. Note that QA4 is not available on single string flights or while only one GPS is powered. If the QA checks do not detect a GPS error, the immediate actions should include deselection of the appropriate GPS (SPEC 55, ITEM 26, 27, and 28) and/or inhibit GPS to NAV (SPEC 55, ITEM 36).

NASA and DoD have a Memorandum Of Agreement (MOA) that describes the interaction of MCC-H with the Falcon AFB 2nd Space Operations Squadron (2SOPS) regarding the GPS satellite constellation. Key points of the proposed agreement are:

- NASA agrees to the following:
 - NASA shall provide 2 SOPS the shuttle launch and landing schedules at least 7 days prior to the effective date.
 - NASA shall provide launch and landing schedule changes to 2 SOPS as soon as practical but not later than 24 hours in advance.
- 2 SOPS agrees to the following:
 - Provide access to GPS constellation status through 2 SOPS website
 - Provide realtime GPS status updates through the 24 hour Control Center from 15 minutes prior to deorbit burn through landing. Updates will be provided via telephone to MCC-H.
 - Commanding to GPS satellites (for nominal maintenance tasks) will be curtailed during the shuttle entry phase.

GNC RESPONSIBILITIES FOR SATELLITE INTEGRITY MONITORING

GNC responsibilities for satellite monitoring include observing GPS receiver performance and coordinating any satellite deselect actions with the Flight Dynamics Officer (FDO) and Guidance and Procedures Officer (GPO). The FDO/GPO/LSO console will use their ROLM phones and

security clearance to talk to the DoD. The LSO console is the primary MCC-H contact to talk to 2 SOPS about GPS satellite constellation failures.

GPS SATELLITE LOCK DURING ASCENT

During prelaunch and ascent, the lower GPS antennas are obstructed by the External Tank, and the orbiter is rolled to a heads down attitude limiting the upper antenna field of view. Immediately at liftoff the GPS typically is tracking 4 satellites, but during the roll program, GPS satellite lock drops off one or more satellites resulting in a high GDOP and FOM for a period of time. Satellite tracking dramatically improves after the ascent roll-to-heads up is complete, and GPS satellite tracking is typically nominal after MECO and ET separation after the lower antennas are unobstructed. Less than 4 satellite tracking during powered ascent is not an issue, since the GPS is not used during powered flight and the GPS is receiving aiding data by the IMUs via the GPC to update its position and velocity.

GPS SATELLITE LOCK ON-ORBIT

On-orbit the GPS will change satellites more rapidly than in the stationary prelaunch or lower velocity entry configuration because the orbiter is moving at orbital velocities with respect to the satellite constellation. Satellite lock will typically drop below 4 satellites only for several seconds to allow the MAGR-S to reconfigure the channels to track new satellites. Extended periods of time (2 minutes or more) with less than 4 satellites on-orbit are uncommon.

Orbiter maneuvers will affect the line of sight of the hemispherical GPS antennas to the satellites. Expect orbiter maneuvers to cause satellites to drop out and selection of other satellites to occur. Satellite dropouts due to orbiter maneuvers are not predictable because of the dynamics of the orbiters trajectory with respect to the orbiting satellite constellation and starting and ending orbiter attitudes. The best thing is to expect possible dropouts of GPS during maneuvers. Extended LVLH attitude holds with the orbiter +/- Z axis pointed at the earth will result in limited field of view of either the upper or lower antennas.

For mated shuttle/station configurations, or RMS/payload configurations, it is possible to see multipath effects on the upper antennas. This may result in a decrease in the number of satellites available or low C/No ratios on a given channel.

GPS SATELLITE LOCK DURING ENTRY

During entry, it is not uncommon for the GPS to continuously track one or more satellites from very high up (150kft) through landing. Depending on the entry trajectory and the location of the satellite tracks during entry, the satellites selection and length of lock may vary greatly from one flight to the next. Like on-orbit, GPS satellite lock may vary during maneuvers to and from deorbit burn attitude and Entry Interface attitude. Satellite lock during entry below 200 kft typically always has 4 or more satellites, with brief periods (up to 30 seconds) of less than 4 satellites. In addition, satellites in the periphery of the antennas (in the orbiter XY body axis plane) may jump in and out of lock during entry roll maneuvers.

ENTRY PLASMA REGION

Plasma effects during the early portions of entry affect satellite lock on the lower antennas causing a drop off in signal strength (typically to the 20 dB C/No range), eventually leading to antenna blockage, typically from 280kft to 200kft. This may vary from flight to flight and satellite to satellite depending on atmospheric conditions and satellite line of sight angles to the antenna. The following table lists STS-84 and STS-85 plasma effects on the MAGR-S GPS DTO 700-14:

STS-84 PLASMA REGION EFFECTS ON SAT LOCK		
	FROM	TO
CHANNEL 1	266,100 feet	228,200 feet
CHANNEL 2	276,000 feet	222,900 feet
CHANNEL 3	276,700 feet	244,200 feet
CHANNEL 4	260,300 feet	237,400 feet
CHANNEL 5	321,200 feet	212,150 feet

STS-85 PLASMA REGION EFFECTS ON SAT LOCK		
	FROM	TO
CHANNEL 1	259,350 feet	195,900 feet
CHANNEL 2	321,250 feet	199,500 feet
CHANNEL 3	316,400 feet	236,400 feet
CHANNEL 4	263,400 feet	257,500 feet
CHANNEL 5	285,250 feet	213,250 feet

CARRIER TO NOISE RATIO (C/No)

The carrier to noise ratio (C/No) also called the signal to noise ratio (S/No), indicates the strength of the GPS receiver lock on a particular satellite on a given channel. Low C/No ratios are typically the result of poor line of sight angles of the antenna to the satellites, multi-path effects, tracking the same satellite on both upper and lower antennas (induced multi-path), and radio frequency interference (RFI). C/No ratios will tend to fluctuate in the 20 to 30 dB range for satellites with elevation angles of less than 15 degrees with respect to the antenna. C/No will typically be in the mid 40 dB range with little fluctuation for satellites with elevation angles above 50 degrees with respect to the antenna. The following table gives ranges of good, marginal and poor carrier to noise ratios, and their associated channel tracking states:

CARRIER TO NOISE (C/No) RATIOS		
	C/No RANGE (dB)	CHANNEL STATE
SOLID TRACKING	26 - higher	5
MARGINAL	14 to 25	3
POOR TRACKING	0 to 13	7

CHANNEL STATES

The channel state indicates the type of lock the GPS receiver has on a satellite on a logical channel. The following table indicates what the various MAGR-S channel states indicate:

CHANNEL STATE DEFINITIONS		
	DESCRIPTION	COMMENTS
STATE 0	Idle Channel	Not used for channels 1 through 5. Has been observed on the peripheral channel.
STATE 1	Tracking in C/A code	GPS will transition to P (Y) tracking when Handover Word acquired
STATE 2	Tracking in P(Y) code	GPS has an accurate estimate of position, velocity and time. Likely after power cycle.
STATE 3	Pseudo-range measurement only phase	Can result from low C/No ratio and often occurs as a result of poor antenna line of sight angles (less than 15 degrees). State 3 tracking is not reliable in PVA submode.
STATE 4	Not Used	Used in GEM to indicate non-coherent carrier phase tracking. This state is as coherent as its explanation.
STATE 5	Pseudo-range and delta Pseudo-range measurement phase	Most accurate tracking mode. C/No is typically above 26 dB when State 5 present tracking
STATE 6	Not Used	N/A
STATE 7	Recovery State	GPS is trying to reacquire a satellite which has lost lock. GPS will try to reacquire lost satellite for 10 seconds before moving to alternate satellite selection list.

FIGURE OF MERIT (FOM)

FOM reflects the estimated position accuracy of the GPS. The FOM is computed by the GPS performance monitor. FOM estimates take into account the selected satellite geometry (GDOP), satellite error based on the use of the ephemeris or almanac, uncertainty in the estimated ionospheric errors, uncertainty in the estimated tropospheric errors, and the User Range Accuracy (URA) for each satellite. The URA for each satellite is an estimate of the satellite navigation message accuracy based on the space and ground segments.

On-orbit (OPS 2 and 8) a FOM greater than 2 will cause a QA1 FAIL. During entry (OPS 3 and 6), a FOM greater than 5 will cause a QA1 FAIL. The following table lists the range of FOM and corresponding position errors:

FOM	Position Error in feet	Position Error in meters	Position Error in nmi
1	0 - 82	0 -25	0 - 0.0135
2	83 - 164	26 - 50	0.0136 - 0.0270
3	165 - 246	51 - 75	0.0271 - 0.0405
4	247 - 328	76 - 100	0.0406 - 0.0540
5	329 - 656	101 - 200	0.0541 - 0.1080
6	657 - 1640	201 - 500	0.1081 - 0.2700
7	1641 - 3281	501 - 1000	0.2701 - 0.5400
8	3282 - 16405	1001 - 5000	0.5401 - 2.700
9	> 16406	> 5000	> 2.701

GEOMETRIC DILUTION OF PRECISION (GDOP)

GDOP is an indication of how well the GPS satellite geometry enables the receiver to resolve position errors. GDOP ranges from 1 to 15, with 1 being the best GDOP. The lower the GDOP, the more the position error is visible to the filter. As GDOP increases, the line of sight vectors to the selected satellites exhibit a higher linear correlation. The MAGR-S is programmed to choose a lower GDOP based on weighted criteria. An ideal GDOP (of 1.58) results in one satellite directly overhead, and 3 spread equally at 120 degree intervals at 10 degrees above the horizon. Keep in mind that satellites near the horizon have greater errors due to ionospheric and tropospheric errors, and lower corresponding C/No ratios. In some cases a better GDOP may exist, but may not have a strong enough signal strength to maintain lock.

GDOP will typically spike for brief periods due to satellite switching, or near the end of tracking of a particular set of satellites that has a geometry that is getting poorer. When this occurs, GDOP will spike (also called a GDOP chimney due to its shape when plotted against time). The GDOP lowers when a better set of satellites is selected.

REFERENCES

Ascent/Entry Flight Techniques Panel, GPS Splinter #1, 1/8/98

GPS Performance Post-Flight Report for STS-84, Flight Design and Dynamics Division, 12/22/97

GPS Performance Post-Flight Report for STS-85, Flight Design and Dynamics Division, 1/16/98

Liebman, Ed, Guidance and Control Systems Engineer, Mission Operations Directorate

Memorandum of Agreement between National Aeronautics and Space Administration and Department of Defense, United Space Command, 2nd Space Operations Squadron, dated 3/13/98

Nuss, Ray, GPS Subsystem Manager, Engineering Directorate

Sarafin, Michael L., Guidance and Control Systems Engineer, Mission Operations Directorate

TITLE

GPS TROUBLESHOOTING

PURPOSE

To aid GNC console operators in troubleshooting GPS related anomalies and failures. This SCP discusses the following:

- Recovery actions for a GPS not tracking satellites (lost GPS)
- Recovery actions for a GPS hardware failure (Power-fail, Commfault, RPF)
- Rationale for GPS power-up/power-down procedure
- Potential gotcha's in GPS troubleshooting procedures

BACKGROUND

The Miniature Airborne GPS Receiver - Shuttle (MAGR-S) consists primarily of electronics and contains very little mechanical hardware. As a result troubleshooting related to MAGR-S related hardware failures is limited. This SCP outlines potential failures and related recovery actions.

PROCEDURE

GPS NOT TRACKING SATELLITES (LOST)

For cases where the GPS appears to be lost, it is not uncommon to have the following signature:

- No satellites locked
- GPS computed altitude is in error by a large amount
- GPS position and velocity data is either static (not as in static telemetry but not updating), or is grossly in error.
- GPS time is incorrect by a significant amount and/or the Universal Time Constant (UTC) flag is not valid.
- GPS is tracking in the PVA submode (i.e., not INS)

For cases where one or more of the above is true for an extended period of time, it is recommended to *command the GPS to INIT for 5 seconds, then back to NAV*. This will provide the GPS with a new state vector, transferred from the orbiter. Once the GPS has the new INIT data, it should begin to lock onto satellites. If the GPS is not tracking at least 1 satellite in 5 minutes, GNC should begin to look into other failures.

If a CPU failure occurred, an RPF flag should be present, indicating the internal performance monitor has identified a problem. For troubleshooting of this failure, refer to the GPS POWER-FAIL, RPF, COMMFAULT troubleshooting located below.

Consideration should be given to the orbiter attitude with respect to the location of the GPS antennas. It may be possible to have either the upper or the lower antennas blocked due to the earth or structure (space station, HST, RMS mounted payload, etc).

Other areas to troubleshoot GPS hardware include failure of an antenna pre-amplifier, the antenna assembly, or antenna cabling. For troubleshooting one of these areas, refer to the bus loss tables for the antenna pre-amplifiers, and to the GPS drawings for locations of the antenna assemblies and cabling.

It is important to note that the GPS needs a current state vector. Without a current vector, the GPS may become lost and may not be recoverable without a new state. With IMU aiding data via the GPC, the GPS is capable of tracking satellites without problems (including at orbital velocities) in the INS submode. It is only when the GPS loses IMU aiding data for an extended period of time that it may become lost (GPS downmodes to PVA submode).

If the GPS loses IMU aiding data and is power-cycled (even for an few seconds), the GPS will likely become lost, since the GPS zeros out its velocity terms and assumes it is at its last know position. The MAGR-S operates in a manner whereby it calculates the delta pseudo-range and integrates it to compute the pseudo-range. So if the velocity terms are zeroed out, even if the position is accurate, the GPS will likely be lost (especially at orbital velocities).

GPS POWER-FAIL, RPF, OR COMMFAULT

For a GPS that has annunciated a power-fail or a commfault, and the problem has been isolated to the GPS (i.e., not the associated MDM or bus), it is recommended to power-cycle the GPS. *To accomplish this, it is recommended that the crew run the ORB OPS, GPS POWER-DOWN procedure, skipping the antenna pre-amp steps (STEP 3). Once the power-down is complete, it is recommended that the crew run the GPS POWER-UP procedure, skipping the antenna pre-amp steps (STEP 1).* Performing the power-down, followed by the power-up will assure an orderly power-cycle of the GPS allowing for the correct wait times, and ensure that the GPS is commanded to the correct mode with the necessary initialization data.

For a Receiver Processor Fail (RPF), sometimes called RPU fail, it is recommended that a GPC commanded self-test be performed. After evaluation of the GPS S/TEST has been completed per the GNC GPS SELF-TEST SCP, and it is deemed necessary to attempt to recover the failed GPS, a power cycle is recommended per the procedure outlined above for a power-fail or commfault.

BAD GPS DATA - For a case where the GPS is computing a bad navigation state vector, the error should be caught by the QA1, QA2 and QA4 flight software checks. QA1 is the Figure of Merit (FOM) check which is made by the MAGR-S internally and shipped to the GPC. QA2 is the GPS to NAV compare made by the GPC. QA4 is the GPS to GPS compare made in the GPC. Note that QA4 is not available on single string flights or while only one GPS is powered. For additional detail on the QA checks, refer to the GPS QA SCP.

If the QA checks do not detect an error, the immediate actions should be to deselect the appropriate GPS (SPEC 55, ITEM 26, 27, and 28) and/or inhibit GPS to NAV (SPEC 55, ITEM 36).

For a suspected satellite problem refer to the GPS SATELLITE MONITORING SCP

LOSS OF ENCRYPTION CAPABILITY

If the GPS has lost encryption capability, the GPS processor could downmode to SPS tracking, with all channels in C/A or P tracking (no Y-tracking) if spoofing is enabled. Note that it is not uncommon to see brief periods of C/A code tracking with a keyed receiver. If the GPS had been zeroized, inadvertently or deliberately, the zeroize pin connector will be shorted out, the GPS will downmode to SPS. There is no way to recover from a zeroize, since it requires ground support equipment. The GPS tracking capability will be degraded to SPS errors if spoofing is enabled, but is not an issue since GPS is certified during entry with SPS errors (refer to the GPS Systems Briefs for PPS and SPS error budgets).

PROCEDURAL GOTCHA'S

The ORB OPS book contains GPS Power-Up and Power-Down procedures. The following is a list of rationale for the procedures and a list of procedural gotcha's:

GPS POWER REMOVED FOR LESS THAN 30 SECONDS - If the GPS power is removed for less than 30 seconds, the GPS will pick back up in its previous submode. If the GPS was previously in NAV, it will return to NAV (unless commanded otherwise), attempting to track satellites and provide a state vector. If the GPS was previously in INIT, it will return to INIT mode. If powered off for less than 30 seconds, the GPS will not attempt to perform the power-up Self-Test or INIT.

GPS POWER REMOVED FOR MORE THAN 30 SECONDS - If the GPS power is removed for more than 30 seconds, the GPS will mode up through a power-up self-test, request initialization data, and mode to navigation submode itself, unless the GPC commands it to a different submode. If the GPC commands it to a different submode the GPS will go through self-test, initialization, then to the GPC commanded submode (INIT, S/TEST, NAV).

GPS POWERED DOWN DURING A GPC COMMANDED S/TEST - The GPS will remain in the GPC commanded submode, unless it is commanded to a different submode after power is reapplied and the I/O reset is performed. If S/TEST is commanded when I/O is re-established, the crew has 6 seconds to change their mind after the S/TEST command is first issued; otherwise, the GPS is in S/TEST mode for 2 to 2.5 minutes. If another submode (INIT or NAV) is commanded while the GPS is in S/TEST, it waits until the S/TEST is complete before it honors the next command. The only way to recover from an inadvertent S/TEST command is to let the self-test complete, or to power the GPS off for at least 30 seconds, then power it on in INIT or NAV. In either case the GPS is not useable for about 2 minutes.

EARLY GPS I/O RESET - If an I/O RESET is performed too early (prior to 22 to 25 seconds) after initial GPS power-up, the serial interface on the GPS side of the MDM will not be ready to talk to the MDM and a commfault will be annunciated. To avoid this condition, wait at least 30 seconds after power was applied, then perform the I/O RESET.

LATE GPS I/O RESET - If an I/O RESET is performed late (after 1 minute), the GPS will have moded through power-up self-test, through initialization, and into navigation submode and should be searching for satellites. If this is the case, no initialization data was passed to the GPS via the GPS request for initialization data. This is why procedurally, we

command the GPS to INIT, then to NAV, instead of straight to NAV. If the I/O RESET was late, the GPS did not automatically get a new state vector and may be lost.

GPS SATELLITE LOCK ON TIME - It can take up to 10 minutes for GPS to lock onto at least 4 satellites after initial power-up. If no INIT data was passed from the GPC to the GPS after initial power-up, it is possible for the GPS to never lock onto 4 satellites (especially at orbital velocities).

WAIT TIME BETWEEN INIT AND NAV - The generic power-up procedure contains a wait time between the INIT and NAV command. The wait is to ensure that the orbiter state vector transfer is completed (typically only takes 2 to 3 seconds).

TIME VARIATIONS IN STEPS - It is important to note that changes to the GPS firmware and variations in the hardware may result in small variations in the time required for a given GPS to perform an action. The biggest factor would be code changes due to firmware fixes or upgrades.

REFERENCES

Ascent/Entry Flight Techniques Panel, GPS Splinter #1, 1/8/98

Liebman, Ed, Guidance and Control Systems Engineer, Mission Operations Directorate

Nuss, Ray, GPS Subsystem Manager, Engineering Directorate

Sarafin, Michael L., Guidance and Control Systems Engineer, Mission Operations Directorate

TITLE

GPS FLIGHT SOFTWARE - QA CHECKS, AIF FLAGS

PURPOSE

To aid GNC console operators in monitoring, evaluating, and using the various onboard GPS flight software functions. This SCP discusses the following:

- QA 1 - Figure of Merit (FOM)
- QA 2 - GPS to Navigation (NAV) compare
- QA 3 - GPS to last cycle compare
- QA 4 - GPS to GPS (LRU) compare
- QA Override
- GPS QA and GAX I-Loads
- GPS to NAV and GPS to G&C A/I/F Functions

BACKGROUND

The onboard GPS flight software contains several checks called Quality Assessment (QA) to monitor GPS performance. The GPS QA scheme is unlike redundancy management (RM) schemes used for navaids/sensors in the past, in that it is effective on a cycle-by-cycle basis and will not cause an LRU to “fail” if it exceeds the QA thresholds by permanently deselecting the LRU. Instead, the QA checks inhibit that LRUs data from being available for use by the selection filter for the cycle(s) during which it is out of limits. When the LRU exceeding QA limits returns to within the QA threshold, it is automatically available for use by the selection filter. With the GPS QA scheme the only way to permanently remove a GPS from the selection filter availability is to manually deselect it. The QA threshold must be out of limits for an I-loaded number of cycles before a crew alert is annunciated.

BFS single string does not have QA checks. FOM is the only onboard method of evaluating BFS GPS single string data. On the ground, we are able to compare BFS GPS data to ground tracking, IMUs 1, 2, and 3, and onboard navigation. BFS three-string does not use QA3, and has no onboard insight to QA2 or QA4 failures.

The PASS GPS STATUS display is located below. SPEC 55 is the prime crew interface to GPS 1, 2, and 3, and allows direct insight to the QA checks. A QA fail is displayed as a down arrow next to the appropriate QA position or velocity check.

XXXX/055/				GPS STATUS			XX X DDD/HH:MM:SS					
I/O	IO	X	GPS1S	GPS2S	GPS3S	DDD/HH:MM:SS						
STAT	XXXX		XXXX	XXXX	XXXX	GPS MINUS NAV						
MODE	XXXX		XXXX	XXXX	XXXX	ΔH	$\pm XXXXXX$	$\Delta \dot{H}$	$\pm XXX.XX$			
S/TEST	11XS		12XS	13XS	14XS	ΔDR	$\pm XXXXXX$	$\Delta \dot{DR}$	$\pm XXX.XX$			
INIT	14X		15X	16X	17X	ΔCR	$\pm XXXXXX$	$\Delta \dot{CR}$	$\pm XXX.XX$			
NAV	17X		18X	19X	20X	X LAT	X LON	ALT				
RESTART	20X		21X	22X	23X	XX.XX	XXX.XX	XXX.XXXX				
GDOP	XX		XX	XX	XX							
DG FAIL	S		S	S	S	AUT INH FOR						
DES RCVR	26X		27X	28X	29X	GPS TO G&C	S32X	33X	34X			
QA OVRD	29XS		30XS	31XS	32XS	GPS TO NAV	S35X	36X	37X			
SF CAND	X		X	X	X	METERING OVERRIDE			38X			
QA1 P 1 σ	XXXXXS		XXXXXS	XXXXXS	XXXXXS	SATELLITES						
QA2 POS	X.XX		X.XX	X.XX	X.XX	TRKD	C1	C2	C3	C4	C5	C6
VEL	X.XX		X.XX	X.XX	X.XX	GPS1	XX	XX	XX	XX	XX	XX
QA3 POS	X.XXS		X.XXS	X.XXS	X.XXS	GPS2	XX	XX	XX	XX	XX	XX
VEL	X.XXS		X.XXS	X.XXS	X.XXS	GPS3	XX	XX	XX	XX	XX	XX
	1-2		2-3	3-1		DES	43	XX	XX	XX	XX	
QA4 POS	X.XXS		X.XXS	X.XXS	X.XXS			XX	XX	XX	XX	
VEL	X.XXS		X.XXS	X.XXS	X.XXS			XX	XX	XX	XX	
XXX.X	LAST SEL FIL UPDATE											

QA 1 FOM

The Figure of Merit (FOM) or QA1 is not an orbiter flight software check of the GPS, but rather an internal GPS hardware performance estimate of one sigma position errors expected from the associated GPS navigation solution. FOM, also called P1 σ (pronounced P-one-sigma) in three string GPS, is displayed on SPEC 55 and shipped directly from the GPS to the GPC for use by the GPC in determining if that GPS solution will be used as a SF candidate to update navigation.

The MAGR-S FOM calculation is heavily based on satellite geometry (GDOP). It is not uncommon to see a high GDOP causing a high FOM several seconds later. High FOM's due to a high GDOP will correct themselves when a better geometry of satellites moves into view. A high FOM due to reasons other than a high GDOP should be looked at more closely, since it indicates the GPS has off nominal performance not directly attributable to poor satellite geometry.

The QA1 check is available in both the PASS and BFS, and also in the single and three string GPS configurations. One difference to note between the PASS and BFS, is that the PASS uses a less than function "<" for QA1, whereas the BFS uses a less than or equal "<=" to function to determine QA1 failures. This results in different I-loaded thresholds for QA1.

FOM	Displayed Position Error (feet)**	Position Error (feet)	Position Error (meters)	Position Error (nmi)
0	(blank)	0	0	0
1	75	0 - 82	0 - 25	0 - 0.0135
2	175	83 - 164	26 - 50	0.0136 - 0.0270
3	250	165 - 246	51 - 75	0.0271 - 0.0405
4	325	247 - 328	76 - 100	0.0406 - 0.0540
5	650	329 - 656	101 - 200	0.0541 - 0.1080
6	1650	657 - 1640	201 - 500	0.1081 - 0.2700
7	3275	1641 - 3281	501 - 1000	0.2701 - 0.5400
8	16400	3282 - 16405	1001 - 5000	0.5401 - 2.700
9	99999	>16405	> 5000	> 2.701

** The position error in this column is what is displayed onboard via SPEC 55. It is a rounded conversion of meters to feet. Yes, I know if you convert the FOM in meters to feet from the table above, they do not exactly agree!

QA 2 - GPS TO NAV COMPARE

QA2 is the onboard navigation comparison to GPS. The orbiter flight software check compares the GPS 1, 2, 3 solution with the on-board navigation state. If the GPS 1, 2, or 3 comparison exceeds any of the QA2 thresholds, a QA2 fail is declared for position, or velocity, or both.

The QA2 limits are I-loaded and time dependent (ramp up to a max threshold over time since the last GPS update was performed). If any of the QA2 position or velocity components exceed the QA2 thresholds, the whole GPS state fails QA2. Nominally, QA 2 failures will be driven by error growth in the onboard propagated navigation state.

After the QA2 check, all eligible GPS states are sent to the selection filter, then navigation (reference the GPS Systems Brief for a diagram of the QA checks and the selection filter). Once the selected state is sent to NAV, navigation performs its own comparison, called the Nav Edit Ratio function. The Nav Edit Ratio function is sometimes called the "secondary QA2 check". If the secondary QA2 check is failed (RATIO > 1), the LRU with the high edit ratio may be used, by first Overriding QA to bypass its primary QA2 check, then forcing GPS to NAV.

The QA2 check is not available in the BFS single string GPS configuration, but is available in the BFS three string GPS flight software. There is no onboard indication of QA2 data output on the BFS SPEC 55.

QA3 - GPS TO LAST CYCLE COMPARE

QA3 compares a given GPS to its previous nav cycle to see if any large jumps in velocity or position were detected. The receiver must have a valid nav solution on the current and previous nav cycles, otherwise the GPS fails QA3. QA3 is of limited value, but it should catch any rapid spikes in position or velocity from one cycle to the next.

The PASS flight software provides crew insight to QA3 on SPEC 55 in single string and triple string configurations. The position and velocity ratios (difference/threshold) is displayed along with a status indicator.

BFS does not support QA3.

QA4 - GPS TO GPS COMPARE

QA4 compares one GPS solution to the other GPS solutions. If a common pair of position or velocity differences exceeds the QA4 threshold, the common receiver fails the LRU to LRU check. A QA4 dilemma requires crew intervention to resolve.

It is possible to have a QA4 Dilemma at the 3-level and at the 2-level. A QA4 dilemma will be present at the 3 level, if all three LRU to LRU difference checks exceed the QA4 threshold. To resolve a 3-level dilemma, the GNC operator should look at the other QA checks to observe how each of the LRUs are violating the QA1, QA2, and QA3 checks. It is recommended to perform a QA Override on the LRU with the smallest FOM to allow NAV to process GPS data. Another option is to deselect the LRU with the largest FOM, to remove the worst GPS from the 3-level dilemma. However, if the deselect option is selected, a 2-level dilemma may be present. If the 2-level dilemma occurs, follow the steps located below for a 2-level dilemma.

A QA4 miscompare occurs at the two level when both selected GPS LRUs disagree by more than the QA4 threshold. For a QA4 miscompare at the 2-level, it is recommended to deselect the LRU with the largest FOM. If both LRUs have the same FOM, then deselect the LRU that disagrees most with nav (QA2).

Note that QA4 does not function while on-orbit with only a single GPS powered.

The PASS flight software provides crew insight to QA4 via position and velocity ratio (difference/threshold) on SPEC 55 along with status indicators.

BFS supports a GPS to GPS compare (not called QA4). BFS does not have QA 4 dilemma logic like the PASS, or crew interface to QA4 output on BFS SPEC 55.

QA FAULT SUMMARY MESSAGES

RM DMLA GPS - Will be annunciated for a QA4 dilemma at the 2 or 3 LRU level

G55 GPS QA 1, 2, 3 - Will be annunciated for a GPS 1, 2, 3 fail of QA 1, 2, 3, or 4 for greater than an I-loaded number of cycles.

GPS SELECTION FILTER

3-LEVEL GPS STATE SELECTION

PASS performs an MVS of the GPS position vectors by using the GPS solution with the smallest position vector differences when compared to the other two LRUs. The FOM for the selected state is then used for display and to scale the covariance updates.

BFS uses a component-by-component mid-value select (MVS) scheme, and the FOM is set equal to the mid-value of the receiver FOMs.

2-LEVEL GPS STATE SELECTION

PASS averages the two solutions to create a selected state and uses the larger FOM for display.

BFS uses the GPS state with the smaller FOM. If both FOMs are the same, BFS uses the lowest numbered LRU.

1-LEVEL GPS STATE SELECTION

PASS and BFS use the available GPS solution and FOM.

0-LEVEL GPS STATE SELECTION

If no nav state is available from a GPS, the GPC will continue to propagate the last valid selected state to current time using IMU data. If no GPS update has been performed within an I-loaded period of time, a crew alert message is annunciated.

QA OVERRIDE

The QA Override function is only available in the PASS and not supported by the BFS. The QA Override function is available on SPEC 55, via an ITEM 29, 30 and 31. Commanding QA Override makes a GPS available for the selection filter even though it may have failed one or more of the QA checks. Note that invoking QA Override does not override crew deselections or a GPS data good failure. Invoking QA Override does not clear a 2-level QA4 Dilemma.

GPS TO NAV A/I/F FUNCTION

The GPS_TO_NAV Auto function, automatically updates navigation with a selected GPS state at an I-loaded interval.

The GPS_TO_NAV Inhibit function inhibits GPS data from updating navigation. GPS_TO_NAV is automatically moded to Inhibit at OPS and major mode transitions (i.e., OPS 2 to 8, OPS 2 to 3, and MM 201 to 202). Automatic moding of GPS_TO_NAV to Inhibit at OPS transitions does not preclude the crew from manually moding to Auto or Force. After burn targeting, GPS_TO_NAV should remain in inhibit, otherwise Lambert targeting could be corrupted if a GPS update occurs, prior to an OMS/RCS burn (FSW DR 110338). Note that use of QA Override does not bypass the inhibit function.

The GPS_TO_NAV Force function forces GPS data into navigation on the cycle the force is commanded (one shot force function), then modes back to the previous GPS Auto/Inhibit state.

Note that the GPS to NAV A/I/F function consists of two flags, the Auto/Inhibit flag, and the Force On/Force Off flag. The Auto and Inhibit flags are mutually exclusive. If a Force flag is ON the same time the Auto or Inhibit flag is present, the Force flag takes precedence on that cycle. So it is possible to have an Auto and a Force, or an Inhibit and a Force flag present at the same time for a single cycle.

The GPS_TO_NAV A/I/F function is available in the PASS and BFS, single and triple string GPS configurations.

If the GPS_LOCKOUT I-load flag is equal to 1 or 0, GPS_TO_NAV and GPS_TO_G&C will always remain in Inhibit, and are not able to be moded to Auto or Force.

GPS TO G&C A/I/F FUNCTION

The GPS_TO_G&C Auto function, automatically updates the User Parameter Processor (UPP) at the navigation cycle frequency. No nominal, or off nominal, operational use for GPS_TO_G&C in Auto has been identified.

The GPS_TO_G&C Inhibit function, inhibits GPS data from updating the UPP. This is the planned state of GPS_TO_G&C at all times, since it has no nominal operational use.

The GPS_TO_G&C Force function, continuously forces GPS data to the UPP. No nominal operational use for GPS_TO_G&C in force has been found. The GPS_TO_G&C Force function may be employed if onboard nav is badly corrupted between GPS update cycles, by degraded nav aids. The prime example of this, is a last IMU with bad accelerometer outputs. The IMU is good for attitude control, but is corrupting navigation. By forcing GPS to G&C navigation is bypassed completely in the UPP.

Note that the GPS_TO_G&C A/I/F flag is a single flag. All three states (A, I, F) are mutually exclusive. The GPS to G&C function is available only in the PASS, single and triple string GPS configurations.

GPS QA AND GAX I-LOADS

GPS has a considerable number of I-loads related to QA checks and GNC Annunciation (GAX) messages for crew alerts. Many of the I-loads are dependent on the OPS mode and the flight software OI being flown. The following tables contain the PASS I-loads for OI-30. Keep in mind that these parameters are merely I-loads and may change as we learn more about GPS flight operations.

NOTE: A number of I-loads have been increased to their maximum values in order to avoid nuisance alarms, specifically during crew sleep periods.

OI-30 PASS GPS I-LOADS (FOR ALL OPS)	
DOWNLIST SCALE FACTORS	
DELR_SF	0.0016457884 (ft)
DELV_SF	0.1 (fps)
DELR_UVW_POS_SF	10.0 (ft)
DELV_UVW_VEL_SF	0.1 (fps)
QA2_RTOL_SF	10.0 (ft)
QA2_VTOL_SF	0.1 (fps)
QA2_DELR_RATIO_SF	0.01 (fps)
QA2_DELV_RATIO_SF	0.01 (fps)
QA3_DELR_RATIO_SF	0.01 (fps)
QA3_DELV_RATIO_SF	0.01 (fps)
QA4_DELR_RATIO_SF	0.01 (fps)
QA4_DELV_RATIO_SF	0.01 (fps)
DT_QA2_SF	1.0 (sec)
GPS CONFIGURATION DATA	
GPS_INSTALLED	ON, ON, ON (3 receivers) OFF, ON, OFF (1 receiver)
GPS_LOCKOUT	3 (1 or 3 receivers)
GPS GAX MESSAGE COUNTERS	
GPS_FAIL_FOM_GAX_MSG_CNT_MIN	32,760 nav cycles (~34 hours) *
GPS_QA3_GAX_MSG_CNT_MIN	32,760 nav cycles (~34 hours) *
GPS_QA4_GAX_MSG_CNT_MIN	32,760 nav cycles (~34 hours) *
GPS_QA4_DILEMMA_GAX_MSG_CNT_MIN	32,760 nav cycles (~34 hours) *
GPS DATA QUALITY ASSESSMENT	
GPS_QA_TIME_THRESH	1.90 sec
GPS STATE PROPOGATION	
GPS_IMU_VEL_THRESH	0.05 fps

OI-30 PASS GPS I-LOADS (FOR OPS 2 and 8)	
GPS GAX MESSAGES/ALERTS	
GPS_ALERT_DT	1,728,000.0 (sec) (~20 days)
GPS_GAX_OFF_ALERT_RMNDR_DT	1,728,000.0 (sec) (~20 days)
N_RATIOS_ABOVE_LIMIT_MIN	32,760 nav cycles (~34 hours)
GPS QA TOLERANCES	
MAX_FOM_ACCEPT_PFS	2
GPS_QA2_RTOL_UVW_A(1-3)	500.0, 500.0, 500.0 (ft)
GPS_QA2_RTOL_UVW_B(1-3)	0.13889, 1.89815, 0.09259 (fps)
GPS_QA2_RTOL_UVW_C(1-3)	0.0, 0.0, 0.0 (ft/s ²)
GPS_QA2_RTOL_MAX_UVW(1-3)	2000.0, 21000.0, 1500.0 (ft)
GPS_QA2_VTOL_UVW_A(1-3)	2.0, 1.0, 1.0 (fps)
GPS_QA2_VTOL_UVW_B(1-3)	0.00203, 0.00009, 0.00009 (ft/s ²)
GPS_QA2_VTOL_UVW_C(1-3)	0.0, 0.0, 0.0 (ft/s ³)
GPS_QA2_VTOL_MAX_UVW(1-3)	24.0, 2.0, 2.0 (fps)
GPS_QA3_RTOL	500.0 (ft)
GPS_QA3_VTOL	2.0 (fps)
GPS_QA4_RTOL	500.0 (ft)
GPS_QA4_VTOL	5.0 (fps)
GPS UPDATE RATE	
T_GPS_CYCLE	5400.0 (sec) (~ 90 minutes)

OI-30 PASS GPS I-LOADS (FOR OPS 1 and 3)	
GPS GAX MESSAGES/ALERTS	
GPS_ALERT_DT	300.0 (sec) (5 min)
GPS_GAX_OFF_ALERT_RMNDR_DT	1,728,000.0 (sec) (~20 days)
N_RATIOS_ABOVE_LIMIT_MIN	5 nav cycles (~19.2 sec) *
GPS QA TOLERANCES	
MAX_FOM_ACCEPT_PFS	5
GPS_QA2_RTOL_UVW_A(1-3)	500.0, 500.0, 500.0 (ft)
GPS_QA2_RTOL_UVW_B(1-3)	1.8056, 8.1944, 3.75 (fps)
GPS_QA2_RTOL_UVW_C(1-3)	0.0, 0.0, 0.0 (ft/s ²)
GPS_QA2_RTOL_MAX_UVW(1-3)	7000.0, 30000.0, 14000.0 (ft)
GPS_QA2_VTOL_UVW_A(1-3)	8.0, 8.0, 8.0 (fps)
GPS_QA2_VTOL_UVW_B(1-3)	0.006111, 0.003333, 0.003333 (ft/s ²)
GPS_QA2_VTOL_UVW_C(1-3)	0.0, 0.0, 0.0 (ft/s ³)
GPS_QA2_VTOL_MAX_UVW(1-3)	30.0, 20.0, 20.0 (fps)
GPS_QA3_RTOL	500.0 (ft)
GPS_QA3_VTOL	5.0 (fps)
GPS_QA4_RTOL	500.0 (ft)
GPS_QA4_VTOL	5.0 (fps)
GPS UPDATE RATE	
T_GPS_CYCLE	40.0 (sec)

* Note the nav cycle rate is increased at MLS processing from every 3.84 seconds to 1.94 seconds. The numbers in brackets assume a 3.84 second nav cycle.

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TITLE

GPS SELF-TEST ANALYSIS

PURPOSE

To aid GNC console operators in analyzing the various MAGR-S self-tests. This SCP discusses the following:

- Power-up self-test
- Continuous Built-in self-test (Performance monitor)
- GPC commanded self-test
- Differences between the three types of self-test
- Troubleshooting methods

BACKGROUND

The Miniature Airborne GPS Receiver - Shuttle (MAGR-S) contains extensive logic and performance monitoring capability to determine the health of the receiver. This SCP outlines the various MAGR-S fault logs to aid in determining the type of failure recorded by the MAGR-S during its self-test and related recovery actions.

The MAGR-S is required to have fail safe circuits and devices which provide Built-In Test (BIT) and fault isolation. Failure of these circuits and/or devices are designed to not cause a critical failure or unsafe action.

PROCEDURE

POWER-UP SELF-TEST

The power-up self-test is performed by the MAGR-S every time the receiver is powered off for more than 30 seconds. If the GPS is powered off for less than 30 seconds, the receiver considers it a momentary power interrupt and when power is reapplied, picks right back up with its previous mode and does not perform a power up self-test or initialization. If the I/O RESET is established late (after approximately 40 seconds) the power-up self-test will not be seen by the GPC.

If the GPS demonstrates any unusual performance during initial power-up, a GPC commanded self-test should be performed at the earliest convenience to gain additional insight to the problem. The power-up self-test results are not sent to the GPC and may be missed on telemetry if the I/O RESET is performed late (after approximately 40 seconds after initial power-up).

CONTINUOUS BUILT-IN SELF-TEST

The continuous built-in self-test is called the Performance Monitor (PM) by Collins Avionics. The PM continuously checks numerous internal parameters to determine if the electronics are healthy. The continuous BIT is used to verify the operability of the GPS

subsystem and detect failures that could render the LRU inoperable or result in erroneous output.

In a case where the PM (continuous BIT) detects an internal fault, the GPS will declare itself failed by setting the Navigation Data Good Fail (DGF) flag. The new navigation data output associated with the DGF receiver will not update. Because GPS data is not being updated, it is not uncommon to see a QA2 failure (GPS to NAV miscompare).

Note that the DGF flag is set to a default “fail” on an OPS Mode transition. The DGF flag must have at least one cycle of valid data meeting the criteria noted below, before it is set “good” after the OPS transition. A DGF fail flag will not reset to its default value on an OPS 1 to 6 transition (it will retain its previous value for the OPS 1 to 6 transition). There is no provision for the crew to manually override a DGF failure.

The Navigation Data Good (DG) flag is set true when all of the following conditions are true:

1. Internal MAGR-S Kalman Filter estimated error < 1,000m. Note that this estimated Kalman Filter position error is different than the Figure of Merit (FOM).
2. The GPS receiver is in the NAV mode.
3. The Performance Monitor (PM) did not detect a critical failure in the previous second.
4. Time Tag processing is operating normally (the receiver state time tag is no more than 3.84 seconds older than the current navigation filter state time tag).

If a Data Good Failure (DGF) is set by the MAGR-S, the crew will see a down arrow “↓” in the DG FAIL status field on SPEC 55, and the text “DGF” in the STAT field on SPEC 55. A Data Good Fail (DGF) will downmode the affected receiver in the Selection Filter (SF) for the PASS and BFS (see Figure 1). No capability exist to manually override a DGF.

The PM runs in background continuously any time the MAGR-S is in the navigation submode. The continuous BIT function executes and reports its status to the MAGR-S at least once every 5 seconds.

If PM (continuous BIT) detects a fault for an extended period of time (5 minutes or more), the recommended recovery method would be to command a filter restart (RESTART) via SPEC 55, ITEM 20, 21, or 22 for GPS 1, 2, 3 respectively. It is not always required to perform manual troubleshooting for a DGF, since a DGF flag will clear if the GPS performs an automatic reset.

BFS supports the DGF indication on BFS SPEC 55 and uses the same signal from the MAGR-S to set the DGF fail flag in the STAT field on BFS SPEC 55. BFS does not have a manual restart capability on SPEC 55.

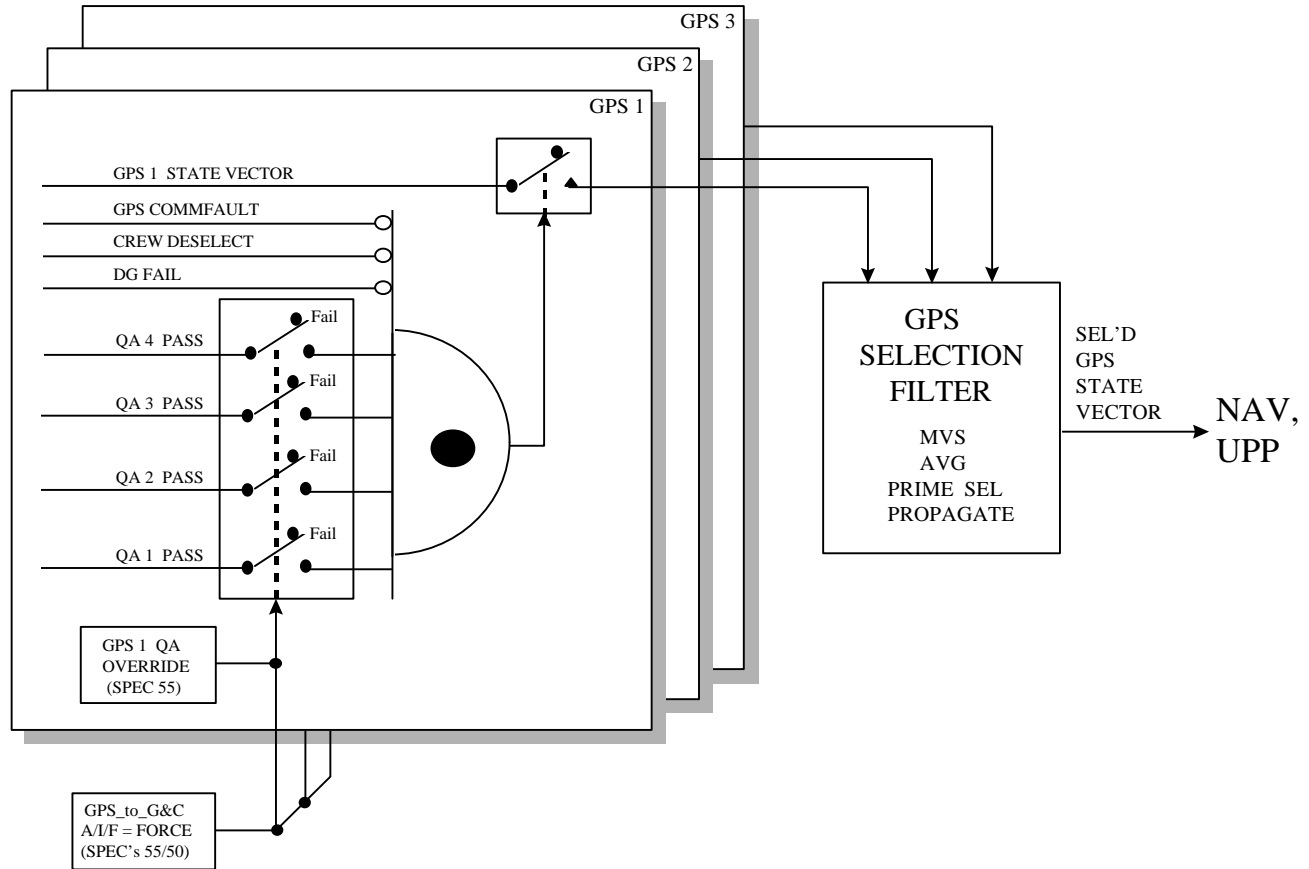


FIGURE 1 - GPS SELECTION FILTER CRITERIA

GPC COMMANDED SELF-TEST

A GPC commanded self-test can be issued via SPEC 55, ITEM 11, 12, 13, for GPS 1, 2, and 3 respectively. The self-test may be used to checkout the health of the receiver for entry, and/or to aid in troubleshooting a malfunctioning receiver.

When the self-test item entry is issued on SPEC 55, the crew has 6 seconds to change the command before self-test is entered. Once the self-test has begun, it continues to completion (which takes approximately 2 minutes). Any mode command issues after the start of self-test will be buffered by the GPC until the test is complete.

In OI-26B, the GPC does nothing with the GPC commanded self-test data. The self-test fault log words are downlisted at the completion of the self-test, with no provision for crew insight to pass/fail status.

In OI-27 the FSW has a single bit that sums all of the GPS fault logs and annunciates a failure to the crew if the fail bit is set. The crew has no insight as to what caused the failure, and the ground will have to analyze the self-test telemetry data to determine the cause of the fault. The self-test results are downlisted at the completion of the self-test.

In TEST mode, the GPS receiver performs full commanded self-test using the GPS R/P Built-In-Test (BIT) capability for fault isolation and identification. After the first 6 seconds in TEST mode, the receiver will mode itself to BIT during which period (about 2 minutes) there is no output from the receiver. All GPS receiver data, including the data header, received by the GPC will be zero. When BIT is complete, the receiver will again output valid header and data (BIT FAULT LOG WORDS). The result of the self-test (pass or fail) will be in the bit 4 of word 1 in the BIT Fault Log (Collins Fault Log Word 10) and will be available for crew display (OI-27 and subs only). Upon completion of the commanded BIT, the receiver will remain in TEST mode and will not automatically transition to INIT or NAV.

If the receiver is commanded to INIT or NAV during the first 6 seconds of TEST mode, the receiver will not complete the commanded BIT and will transition to the new commanded mode immediately. A new self-test can only be commanded when the GPS is in INIT or NAV. Reissuing a self-test command when a self-test is already in progress will result in an ILLEGAL ENTRY message.

Note that the GPC commanded self-test (BIT), is different than the Power-on self-test (BIT).

Valid self-test data will be sent to the GPC upon completion of the self-test.

BFS does not support a GPC commanded self-test capability.

HOW TO ANALYZE A GPC COMMANDED SELF-TEST:

The following pages outline the self-test data passed to the GPC at the completion of a GPC commanded self-test. For a nominal self test all 18 self-test fault log words on downlist will be 0000 in hexadecimal format. To analyze the self-test data, the GNC operator should pull all 18 fault log words on downlist from MEWS/ODRC in hexadecimal format. If any of the fault log words are not 0000, the non-zero fault log words should be compared with the following tables to determine the cause of the self-test failure.

RECOVERY METHODS:

The primary method to recover a GPS that has failed self-test (continuous, power-up, or GPC commanded) is to power cycle the GPS, making sure the GPS receiver is powered off for at least 30 seconds. Since the MAGR-S contains mostly electronics, recovery methods are limited.

If the GPS has a problem suggesting degraded performance associated with the PPS code or KYK-13 (encrypt key), purposely zeroizing the GPS should be considered in an attempt to recover the GPS in the less accurate SPS mode. To zeroize the GPS, the crew should be instructed to move the Encrypt switch to the zeroize position either while the GPS is powered, or to zeroize then power the GPS (if power is off).

GPC GPS I/O Data Format				
I/O Data Block Name	Size (Halfwords)	Message Contents		
		TEST Mode	INIT Mode	NAV Mode
GPC_TO_GPS_DATA_ONE(I)*		Message 1	Message 1	Message 1
GPC_TO_GPS_DATA_TWO(I)*		(None)***	Message 2	Message 3
GPS_TO_GPC_DATA_ONE(I)*		Message 4	Message 5	Message 6

* I = GPS receiver LRU number 1 to 3

*** In TEST mode, this second data block to be sent to the receiver will be all zero or blank. The header, first halfword to the GPC_TO_GPS_DATA_TWO data block, contains HEX '0000' will signal the receiver to ignore the rest of the data block message. Thus the GPS receiver will only use the first data block, GPC_TO_GPS_DATA_ONE, in test mode.

- Message 1 contains GPS Receiver Aiding data (position and velocity)
- Message 2 contains Antenna Correction data
- Message 3 contains GPS Receiver Aiding data (attitude and altitude)
- Message 4 contents are located below
- Message 5 contains GPS Receiver Initialization data
- Message 6 contains GPS Receiver Navigation data

Message 4 Format - GPS Receiver Testing Data					
Data Description	Halfword Number	Data Type	Units	Typical LSB	GPS SOP related parameters
Header (HEX 'DDDD')	1	BCH	-	-	-
GPS Receiver (I) navigation word	2-3	HMD	-	-	NAV_MODE_WORD(I)**
GPS receiver (I) test BIT fault log word ***	4-21	HMD	-	-	BIT_FAULT_LOG_WORD (I, 1 to 18)
GPS receiver (I) time totalizing meter (TTM) counter indicating total elapsed receiver operating time	22-23	FXU	hours	1	(not used)
GPS receiver (I) CPCI ID last four (ASCII) characters from the computer program configuration time	24-25	ASCII	-	-	(not used)
Spare	26-32	-	-	-	(not used)

** I = GPS receiver LRU number = 1 to 3

*** GPS receiver bit fault log word is not defined for single string GPS configuration

On SPEC 55, at the completion of the execution of a self-test, the parameter status indicator will provide the crew with a feedback of the pass/fail status of the GPC commanded self-test (for OI-27 and subs only). An up-arrow “↑” is displayed if the self-test passes, and a down-arrow “↓” is displayed if self-test fails. In OPS 9, the up or down-arrow will remain displayed in the status field until the GPS is moded to INIT or NAV. In OPS 9, when the GPS is moded from self-test to any other mode, the self-test status flag is blanked. In all OPS other than OPS 9, the up or down-arrow will remain next to the self-test field at the completion of the test, until the next self-test is issued regardless of the GPS mode. In all OPS other than OPS 9, the self-test status flag is blanked when a new self-test is issued, and remains blank until the completion of the self-test, at which time the new pass/fail status is displayed.

There are no changes to the self-test downlist data from OI-26B and OI-27, other than OI-27 added self-test fault log words for GPS 1 and 3.

Note that the Collins (MAGR-S) firmware considers Bit 0 to be the Most Significant Bit (MSB) and Bit 15 to be the Least Significant Bit (LSB).

The GPC extracts the self-test results for downlist from the GPS_TO_GPC_DATA_ONE word and downlists it in the BIT_FAULT_LOG_WORD.

Flags indicating that a GPS receiver's Built-In-Test is in progress are packed into the GPS_SOP_COLLECTION_WORD as follows:

BIT 9 of GPS_SOP_COLLECTION_WORD = GPS_BIT_SOP₁

BIT 10 of GPS_SOP_COLLECTION_WORD = GPS_BIT_SOP₂

BIT 11 of GPS_SOP_COLLECTION_WORD = GPS_BIT_SOP₃

Definition of GPS_SOP_COLLECTION_WORD

Definition of GPS_SOP_COLLECTION_WORD					
Parameter Description	MSID	Bit #	Bit Value	Meaning	Related Parameter
GPS 1 Built-In Test in progress flag	V93X1002X	9	1	GPS receiver 1 BIT in progress	GPS_BIT_SOP ₁
GPS 2 Built-In Test in progress flag	V93X1003X	10	1	GPS receiver 2 BIT in progress	GPS_BIT_SOP ₂
GPS 3 Built-In Test in progress flag	V93X1004X	11	1	GPS receiver 3 BIT in progress	GPS_BIT_SOP ₃

GPS TO GPC DATA PASSED DURING GPC COMMANDED SELF-TEST		
Contents for self-test results	Meaning	Halfword Number
HEADER_4(I), (DDDD)	N/A	1
NAV_MODE_WORD_RCVR(I)	N/A	2-3
FAULT_LOG_WORD_RCVR(I,1)	SRU/LRU Status Summary	4
FAULT_LOG_WORD_RCVR(I,2)	Conflicts while logging errors	5
FAULT_LOG_WORD_RCVR(I,3)	I/O Processor (IOP) software execution errors (Control 0)	6
FAULT_LOG_WORD_RCVR(I,4)	I/O Processor (IOP) software execution errors (Control 1)	7
FAULT_LOG_WORD_RCVR(I,5)	I/O Processor (IOP) software execution errors (Control 2)	8
FAULT_LOG_WORD_RCVR(I,6)	Navigation Processor (NP) software execution errors (Control 0)	9
FAULT_LOG_WORD_RCVR(I,7)	Navigation Processor (NP) software execution errors (Control 1)	10
FAULT_LOG_WORD_RCVR(I,8)	Navigation Processor (NP) software execution errors (Control 2)	11
FAULT_LOG_WORD_RCVR(I,9)	Low Power Time (LPT) status	12
FAULT_LOG_WORD_RCVR(I,10)	Tracking subsystem status (Control 0)	13
FAULT_LOG_WORD_RCVR(I,11)	Tracking subsystem status (Control 1)	14
FAULT_LOG_WORD_RCVR(I,12)	Tracking subsystem status (Control 2)	15
FAULT_LOG_WORD_RCVR(I,13)	Tracking subsystem status (Control 4)	16
FAULT_LOG_WORD_RCVR(I,14)	Interface Manager Software Errors	17
FAULT_LOG_WORD_RCVR(I,15)	Security Module Status (Control 0)	18
FAULT_LOG_WORD_RCVR(I,16)	Security Module Status (Control 1)	19
FAULT_LOG_WORD_RCVR(I,17)	MDM Interface Status (Control 0)	20
FAULT_LOG_WORD_RCVR(I,18)	MDM Interface Status (Control 1)	21
SET OPERATING TIME	Receiver Operating Time	22-23
CPCI ID	Computer Program Configuration Control ID	24-25

ACCESS TO SELF TEST DATA DURING OPS2:

Nominally GPS 1, 2 and 3 Self-test Fault Log Words 1-5 are the only available telemetry in the OPS2 downlist (GPS 1, 2 and 3 Fault Log Words 6-17 are not in the OPS2 downlist). Only in the OPS8 telemetry are all of the GPS 1, 2 and 3 Fault Log Words contained in the downlist. Tables 4.13-1- 4.13-3 provide the necessary HAL names and memory locations which can be used to access the data during OPS2. When submitting an SOP4.8 VPDR form from the FCOH, verification that the memory location in table 4.13-1, 2 or 3 is the correct address for the corresponding HAL variable is suggested. To assess the GPS Fault Log Words not available in OPS2 telemetry, perform a GPS Self-test per the procedure contained in the Generic Orbit OPS Checklist, then view the desired parameters on the variable downlist. By accessing the GPC's memory directly, the GPS self test data for each of the receivers is available at anytime in order to better quantify its health and operational status.

NOTE: All GPS Fault Log Words are reset to 0000 on an OPS 000 transition (i.e. OPS 2 to 8, 8 to 2, 2 to 3 or 3 to 2) and are not carried in the major function base.

**TABLE 4.13-1:
GPS1'S FAULT LOG HAL NAMES AND MEMORY LOCATIONS FOR OPS2**

				OPS 2
Self-Test Variable Name	MSID	Measurement Name	HAL NAME	Memory Address
FAULT_LOG_WORD_RCVR(1,1)	V74M4942P	GPS1 LOG WD1	CGPB_GPS_LOG_WD1\$(1;)	0D270 *
FAULT_LOG_WORD_RCVR(1,2)	V74M4943P	GPS1 LOG WD2	CGPB_GPS_LOG_WD2\$(1;)	0D271 *
FAULT_LOG_WORD_RCVR(1,3)	V74M4944P	GPS1 LOG WD3	CGPB_GPS_LOG_WD3\$(1;)	0D272 *
FAULT_LOG_WORD_RCVR(1,4)	V74M4945P	GPS1 LOG WD4	CGPB_GPS_LOG_WD4\$(1;)	0D273 *
FAULT_LOG_WORD_RCVR(1,5)	V74M4946P	GPS1 LOG WD5	CGPB_GPS_LOG_WD5\$(1;)	0D274 *
FAULT_LOG_WORD_RCVR(1,6)	V74M4947P	GPS1 LOG WD6	CGPB_GPS_LOG_WD6\$(1;)	0D275 *
FAULT_LOG_WORD_RCVR(1,7)	V74M4948P	GPS1 LOG WD7	CGPB_GPS_LOG_WD7\$(1;)	0D276 *
FAULT_LOG_WORD_RCVR(1,8)	V74M4949P	GPS1 LOG WD8	CGPB_GPS_LOG_WD8\$(1;)	0D277 *
FAULT_LOG_WORD_RCVR(1,9)	V74M4950P	GPS1 LOG WD9	CGPB_GPS_LOG_WD9\$(1;)	0D278 *
FAULT_LOG_WORD_RCVR(1,10)	V74M4951P	GPS1 LOG WD10	CGPB_GPS_LOG_WD10\$(1;)	0D279 *
FAULT_LOG_WORD_RCVR(1,11)	V74M4952P	GPS1 LOG WD11	CGPB_GPS_LOG_WD11\$(1;)	0D27A *
FAULT_LOG_WORD_RCVR(1,12)	V74M4953P	GPS1 LOG WD12	CGPB_GPS_LOG_WD12\$(1;)	0D27B *
FAULT_LOG_WORD_RCVR(1,13)	V74M4954P	GPS1 LOG WD13	CGPB_GPS_LOG_WD13\$(1;)	0D27C *
FAULT_LOG_WORD_RCVR(1,14)	V74M4955P	GPS1 LOG WD14	CGPB_GPS_LOG_WD14\$(1;)	0D27D *
FAULT_LOG_WORD_RCVR(1,15)	V74M4956P	GPS1 LOG WD15	CGPB_GPS_LOG_WD15\$(1;)	0D27E *
FAULT_LOG_WORD_RCVR(1,16)	V74M4957P	GPS1 LOG WD16	CGPB_GPS_LOG_WD16\$(1;)	0D27F *
FAULT_LOG_WORD_RCVR(1,17)	V74M4958P	GPS1 LOG WD17	CGPB_GPS_LOG_WD17\$(1;)	0D280 *
FAULT_LOG_WORD_RCVR(1,18)	V74M3098P	GPS1 LOG WD18	CGPB_GPS_LOG_WD18\$(1;)**	0D281 *

* NOTE: MEMORY ADDRESSES ARE FOR OPS2 OI-27, CONFIRM WITH DPS CORRECT MEMORY LOCATION

** NOTE: 18th WORD IS CODED THOUGH IT IS NOT USED AND SHOULD ALWAYS BE 0000

**TABLE 4.13-2:
GPS2'S FAULT LOG HAL NAMES AND MEMORY LOCATIONS FOR OPS2**

				OPS 2
Self-Test Variable Name	MSID	Measurement Name	HAL NAME	Memory Address
FAULT_LOG_WORD_RCVR(2,1)	V74M1942P	GPS2 LOG WD1	CGPB_GPS_LOG_WD1\$(2;)	0D282 *
FAULT_LOG_WORD_RCVR(2,2)	V74M1943P	GPS2 LOG WD2	CGPB_GPS_LOG_WD2\$(2;)	0D283 *
FAULT_LOG_WORD_RCVR(2,3)	V74M1944P	GPS2 LOG WD3	CGPB_GPS_LOG_WD3\$(2;)	0D284 *
FAULT_LOG_WORD_RCVR(2,4)	V74M1945P	GPS2 LOG WD4	CGPB_GPS_LOG_WD4\$(2;)	0D285 *
FAULT_LOG_WORD_RCVR(2,5)	V74M1946P	GPS2 LOG WD5	CGPB_GPS_LOG_WD5\$(2;)	0D286 *
FAULT_LOG_WORD_RCVR(2,6)	V74M1947P	GPS2 LOG WD6	CGPB_GPS_LOG_WD6\$(2;)	0D287 *
FAULT_LOG_WORD_RCVR(2,7)	V74M1948P	GPS2 LOG WD7	CGPB_GPS_LOG_WD7\$(2;)	0D288 *
FAULT_LOG_WORD_RCVR(2,8)	V74M1949P	GPS2 LOG WD8	CGPB_GPS_LOG_WD8\$(2;)	0D289 *
FAULT_LOG_WORD_RCVR(2,9)	V74M1950P	GPS2 LOG WD9	CGPB_GPS_LOG_WD9\$(2;)	0D28A *
FAULT_LOG_WORD_RCVR(2,10)	V74M1951P	GPS2 LOG WD10	CGPB_GPS_LOG_WD10\$(2;)	0D28B *
FAULT_LOG_WORD_RCVR(2,11)	V74M1952P	GPS2 LOG WD11	CGPB_GPS_LOG_WD11\$(2;)	0D28C *
FAULT_LOG_WORD_RCVR(2,12)	V74M1953P	GPS2 LOG WD12	CGPB_GPS_LOG_WD12\$(2;)	0D28D *
FAULT_LOG_WORD_RCVR(2,13)	V74M1954P	GPS2 LOG WD13	CGPB_GPS_LOG_WD13\$(2;)	0D28E *
FAULT_LOG_WORD_RCVR(2,14)	V74M1955P	GPS2 LOG WD14	CGPB_GPS_LOG_WD14\$(2;)	0D28F *
FAULT_LOG_WORD_RCVR(2,15)	V74M1956P	GPS2 LOG WD15	CGPB_GPS_LOG_WD15\$(2;)	0D290 *
FAULT_LOG_WORD_RCVR(2,16)	V74M1957P	GPS2 LOG WD16	CGPB_GPS_LOG_WD16\$(2;)	0D291 *
FAULT_LOG_WORD_RCVR(2,17)	V74M1958P	GPS2 LOG WD17	CGPB_GPS_LOG_WD17\$(2;)	0D292 *
FAULT_LOG_WORD_RCVR(2,18)	V74M1397P	GPS2 LOG WD18	CGPB_GPS_LOG_WD18\$(2;)**	0D293 *

* NOTE: MEMORY ADDRESSES ARE FOR OPS2 OI-27, CONFIRM WITH DPS CORRECT MEMORY LOCATION

** NOTE: THE 18TH WORD IS CODED THOUGH IT IS NOT USED AND SHOULD ALWAYS BE 0000

**TABLE 4.13-3:
GPS3'S FAULT LOG HAL NAMES AND MEMORY LOCATIONS FOR OPS2**

Self-Test Variable Name	MSID	Measurement Name	HAL NAME	OPS 2 Memory Address
FAULT_LOG_WORD_RCVR(3,1)	V74M5942P	GPS3 LOG WD1	CGPB_GPS_LOG_WD1\$(3;)	0D294 *
FAULT_LOG_WORD_RCVR(3,2)	V74M5943P	GPS3 LOG WD2	CGPB_GPS_LOG_WD2\$(3;)	0D295 *
FAULT_LOG_WORD_RCVR(3,3)	V74M5944P	GPS3 LOG WD3	CGPB_GPS_LOG_WD3\$(3;)	0D296 *
FAULT_LOG_WORD_RCVR(3,4)	V74M5945P	GPS3 LOG WD4	CGPB_GPS_LOG_WD4\$(3;)	0D297 *
FAULT_LOG_WORD_RCVR(3,5)	V74M5946P	GPS3 LOG WD5	CGPB_GPS_LOG_WD5\$(3;)	0D298 *
FAULT_LOG_WORD_RCVR(3,6)	V74M5947P	GPS3 LOG WD6	CGPB_GPS_LOG_WD6\$(3;)	0D299 *
FAULT_LOG_WORD_RCVR(3,7)	V74M5948P	GPS3 LOG WD7	CGPB_GPS_LOG_WD7\$(3;)	0D29A *
FAULT_LOG_WORD_RCVR(3,8)	V74M5949P	GPS3 LOG WD8	CGPB_GPS_LOG_WD8\$(3;)	0D29B *
FAULT_LOG_WORD_RCVR(3,9)	V74M5950P	GPS3 LOG WD9	CGPB_GPS_LOG_WD9\$(3;)	0D29C *
FAULT_LOG_WORD_RCVR(3,10)	V74M5951P	GPS3 LOG WD10	CGPB_GPS_LOG_WD10\$(3;)	0D29D *
FAULT_LOG_WORD_RCVR(3,11)	V74M5952P	GPS3 LOG WD11	CGPB_GPS_LOG_WD11\$(3;)	0D29E *
FAULT_LOG_WORD_RCVR(3,12)	V74M5953P	GPS3 LOG WD12	CGPB_GPS_LOG_WD12\$(3;)	0D29F *
FAULT_LOG_WORD_RCVR(3,13)	V74M5954P	GPS3 LOG WD13	CGPB_GPS_LOG_WD13\$(3;)	0D2A0 *
FAULT_LOG_WORD_RCVR(3,14)	V74M5955P	GPS3 LOG WD14	CGPB_GPS_LOG_WD14\$(3;)	0D2A1 *
FAULT_LOG_WORD_RCVR(3,15)	V74M5956P	GPS3 LOG WD15	CGPB_GPS_LOG_WD15\$(3;)	0D2A2 *
FAULT_LOG_WORD_RCVR(3,16)	V74M5957P	GPS3 LOG WD16	CGPB_GPS_LOG_WD16\$(3;)	0D2A3 *
FAULT_LOG_WORD_RCVR(3,17)	V74M5958P	GPS3 LOG WD17	CGPB_GPS_LOG_WD17\$(3;)	0D2A4 *
FAULT_LOG_WORD_RCVR(3,18)	V74M3108P	GPS3 LOG WD18	CGPB_GPS_LOG_WD18\$(3;)**	0D2A5 *

* NOTE: MEMORY ADDRESSES ARE FOR OPS2 OI-27, CONFIRM WITH DPS CORRECT MEMORY LOCATION

** NOTE: THE 18TH WORD IS CODED THOUGH IT IS NOT USED AND SHOULD ALWAYS BE 0000

POWER-ON SELF TEST FAULT LOG AND GPC COMMANDED SELF-TEST LOG

TLM MSID (Parent Word): V74M4942P; V74M1942P; V74M5942P			
GPC Parameter: BIT_FAULT_LOG_WORD(1,1; 2,1; 3,1)			
Collins Self-Test Fault Log Word Number: 10			
Contains: SRU/LRU Status Summary			
Device: BID'SRU'SUM			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	N/A	Spare
14	4000	N/A	Spare
13	2000	N/A	Spare
12	1000	N/A	Spare
11	0800	N/A	Spare
10	0400	N/A	Spare
9	0200	N/A	Spare
8	0100	N/A	Spare
7	0080	N/A	Spare
6	0040	N/A	Spare
5	0020	External Failure	KYK-13 LRU
4	0010	Fail	Receiver LRU ^{1,3}
3	0008	N/A	Memory Battery Low ²
2	0004	Fail	Signal Processor
1	0002	Fail	Processor - indicates the primary CPU has failed
0	0001	Fail	Power Supply - indicates the primary internal power supply has failed ³

NOTES:

- 1 BIT 4 (HEX 0010) - Indicates a master Receiver Processor Unit (RPU) Failure. This Bit causes the "GPS X FAIL" GAX message to be annunciated to the crew on the Fault Summary Line.
- 2 BIT 3 (HEX 0008) - Indicates that the MAGR-S internal battery power has failed due to low voltage output. If primary power (FPC X) is removed from the receiver, the GPS will lose all current almanac and state vector information stored in memory and will default to the EEPROM for almanac and state information. Loss of current almanac data could result in a cold-start of the receiver with extended time required to acquire 4 satellites (up to 10 minutes). Loss of internal battery power while the receiver is powered off will also result in loss of the Encrypt Key Nav message essentially resulting in a zeroize of the receiver. If a GPS power-down is required, this receiver should be considered to be left powered on, because a power-off will result in a full cold-start and downmode to SPS. The battery low indication is set by the PM if the battery voltage is less than or equal to 3.3 VDC and is reset if the battery voltage is greater than or equal to 3.4 VDC.
- 3 BIT 4 (HEX 0010) and BIT 0 (HEX 0001) of BIT_FAULT_LOG_WORD1 are reversed in the OI-26B software release. Impacts could result in false RPF indication on SPEC 55. The OI-27 release is correct in flight software and the above table is valid as written.

TLM MSID (Parent Word): V74M4943P; V74M1943P; V74M5943P			
GPC Parameter: BIT_FAULT_LOG_WORD(1,2; 2,2; 3,2)			
Collins Self-Test Fault Log Word Number: 6			
Contains: Conflicts while logging errors			
Device: BID'LOG'FAIL			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	Info	Device out of range (unknown device)
14	4000	N/A	Control out of range for device BID'LRU'SUM
13	2000	Info	Control out of range for device BID'INT'PROC
12	1000	Info	Control out of range for device BID'REC'PROC
11	0800	N/A	Control out of range for device BID'SRU'SUM
10	0400	Info	Control out of range for device BID'LPTS
9	0200	Info	Control out of range for device BID'INSRU
8	0100	N/A	Control out of range for device BID'LOG'FAIL
7	0080	N/A	Control out of range for device BID'SW'VERS
6	0040	N/A	Control out of range for device BID'PPSSM
5	0020	Info	Control out of range for device BID'TRACK'SUB
4	0010	Info	Control out of range for device BID'AE
3	0008	Info	Control out of range for device BID'IM
2	0004	N/A	Control out of range for device BID'CPCI
1	0002	Info	Control out of range for device BID'CDU1
0	0001	N/A	Reserved

NOTE:

This Fault log contains information about various software processing errors. Details of the failure should be sought out in the following pages of fault logs.

TLM MSID (Parent Word): V74M4944P; V74M1944P; V74M5944P			
GPC Parameter: BIT_FAULT_LOG_WORD(1,3; 2,3; 3,3)			
Self-Test Fault Log Word Number: 13			
Contains: I/O Processor software execution errors			
Device: BID'INT'PROC			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	Fail	Type Conversion
14	4000	Fail	User trap 7
13	2000	Fail	LENV in user PSD = 0
12	1000	Fail	Illegal header
11	0800	Fail	Stack underflow
10	0400	Fail	Stack overflow
9	0200	Fail	Non-local search error
8	0100	Fail	Illegal instruction
7	0080	Fail	Outer procedure return
6	0040	Fail	RLS by wrong task (task already in event queue)
5	0020	Fail	Resource assigned (task already in time queue)
4	0010	Fail	Bad resource ID (start time too short)
3	0008	Fail	Cycle overlap
2	0004	Fail	No more PSD memory available
1	0002	Fail	Task not scheduled or divide by zero
0	0001	Fail	Task scheduled or arithmetic overflow

NOTE:

This fault log indicates an internal software I/O processing failure.

TLM MSID (Parent Word): V74M4945P; V74M1945P; V74M5945P			
GPC Parameter: BIT_FAULT_LOG_WORD(1,4; 2,4; 3,4)			
Self-Test Fault Log Word Number: 14			
Contains: I/O Processor Software Execution Errors			
Device: BID'INT'PROC			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	Fail	EXEC bus error to AAMP2
14	4000	Fail	EXEC AAMP2 BIT fault
13	2000	Fail	EXEC trap 6
12	1000	Fail	EXEC illegal header
11	0800	Fail	EXEC stack underflow
10	0400	Fail	EXEC stack overflow
9	0200	Fail	EXEC non-local search error
8	0100	Fail	EXEC illegal instruction
7	0080	Fail	Halt instruction
6	0040	Fail	Bus error
5	0020	Fail	Bus timeout
4	0010	Fail	Negative SQRT operand
3	0008	Fail	Break point
2	0004	Fail	Exponent overflow
1	0002	N/A	Reserved
0	0001	Fail	T-1000 time interrupt difference between interrupts is greater than tolerance limits

NOTE:

This fault log indicates an internal software I/O processing failure.

TLM MSID (Parent Word): V74M4946P; V74M1946P; V74M5946P			
GPC Parameter: BIT_FAULT_LOG_WORD(1,5; 2,5; 3,5)			
Self-Test Fault Log Word Number: 15			
Contains: I/O Processor Software Execution Error			
Device: BID'INT'PROC			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	Fail	Unknown trap or exception detected
14	4000	Fail	Trap procid is zero
13	2000	Fail	Interrupt procid is zero
12	1000	Fail	Non-mask procid is zero
11	0800	Fail	Bus error procid is zero
10	0400	Fail	EXEC procid is zero
9	0200	Fail	Other processor failed to ACK interprocessor interrupt
8	0100	Fail	Unable to clear interprocessor interrupt
7	0080	Fail	Interprocessor interrupt not received from other processor
6	0040	Fail	Processors failed to sync
5	0020	Fail	Interprocessor wrap processors failed to sync
4	0010	Fail	Number of T-20's occurring for each T-1000 is not 50
3	0008	Fail	Number of T-10's occurring for each T-1000 is not 100
2	0004	Fail	No T-1000 interrupt detected
1	0002	Fail	No T-20 interrupt detected
0	0001	Fail	No T-10 interrupt detected

NOTE:

This fault log indicates an internal software I/O processing failure.

TLM MSID (Parent Word): V74M4947P; V74M1947P; V74M5947P			
GPC Parameter: BIT_FAULT_LOG_WORD(1,6; 2,6; 3,6)			
Self-Test Fault Log Word Number: 16			
Contains: NAV Processor Software Execution Errors			
Device: BID'REC'PROC			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	Fail	Type conversion
14	4000	Fail	User trap 7
13	2000	Fail	LENV in user PSD = 0
12	1000	Fail	Illegal header
11	0800	Fail	Stack underflow
10	0400	Fail	Stack overflow
9	0200	Fail	Non-local search error
8	0100	Fail	Illegal instruction
7	0080	Fail	Outer procedure return
6	0040	Fail	RLS by wrong task (task already in event queue)
5	0020	Fail	Resource assigned (task already in time queue)
4	0010	Fail	Bad resource ID (start time too short)
3	0008	Fail	Cycle overlap
2	0004	Fail	No more PSD memory available
1	0002	Fail	Task not scheduled or divide by zero
0	0001	Fail	Task scheduled or arithmetic overflow

NOTE:

This fault log indicates an internal navigation software processing failure.

TLM MSID (Parent Word): V74M4948P; V74M1948P; V74M5948P GPC Parameter: BIT_FAULT_LOG_WORD(1,7; 2,7; 3,7) Self-Test Fault Log Word Number: 17 Contains: NAV Processor Software Execution Errors Device: BID'REC'PROC			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	Fail	EXEC bus error on AAMP2
14	4000	Fail	EXEC AAMP3 BIT fault
13	2000	Fail	EXEC trap 6
12	1000	Fail	EXEC illegal header
11	0800	Fail	EXEC stack underflow
10	0400	Fail	EXEC stack overflow
9	0200	Fail	EXEC non-local search error
8	0100	Fail	EXEC illegal instruction
7	0080	Fail	HALT instruction
6	0040	Fail	Bus error
5	0020	Fail	Bus timeout
4	0010	Fail	Negative SQRT operand
3	0008	Fail	Break point
2	0004	Fail	Exponent overflow
1	0002	Fail	Reserved
0	0001	Fail	T-1000 time interrupt difference between interrupts is greater then tolerance limits

NOTE:

This fault log indicates an internal navigation software processing failure.

TLM MSID (Parent Word): V74M4949P; V74M1949P; V74M5949P GPC Parameter: BIT_FAULT_LOG_WORD(1,8; 2,8; 3,8) Self-Test Fault Log Word Number: 18 Contains: NAV Processor Software Execution Errors Device: BID'REC'PROC			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	Fail	Unknown trap or exception detected
14	4000	Fail	Trap procid is zero
13	2000	Fail	Interrupt procid is zero
12	1000	Fail	Non-mask procid is zero
11	0800	Fail	Bus error procid is zero
10	0400	Fail	EXEC procid is zero
9	0200	Fail	Other processor failed to ACK interprocessor interrupt
8	0100	Fail	Unable to clear Interprocessor interrupt
7	0080	Fail	Interprocessor interrupt not received from other processor
6	0040	Fail	Processors failed to sync
5	0020	Fail	Interprocessor wrap processors failed to sync
4	0010	Fail	Number of T-20's occurring for each T-1000 is not 50
3	0008	Fail	Number of T-10's occurring for each T-1000 is not 100
2	0004	Fail	No T-1000 interrupt detected
1	0002	Fail	No T-20 interrupt detected
0	0001	Fail	No T-10 interrupt detected

NOTE:

This fault log indicates an internal navigation software processing failure.

TLM MSID (Parent Word): V74M4950P; V74M1950P; V74M5950P			
GPC Parameter: BIT_FAULT_LOG_WORD(1,9; 2,9; 3,9)			
Self-Test Fault Log Word Number: 19			
Contains: LPTS (Low Power Time Source) Status			
Device: BID'LPTS			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	Fail	LPTS test task did not complete
14	4000	Info	Memory battery low
13	2000	N/A	Spare
12	1000	N/A	Spare
11	0800	N/A	Spare
10	0400	N/A	Spare
9	0200	N/A	Spare
8	0100	N/A	Spare
7	0080	N/A	Spare
6	0040	Fail	Standard deviation of LPTS intervals greater than 1 usec/sec
5	0020	Fail	Maximum/minimum interval greater than 1 +/- 0.01 sec
4	0010	Fail	Average LPTS interval greater than 1000000 +/- 800 usec
3	0008	Fail	Consecutive perfect LPTS intervals occurring between more than two consecutive interrupts
2	0004	Fail	LPTS time tag not incrementing (negative time difference between success LPTS interrupts)
1	0002	Fail	LPTS count not incrementing by a positive integer value of 1
0	0001	Fail	No LPTS interrupts after 1.2 sec wait

NOTE:

The fault log word outlines failures in the Low Time Power Source (LPTS) that will result in failure of the GPS.

TLM MSID (Parent Word): V74M4951P; V74M1951P; V74M5951P			
GPC Parameter: BIT_FAULT_LOG_WORD(1,10; 2,10; 3,10)			
Self-Test Fault Log Word Number: 23			
Contains: Tracking Subsystem Status			
Device: BID'TRACK'SUB			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	N/A	Spare
14	4000	None	AE4 *
13	2000	Fail	AE1 RF Amplifier
12	1000	Fail	AE1 Controller/PM
11	0800	Fail	AE1 Translator
10	0400	Fail	AE1 Power Supply
9	0200	N/A	Spare
8	0100	N/A	Spare
7	0080	N/A	Spare
6	0040	N/A	Spare
5	0020	N/A	Spare
4	0010	N/A	Spare
3	0008	Fail	Navigation Processor
2	0004	Fail	Frequency Standard
1	0002	Fail	Signal Processor
0	0001	Fail	UE Power Supply

NOTE:

- BIT 14 (HEX 4000) - This bit is not used by the MAGR-S. The bit was previously used for the GPS DFT flights in OI-22 and 23 using the 3M GPS receiver, concerning an external pre-amplifier which is not used by the MAGR-S.

TLM MSID (Parent Word): V74M4952P; V74M1952P; V74M5952P GPC Parameter: BIT_FAULT_LOG_WORD(1,11; 2,11; 3,11) Self-Test Fault Log Word Number: 24 Contains: Tracking Subsystem Status Device: BID'TRACK'SUB			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15 - 0	8000-0001		Tracking subsystem - pointer to first error encountered in tracking subsystem diagnostics

TLM MSID (Parent Word): V74M4953P; V74M1953P; V74M5953P GPC Parameter: BIT_FAULT_LOG_WORD(1,12; 2,12; 3,12) Self-Test Fault Log Word Number: 25 Contains: Tracking Subsystem Status Device: BID'TRACK'SUB			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	Fail	L1 AGC (Automatic Gain Control) out of tolerance - quiet mode
14	4000	Fail	VCO (Voltage Control Oscillator) tune voltage out of tolerance - Strong signal mode
13	2000	Fail	VCO (Voltage Control Oscillator) tune voltage out of tolerance - normal mode
12	1000	Fail	PM fault log indicates frequency standard out of frequency
11	0800	N/A	Reserved
10	0400	N/A	Reserved
9	0200	N/A	Reserved
8	0100	Fail	Communication error between processor and the pre-processor
7	0080	Fail	Pre-processor failed self-test
6	0040	Fail	Pre-processor is locked out from Dual Port memory RAM
5	0020	Fail	Dual port Memory RAM failed sensitivity test
4	0010	Fail	Dual port Memory RAM failed addressability test
3	0008	Fail	Pre-processor failed to lock itself out from the Dual Port Memory RAM
2	0004	Fail	Signal processor fail discrete malfunctioned (discrete did not clear when commanded)
1	0002	Fail	Signal processor fail discrete malfunctioned (discrete not set when commanded)
0	0001	Fail	Pre-processor failed to transition to Test mode when commanded

TLM MSID (Parent Word): V74M4954P; V74M1954P; V74M5954P			
GPC Parameter: BIT_FAULT_LOG_WORD(1,13; 2,13; 3,13)			
Self-Test Fault Log Word Number: 27			
Contains: Tracking Subsystem Status			
Device: BID'TRACK'SUB			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	Fail	Complex weight number 3 test failure - fail RF module
14	4000	Fail	Complex weight number 4 test failure - fail RF module
13	2000	Fail	Complex weight number 5 test failure - fail RF module
12	1000	Fail	Complex weight number 6 test failure - fail RF module
11	0800	Fail	Complex attenuation test failed - fail RF module
10	0400	Fail	Some of the complex weights failed - fail RF module
9	0200	Fail	All of the complex weights failed - fail RF module
8	0100	Fail	None of the complex weight tests failed - fail RF module
7	0080	Fail	Some (but not all) complex weight tests failed - fail controller/PM
6	0040	Fail	Fail electronic frequency converter
5	0020	Fail	Fail electronic frequency converter
4	0010	Fail	AE1 reference LNA test failure - fail RF module
3	0008	Fail	Any of the RAM, ROM, or integrator test failed - fail controller/PM
2	0004	Fail	AE1 20us integrator test failed - fail controller/PM
1	0002	Fail	AE1 ROM checksum failure - fail controller/PM
0	0001	Fail	AE1 RAM failure - fail controller/PM

TLM MSID (Parent Word): V74M4955P; V74M1955P; V74M5955P			
GPC Parameter: BIT_FAULT_LOG_WORD(1,14; 2,14; 3,14)			
Self-Test Fault Log Word Number: 36			
Contains: Interface Manager Software Errors			
Device: BID'IM			
BIT NO.	HEXIDE C MASK	SEVERIT Y	DESCRIPTION
15	8000	N/A	Reserved for future expansion
14	4000	N/A	Reserved for future expansion
13	2000	Fail	An interface descriptor tried to define an interrupt handler for an invalid interrupt handler
12	1000	Fail	More than one interface descriptor tried to define an interrupt handler for the same interrupt
11	0800	Fail	An interface descriptor tried to define an unknown task type
10	0400	N/A	Reserved for future expansion
9	0200	N/A	Reserved for future expansion
8	0100	N/A	Reserved for future expansion
7	0080	N/A	Reserved for future expansion
6	0040	N/A	Reserved for future expansion
5	0020	Fail	An EXEC error was detected when attempting to SCHEDULE a task
4	0010	Fail	The Interface Manager stack size was not large enough to fulfill all task stack requests
3	0008	N/A	Reserved for future expansion
2	0004	N/A	Reserved for future expansion
1	0002	N/A	Reserved for future expansion
0	0001	N/A	Reserved for future expansion

TLM MSID (Parent Word): V74M4956P; V74M1956P; V74M5956P			
GPC Parameter: BIT_FAULT_LOG_WORD(1,15; 2,15; 3,15)			
Self-Test Fault Log Word Number: 48			
Contains: Security Module Status			
Device: BID'PPSSM			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	N/A	Spare
14	4000	Fail	PPS-SM (Security Module) checksum failure
13	2000	Fail	Shared RAM failure from the PPS-SM (Security Module) side
12	1000	Fail	Internal RAM failure
11	0800	Fail	Special function register failure
10	0400	N/A	Spare
9	0200	N/A	Spare
8	0100	N/A	Spare
7	0080	Fail	Zeroize switch stuck *
6	0040	Fail	KYK clock not high
5	0020	Fail	KYK clock stuck
4	0010	N/A	Spare
3	0008	N/A	Spare
2	0004	N/A	Spare
1	0002	N/A	Spare
0	0001	Fail	Bad UE command sent to the PPS-SM

NOTE:

* BIT 7 (HEX 0080) - Indicates that a continuous current has been detected in the zeroize switch. The GPS may be stuck in the INIT mode, since a zeroize causes the GPS to re-initialize.

TLM MSID (Parent Word): V74M4957P; V74M1957P; V74M5957P GPC Parameter: BIT_FAULT_LOG_WORD(1,16; 2,16; 3,16) Self-Test Fault Log Word Number: 49 Contains: Security Module Status Device: BID'PPSSM			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000	Fail	PPS-SM present in a unSA/A-S receiver
14	4000	Fail	PPS-SM testing did not complete in the allotted time
13	2000	N/A	Spare
12	1000	N/A	Spare
11	0800	N/A	Spare
10	0400	N/A	Spare
9	0200	N/A	Spare
8	0100	Fail	No source word for the Interrupt
7	0080	N/A	Spare
6	0040	N/A	Spare
5	0020	Fail	Shared RAM failure from the UE side
4	0010	Fail	UE RAM failure, False interrupt occurred. PPS-SM source word equaled zero following NAV processor receipt of KYK-INTF
3	0008	Fail	Bus timeout accessing PPS-SM RAM
2	0004	Fail	Time out accessing PPS-SM (assumed not present)
1	0002	N/A	Spare
0	0001	N/A	Spare

TLM MSID (Parent Word): V74M4958P; V74M1958P; V74M5958P GPC Parameter: BIT_FAULT_LOG_WORD(1,17; 2,17; 3,17) Self-Test Fault Log Word Number: ZEROED FAULT LOG WORD Contains: Device:			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000		undefined
14	4000		
13	2000		
12	1000		
11	0800		
10	0400		
9	0200		
8	0100		
7	0080		
6	0040		
5	0020		
4	0010		
3	0008		
2	0004		
1	0002		
0	0001		

TLM MSID (Parent Word): V74M3098P; V74M1397P; V74M3108P GPC Parameter: BIT_FAULT_LOG_WORD(1,18; 2,18; 3,18) Self-Test Fault Log Word Number: ZEROED FAULT LOG WORD Contains: Device:			
BIT NO.	HEXIDEC MASK	SEVERITY	DESCRIPTION
15	8000		undefined
14	4000		
13	2000		
12	1000		
11	0800		
10	0400		
9	0200		
8	0100		
7	0080		
6	0040		
5	0020		
4	0010		
3	0008		
2	0004		
1	0002		
0	0001		

REFERENCES

Collins Avionics Specification for MAGR-S BIT Fault Logs, CSCI 613-9565-002, dated 5/10/96.

FSSR-14, Volume 1, Navigation Aids Subsystem Operating (SOP) System, OI-26B Version dated September 19, 1996.

FSSR-20, Volume 1, Displays and Controls, OI-26B Version dated September 19, 1997.

FSSR-14, Volume 1, Navigation Aids Subsystem Operating (SOP) System, OI-27 Version dated April 10, 1997.

FSSR-20, Volume 1, Displays and Controls, OI-27 Version dated April 10, 1997.

Liebman, Ed, Guidance and Control Systems Engineer, Mission Operations Directorate.

MAGR-S GPS Systems Requirements Document, SSD-94D0096 Rev B, dated 10/9/98.

MAGR-S Interface Control Document (ICD-MAGR-S-002), Revision B, Collins Avionics, Dated March 15, 1998.

Nuss, Ray, GPS Subsystem Manager, Engineering Directorate.

Sarafin, Michael L., Guidance and Control Systems Engineer, Mission Operations Directorate.

TITLE

GPS ENCRYPT KEY/ZEROIZE OPERATIONS

PURPOSE

To aid GNC console operators in troubleshooting GPS encrypt key anomalies and zeroize operations. This SCP discusses the following:

- Summarizes encrypt key operations
- Identifies impacts to encrypt key failures
- Recommends workarounds to encrypt key failures
- Summarizes the information contained in the PPS_STATUS_WORD

BACKGROUND

The Miniature Airborne GPS Receiver - Shuttle (MAGR-S) utilizes encrypted GPS satellite signals provided by the Department of Defense (DoD). In order to use the encrypted signals, the DoD requires an encrypt key to enable the GPS receiver to decode the encrypted signals. The MAGR-S uses a Group Unique Key (GUK), sometimes referred to as a yearly encrypt key. The device used to load the encrypt key is called the KYK-13 (pronounced "kick-13") key loader. Proper loading of the encrypt key during prelaunch operations allows the MAGR-S to receive satellite signals using Y-code tracking in the PPS submode. Without the encrypt key, the MAGR-S would only be able to track satellites in the SPS mode using C/A and/or P-code.

A number of parameters are downlisted that enable the ground to monitor encrypt key operations and status. The encrypt key parameters are contained in one downlist word per GPS, called the PPS_STATUS_WORD.

PROCEDURE

ENCRYPT KEY OPERATIONS

Prelaunch for each flight, a new GUK encrypt key will be loaded into each MAGR-S. The key and PPS operations will have already been checked out prior to GNC manning in the prelaunch timeframe. Prelaunch encrypt key loading operations begin with zeroizing the receiver, which will delete any current or expired KYK-13 information stored in memory. The next step is to load the future key (if available) to ensure it was loaded into volatile memory before the current key is loaded. The future key is loaded first because the MAGR-S only shows the status of the current key loaded. So by loading the future key first it is possible to confirm that the future key was properly loaded, and that the receiver will know it is a GUK user, and that the future key passes the parity check. The future key will not get satellite encrypt verification because it isn't the current daily key. MAGR-S is capable of storing a maximum of 2 yearly keys in memory (current & future). The future key may not always be available (not yet released by the DoD), so it may not always be stored in memory.

During the flight, at the end of each GPS day (approximately two hours prior to GPS midnight or GMT 2400 hr.), the MAGR-S will internally download a new key for the next day's operations.

Only a single satellite is required for tracking in Nav Mode to download a new encrypt key and almanac (key & almanac are downloaded simultaneously). If the GPS is powered at the time the download occurs, the MAGR-S will continue normal PPS operations and download the new key in the background (transparent to the user).

If the MAGR-S is unpowered at the time the daily key expires, then the next time the MAGR-S is powered, it will power up through power-up self-test, INIT, and NAV normally. Once it gets to the navigation submode, it will begin tracking in SPS mode, until the new key has completed the download. When downloading the new key, invalid key messages are expected (Bit 3: set to 1). If the encrypt key expired while the receiver was powered down, the user should expect to see the GPS in SPS mode for up to 15 minutes with C/A tracking operations prior to moding to PPS mode with Y-code tracking.

GNC monitors the encrypt key (PPS_STATUS_WORD) on ELOG. If an event occurs relating to the encrypt key, it will be logged by ELOG. To determine the exact source of the change in encrypt status, the GNC operator should pull MEWS/ODRC data to determine what changed. Once the MEWS/ODRC data confirms a change in the PPS_STATUS_WORD, it should be compared to the PPS_STATUS_WORD summary at the end of this SCP to determine the impact (if any). Hexadecimal tabular format is recommended.

ZEROIZE OPERATIONS

To preclude unauthorized users from obtaining encrypted GPS data, the MAGR-S employs a zeroize function which erases all the encrypted variables in memory and re-initializes the MAGR-S in the SPS navigation submode. The zeroize switch should be used any time the orbiter performs an abort and lands in a foreign country or in the United States at a non-DoD secure facility. Nominal landings at KSC, Edwards, or Northrup do not require a zeroize. Landings at any site other than KSC, Edwards, or Northrup requires a zeroize to be performed for all three GPS receivers.

When the MAGR-S receives the zeroize command, it erases all of the encrypted variables in the PPS Security Module (PPS-SM) including PPS calculated position, velocity, and time (state vector).

Once the encrypted variables are deleted, the MAGR-S reinitializes itself with a new state vector and modes back into the GPC commanded submode. If the MAGR-S is not under GPC control at the time the zeroize occurs, it will perform reinitialization, and then mode itself directly into the navigation submode. Once the zeroized GPS is in NAV mode, it will utilize the SPS submode only with C/A and P-code tracking (no Y-code tracking).

When the MAGR-S does the reinitialization after a zeroize, it loses track of all satellites it had been previously tracking and must reacquire the satellites in view.

The nominal FOM corresponding to SPS accuracies will typically be about FOM = 4 or 5. SPS operations will likely cause a QA1 (FOM <6) or a QA2 failure to occur due to the GPS errors. In this case, QA OVERRIDE should be invoked to allow the selection filter to use the GPS data with the SPS errors. Although, use of QA OVERRIDE will not protect failed QA data from entering the selection filter, at the 3-level the SPS data will not be selected by the selection filter for navigation (it will be Mid-Value Selected (MVS'ed) out).

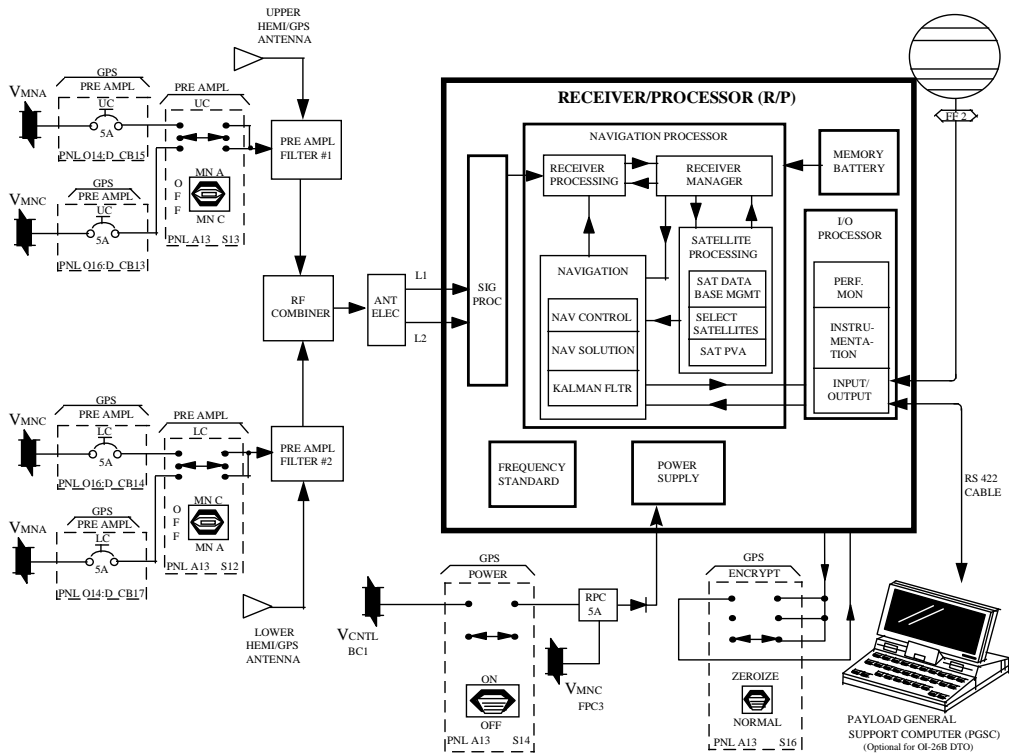
The diagrams on the next pages show the three string GPS and single string GPS switch configurations, including the zeroize switch. Note that the zeroize switch is a guarded switch.

The receiver contains a Precise Positioning Service - Security Module (PPS-SM) that stores all keys entered. The PPS-SM eliminates the need for key protection (e.g. a Special Storage Key) and also protects the cryptographic algorithms. It is the PPS-SM memory variables that are erased when a zeroize occurs.

If a GPS is zeroized (for between 0.1 and 4.5 seconds*), inadvertently or deliberately, the zeroize pin connector will short out, and the GPS will downmode to SPS the next time it is powered, or immediately if it is currently powered. There is no way to recover from a zeroize, since it requires ground support equipment (shuttle is not authorized to carry the KYK-13 key loader in flight).

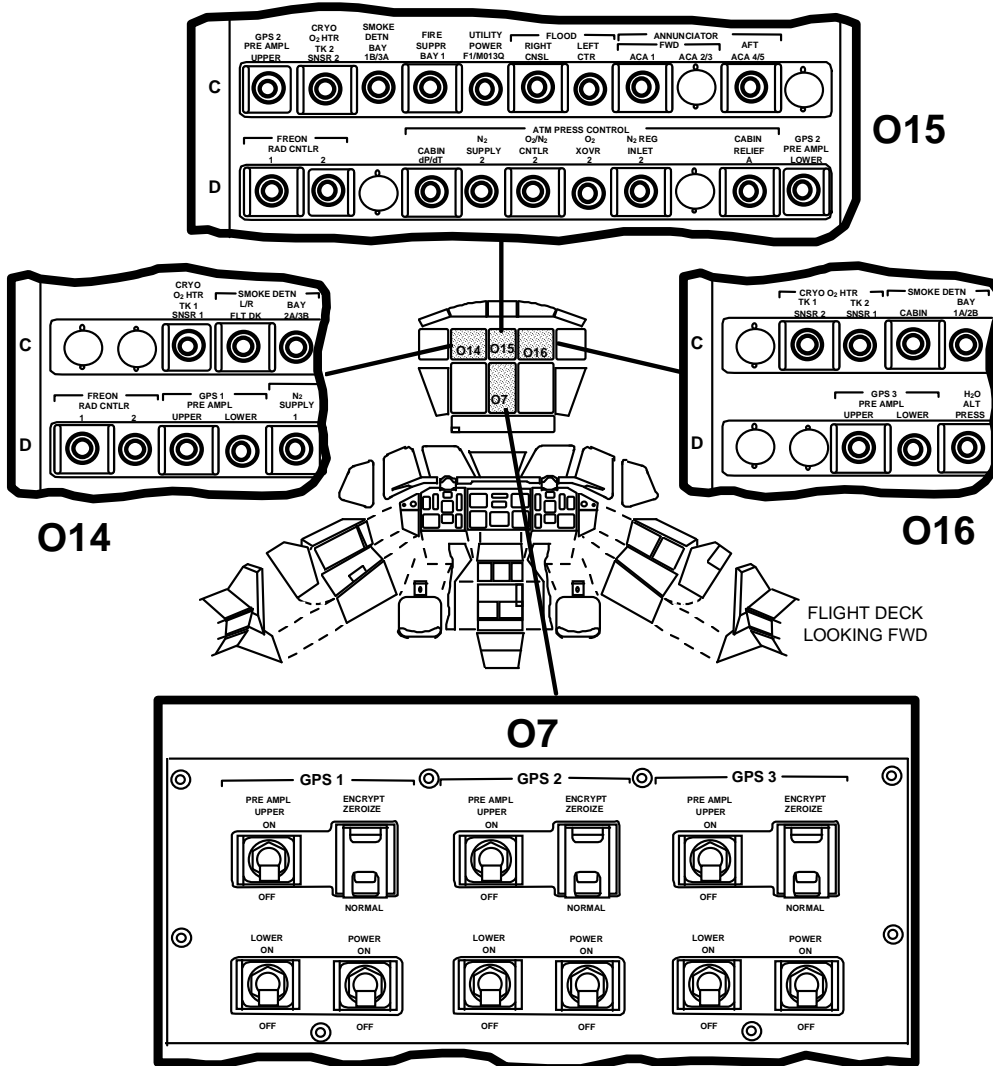
*NOTE: According to engineering, tests show that a bump into the zeroize position for the minimum amount of time possible, will zeroize the unit. However, the encrypt switch was "bumped" to zeroize for an unknown length of time during the TCDT for STS-107, and the MAGR did not zeroize.

The GPS tracking capability will be degraded due to SPS errors if SA effects are present. The crew would likely see additional warnings which would require manual override to use GPS, but otherwise GPS is certified during entry with SPS errors (refer to the GPS Systems Briefs for PPS and SPS error budgets).



SINGLE STRING GPS PANEL CONFIGURATION - This configuration applies to OV-103 and OV-104 for switch locations. Note Encrypt Switch located on Panel A13. Power configuration may vary.

3-String GPS Panel Mods



3 STRING GPS CONFIGURATION - THIS CONFIGURATION APPLIES TO OV-105.

IMPACTS TO ENCRYPT KEY FAILURES

If the GPS has lost encryption capability, the GPS processor will navigate in the SPS submode, with all channels in C/A or P tracking (no Y-tracking). If Selective Availability (SA) effects are present, GPS data will be degraded from the PPS level accuracies. SA effects are the DoD's method of deliberately degrading the state vector produced by the GPS for unauthorized (non-PPS) users of the NAVSTAR system. If the DoD does not employ SA effects, a PPS receiver will still have PPS accuracies. The DoD does not notify users if SA effects are in use, but we should assume that they are in effect.

SPS tracking results in roughly 3 times the one-sigma error for PPS tracking (reference the GPS Systems Brief for details on SPS error budget).

WORKAROUNDS TO ENCRYPT KEY FAILURES

If the GPS has been zeroized, no workaround/IFM capability exists. The GPS will continue to operate in SPS mode with a potentially degraded state vector accuracy. This is not a significant concern since the Shuttle's navigation system is certified to land with SPS accuracies, although the crew would likely see additional warnings which would require manual override to use GPS. Reload of an encrypt key is not ever planned to be performed on-orbit, including IFM capabilities for security reasons.

In-flight failures of the encrypt key may result in a loss of PPS tracking capability. Troubleshooting is limited to a power-cycle of the receiver, performing a commanded self test, and a deliberate zeroize of the GPS.

PPS_STATUS_WORD SUMMARY

The PPS Status word is a 16 bit word downlisted to provide insight to the encrypt key (PPS submode). The following table defines the PPS_STATUS_WORD outputs contained in the downlist. Nominal PPS mode will have a PPS_STATUS_WORD of 8881.

DEFINITION OF PPS_STATUS_WORD - MSID V74M4459P (1459P), (3459P) for GPS 1, (2), (3)			
BIT PARAMETER	BIT #	BIT VALUE	DEFINITION
Daily Key in Use (Verified) V74X4467B, (1467B), (3476B)	0	1 Nominal PPS Mode	Key for the current day has been obtained from and verified against the Satellite Vehicle (SV) subframe data. Guk user mode and daily key has been obtained from satellite.
		0 SPS Mode	The receiver does not contain a verified key for the current day. Could be due to the fact the receiver has been zeroized or hasn't downloaded the daily key yet. (Possibly due to power off)
Daily Key in Use (Unverified) V74X4468B, (1468B), (3468B)	1	1 SPS Mode	The receiver is waiting for subframe data and does not contain a key for the current day. Receiver still needs to download key for the day.
		0 Nominal PPS Mode	Key for the current day has been obtained and verified or the GUK issue number is invalid or expired
Daily Key in Use (Incorrect) V74X4469B, (1469B), (3469B)	2	1	The issue number is invalid. The receiver does not contain a key for the current day. (Could contain an expired key.)
		0 Nominal PPS Mode	Set when a new GUK is entered
Key Failed Parity V74X4470B, (1470B), (3470B)	3	1 SPS Mode	If any key entered contains a parity error
		0	If new keys are entered that pass the parity test
GUV User V74X4471B, (1471B), (3471B)	4	1	Receiver using GUV's. Key is intended for Military (non-shuttle) users.
2 Hour Alert V74X4472B, (1472B), (3472B)	5	1	Indicating that there are 2 hours or less before expiration of the current key, if the subsequent key is not available. Receiver needs to download the future key before the rollover to the next GPS day occurs (which is Midnight GMT).
Insufficient Key V74X4473B, (1473B), (3473B)	6	1	Indicating that insufficient consecutive keys have been loaded to accomplish the mission duration. N/A for Shuttle operations, will always be zero.

BIT PARAMETER	BIT #	BIT VALUE	DEFINITION
Erase Failure No MSIDs on Downlist	7	1	Indicating that the receiver failed to erase or zeroize a portion of memory. Troubleshooting: If fail to zeroize, cycle zeroize switch, holding for one second in the zeroize position. If No Joy then power cycle receiver.
Receiver Contains Keys V74X4474B, (1474B), (3474B)	8	1	Key entry successful
Mission Duration V74W4475B, (1475B), (3475B)	9-15	0-44 Nominally 1 Or 2	Representing the number of consecutive days for which the receiver has keys (from the current day) BIT 9 is the MSB and bit 15 is the LSB. From GMT 0:00 - 22:00 hr. will have one key, One future key will be loaded between 22:00-23:59 hr.

NOTE: Shuttle operations use Group Unique Key (GUK) and Group Unique Variable (GUV), shuttle does not use Crypto Key Weekly (CKW) operations.

REFERENCES

Ascent/Entry Flight Techniques Panel, GPS Splinter #1, 1/8/98

Space Shuttle Flight Software Systems Requirements (FSSR-14), Navigation Subsystem Operations Program (SOP), Volume 1, OI-27 Version, dated January 1, 1997.

Liebman, Ed, Guidance and Control Systems Engineer, Mission Operations Directorate

MAGR-S Interface Control Document (ICD-MAGRS-002), Revision B, dated March 15, 1998.

Nuss, Ray, GPS Hardware Subsystem Manager, Engineering Directorate

Sarafin, Michael L., Guidance and Control Systems Engineer, Mission Operations Directorate

TITLE

GPS CHEATSHEET

PURPOSE

This SCP provides a quicklook reference of the operation of the MAGR-S3S and the orbiter displays.

PROCEDURE

The cheatsheet is a quick under the glass reference guide to various SPEC Displays and operational limits of the Shuttle GPS hardware and software

REFERENCES

1. GPS System Brief, author M. Interbartolo III.

GNC GPS Cheatsheet /OI30

Mixed Configs of 1 or 3 Miniaturized GPS Receivers
 ≥ 24 sats: 6 planes x 4 sats each
 10,900 nm orb (12 hr period) 55 deg incl
 3σ position / velocity accuracies *
 120 ft / 0.3 fps
 * 4 sats in view, GDOP = 3.3 70% of time

Min of 4 sats must be in view
GDOP Geometric Dilution of Precision
 Measure of satellite geometry (4 sat tetrahedron)
 Lower numbers are better, GDOP = 1.58 best

QA1 FOM Figure of Merit
 RCVR estimate of position accuracy
 GPS_FOM_THRESHOLD = 5 [Entry]
 GPS_FOM_THRESHOLD = 2 [Orbit]

FOM	SPEC 55 Position Error (feet)	Position Error (feet)	Position Error (meters)	Position Error (nmi)
0	(blank)	0	0	0
1	75	0 - 82	0 - 25	0 - 0.0135
2	175	83 - 164	26 - 50	0.0136 - 0.0270
3	250	165 - 246	51 - 75	0.0271 - 0.0405
4	325	247 - 328	76 - 100	0.0406 - 0.0540
5	650	329 - 656	101 - 200	0.0541 - 0.1080
6	1650	657 - 1640	201 - 500	0.1081 - 0.2700
7	3275	1641 - 3281	501 - 1000	0.2701 - 0.5400
8	16400	3282 - 16405	1001 - 5000	0.5401 - 2.700
9	99999	>16405	> 5000	> 2.701

QA2 POS & VEL GPS-NAV compare
 ALL components must be satisfied:
 Initial * U/VW 500 500 500 ft (position)
 UD VD WD 2.0 1.0 1.0 fps OPS 2,8 (velocity)
 8.0 8.0 8.0 fps OPS 1,3
 > 90 min U/VW 2000 21000 1500 ft OPS 2,8 (position)
 7000 30000 14000 ft OPS 1,3
 UD VD WD 24.0 2.0 2.0 fps OPS 2,8 (velocity)
 30.0 20.0 20.0 fps OPS 1,3

- limits reset at GPS vector incorp into nav and OPS transitions

QA3 POS & VEL Curr-prev GPS compare
 Vector difference compared to l-loaded limits to check for rapid growth or jumps in GPS solution
 QA3 RTOL 500 ft (position)
 QA3 VTOL 5.0/2.0 fps (OPS 1 & 3/2 & 8 velocity)

QA4 POS & VEL GPS- to-GPS compare
 Vector difference compared to l-loaded limits to isolate bad unit
 3 level – MVS state w/smallest pos error
 2 level – average the GPS states
 1 level – use available state
 0 level – use last valid state prop'ed to current time
 QA4 RTOL 500 ft (position)
 QA4 VTOL 5.0 fps (velocity)

RCVR Data Good flag on if all of the following are true:

- Kal filter pos uncert < 1000 meters
- RCVR in NAV Mode
- No BITE

GPS GAX Messages:

Fault Message	Meaning
G55 GPS FAIL x	Internal receiver BITE fail in GPS 1, 2 or 3
G55 QA FL GPS x	GPS 1,2 or 3 has failed 1 or more QA checks for: (~34 hrs) 32,760 nav cycles for QA1 (~34 hrs) 32,760 nav cycles for QA3 (~34 hrs) 32,760 nav cycles for QA4
RM DLMA GPS	(~34 hrs) 32,760 cycles for GPS QA4 dilemma
NAV EDIT GPS "secondary QA2"	Selected GPS state has failed QA2 checks for 4 nav cycles (~19 sec) or at 140kft and "No Update GPS" flag set
NO UPDATE GPS	No valid GPS state selected for more than 5 min in OPS 301-305, 602-603

GPS Controls [G55] :

GPS to NAV	Result
Auto	State updated every 90 min. Immediate update if in OPS 2 > 90 min. Every 40 sec in OPS 3; Every 9 sec below 17 kft
Inhibit	Nav state not updated w/ GPS data. Automatic INH in MM202
Force	Single-shot update of nav state

```

XXXXXXXXXX / 055 /          GPS STATUS          XX X DDD / HH : MM : SS
                DDD / HH : MM : SS
I / O  10  X  GPS1S  GPS2S  GPS3S
STAT   XXXX  XXXX  XXXX          GPS MINUS NAV
MODE   XXXX  XXXX  XXXX          ΔH ±XXXXXX ΔH ±XXX.XX
S / TEST  11XS  12XS  13XS          ΔDR ±XXXXXX ΔDR ±XXX.XX
INIT    14X   15X   16X          ΔCR ±XXXXXX ΔCR ±XXX.XX
NAV     17X   18X   19X
RESTART 20X   21X   22X          X LAT   X LON   ALT
                XX.XX  XXX.XX  XXX.XXXX
GDOP     XX    XX    XX
DG FAIL  S     S     S          AUT INH FOR
DES RCVR 28X   27X   28X          GPS TO G&C S32X 33X 34X
QA OVRD  29XS  30XS  31XS          GPS TO NAV S35X 36X 37X
SF CAND  X     X     X          METERING OVERRIDE 38X
QA1 P 1 0XXXXXXSXXXXXXSXXXXXS
QA2 POS  X.XX  X.XX  X.XX
VEL     X.XX  X.XX  X.XX
QA3 POS  X.XXS X.XXS X.XXS
VEL     X.XXS X.XXS X.XXS
                1-2   2-3   3-1
QA4 POS  X.XXS X.XXS X.XXS
VEL     X.XXS X.XXS X.XXS
                DES 43  XX  XX  XX  XX
                XXX.X LAST SEL FIL UPDATE          XX  XX  XX  XX
    
```

Check constellation status @ Air Force Website:

- www.schriever.af.mil/gps/
- Satellite Predictor:
- sirius.chinalake.navy.mil/satpred/

Additional download:

- Service: PPS (precise positioning service / military)
- SPS (standard / civilian)
- Kalman Filter Mode: INS (GPC/IMU aiding – best)
- PVA (GPS pos/vel/accel – estim)

TITLE

RM/POWER TABLE

PURPOSE

The purpose of the table is to provide GNC Support/Sensors console a quick reference in finding RM limits, and power information on Sensors hardware, and how to deselect item entries in both PASS and BFS.

BACKGROUND

These tables are located under the glass at the Sensors console. This SCP provides a certified version of the tables that are updated, when necessary, and change out of the old tables.

This table contains RM limits, sigma values, switch and circuit breaker locations, warm-up time, and power used.

System	Redundancy Management						Switch/ Circuit Breakers					Warmup Time (ODB)	POWER (WATTS)
	Parameter	OPS 1/6		OPS 3		I Sigma	LRU	SW Location	CB Location	Access			
		RM Limit	Time	RM Limit	Time					ASC	ENT		
AA	Lat (NY) Norm (NZ)	2.57 fps ² 2.03 fps ²	10 sec 10 sec	4.18 fps ² 6.43 fps ²	10 sec 10 sec		1 2 3 4	O16:F O15:F	O14:E O15:E	NO NO NO NO	NO NO NO NO	5 min	2.4
ADP							Stow ENA (L,R) Stow (L,R) MCA Log MCA Log	C3 C3 MA73C:A		YES YES NO NO	YES YES NO NO	2 motors = 15 sec 1 motor = 30 sec	Heater = 1300 40 per motor
ADTA	PS PAC PAU PAL	.100 (HG) .064 (HG) .100 (HG) .100 (HG)	3 sec 3 sec 3 sec 3 sec	.100 (HG) .064 (HG) .100 (HG) .100 (HG)	3 sec 3 sec 3 sec 3 sec		1 (L) 2 (R) 3 (L) 4 (R)		O14:E O15:E O16:E O16:E	NO NO NO NO	NO NO NO NO	2 sec	64
COAS							- Z + X	O19 O1	L4:Q L4:Q	NO NO	NO NO		12.5
DDU							Left Right Aft		O14:E O15:E O16:E O14:E O16:E	NO NO NO NO NO	NO NO NO NO NO		137
FC PWR							Left Right Aft	F6 F8 A6	See DDU	YES YES NO	YES YES NO		Left = 11 Right = 8 Aft = 8
GPS (MAGR)							Single String 3-String	A13 O7 O7 O7	O14:D, O16:D ¹ O15:C,D ² O14:D O15:C,D O16:D	NO NO NO NO	YES YES YES YES	60 sec	Receiver = 40 2.2 per preamp
IMU HAINS							1 2 3	O14:A O15:A O16:A	None None None	NO NO NO	NO NO NO	50 min @ 75F 120 min @ 35F	Oper = 150 Stby = 78
MLS	Azimuth Elevation Range	0.500 deg 0.400 deg 0.329 NM	12 sec 12 sec 12 sec	0.500 deg 0.400 deg 0.329 NM	12 sec 12 sec 12 sec		1 2 3	O8 O8 O8	O14:E O15:E O16:E	NO NO NO	YES NO YES	3 min	70

¹ OV-103 single string GPS CB's located on panels O14:D and O16:D

² OV-104 single string GPS CB's located on panel O15:C,D

SENSORS OPERATIONAL CHARACTERISTICS

System	Redundancy Management						Switch/Circuit Breakers				Warmup Time (ODB)	POWER (WATTS)	
	Parameter	OPS 1/6		OPS 3		I Sigma	LRU	SW Location	CB Location	Access			
		RM Limit	Time	RM Limit	Time					ASC			ENT
RA	Altitude	37 ft		37 ft		0-10 ft: 1.6 ft 11-66 ft : 2.4 ft > 66 ft: 3 %	1 2	O8 O8	O14:E O15:E	NO NO NO NO	YES NO YES NO	0 min	23
RGA	Roll	SF= 8.00 B = 0.80	10 sec	SF= 8.09 B = 1.19	3 sec		1 2 3 4	O14:A O15:A O16:A O15:A		NO NO NO NO	NO NO NO NO	2 min	Synch = 25 Spinup = 36
	Pitch	SF = 6.50 B = 0.55	10 sec	SF = 6.00 B = 0.65	3 sec					NO NO	NO NO		
	Yaw	SF = 6.50 B = 0.63	10 sec	SF = 6.00 B = 0.65	3 sec					NO NO	NO NO		
		RM LIMIT = (SF %) (Sel Rate) + (B deg/sec)											
SRGA	Pitch	SF = 5.00 B = 0.45	10 sec				1 (L) 2 (R) 3 (L) 4 (R)					5 min	Synch = 18 Spinup = 28
	Yaw	SF = 5.00 B = 0.45	10 sec										
	RM LIMIT = (SF %) (Sel Rate) + (B deg/sec)												
Star Tracker (IDT)						Pos: 60 arcsec Mag: 0.6	-Z -Y	O6 O6	O14:E O15:E	NO NO NO NO	YES NO YES NO	15 min	17
Star Tracker (SST)						Pos: <60 arcsec Mag: <0.6	-Z -Y	O6 O6	O14:E O15:E	NO NO NO NO	YES NO YES NO	15 min	23
Star Tracker Doors							DR Cntrl MCA Log MCA Log	O6 MA73C:A	MA73C:A	NO NO NO	YES NO NO	2 Mtr = 7 sec 1 Mtr = 14 sec	33
TACAN Collins	Range Bearing	0.494 NM 6.00 Deg	5 sec 10 sec	0.494 NM 6.00 Deg	5 sec 10 sec	3 Sigma values At 35 NM Range 0.19 NM Bearing 1.8 Deg	1 2 3	O7 O7 O7	O14:C O15:C(E) ¹ O16:C	NO NO NO NO	YES NO YES NO	30 sec (-40 F to +80 F)	Search = 75 Track = 50 DC PWR = 28 VDC
	Collins TACAN is operational 1 sec after power												
	NAV Entry limits for TACAN deselect: Range > 0.3 NM, Bearing > 1.0 Deg												

¹ CB located on panel O15:E on OV-104; all other vehicles on O15:C

This table contains the SPEC and item entry for deselection of a certain LRU, as well as the auto, inhibit, and force option for the TACANs, GPS, and ADTAs.

BFS DESELECT							
LRU #	SPEC 51				SPEC 50	SPEC 55	N/A
	IMU	AA	RG A	SURF	TACAN	GPS	ADTA
1	25	31	35	39	31	26	cb (O14:E)
2	26	32	36	40	32	27	cb (O15:E)
3	27	33	37	41	33	28	cb (O16:E)
4		34	38	42			cb (O16:E)
					Nav	Nav	Nav
					Auto 50/19	Auto 50/42	Auto 50/25
					Inh 50/20	Inh 50/43	Inh 50/26
					For 50/21	For 50/44	For 50/27
					G&C		
					Auto 50/28		
					Inh 50/29		
					For 50/30		

PASS DESELECT											
LRU #	SPEC 21		SPEC 51		SPEC 50	SPEC 55	SPEC 53			N/A	
	IMU DES	IMU MASK	IMU	ADTA	TACAN	GPS	AA	RG A	SURF	MLS	
1	7	24	25	34	31	26	10	14	18	SW (O8)	
2	8	25	26	36	32	27	11	15	19	SW (O8)	
3	9	26	27	35	33	28	12	16	20	SW (O8)	
4				37			13	17	21		
					Nav	Nav	Nav				*Nav
					Auto 50/25	Auto 50/19	Auto 50/42				Auto 50/50
					Inh 50/26	Inh 50/20	Inh 50/43				Inh 50/51
					For 50/27	For 50/21	For 50/44				For 50/52
					G&C		G&C				
					Auto 50/28		Auto 50/47				
					Inh 50/29		Inh 50/48				
					For 50/30		For 50/49				

*GPS 3 String Only

FOR OI-27 UPDATED 6/9/99

Ref. Orbiter Displays Reference Guide, OI-27

TITLE

AIR DATA TRANSDUCER ASSEMBLY BITES

PURPOSE

The purpose of this SCP is to provide a list, explanation, possible impacts, and actions required for the different Advanced Air Data Transducer (AADT) BITES. The AADT BITES are designed to detect an AADT failure with a minimum probability of 90 percent. To remain consistent with operational nomenclature, the AADT will be referred to as Air Data Transducer Assembly (ADTA).

BACKGROUND

Internal status checks and monitoring are performed by the processors of each ADTA at power-up and during each cycle as part of the built in test (BIT) circuitry. Again, for consistency with ADTA nomenclature, the failure of such tests will be referred to as "BITE" (built in test equipment). The processor performs reasonability checks on other components (e.g. power supply) and on the received pressures and temperature. In the event of an out-of-tolerance condition, a fail bit is set in the ADTA Mode/Status word. At the end of each computational cycle, the pressures, temperature, and ADTA Mode/Status word are sent to the Manchester Input/Output circuit for transfer to the MDM.

In addition to performing continuous BITE tests, each ADTA can be commanded to perform a high or low self-test. The self-test request from the MDM causes three actions. First, the appropriate bit in the ADTA Mode/Status word is set high, indicating a high or low self-test is in progress. Secondly, a set of constants, high or low values, is output from the processor for the different pressures and temperature. Lastly, the processor performs comparison checks on the sensed pressure measurements and compares them to a threshold. An out-of-tolerance condition results in a fail bit being set in the Mode/Status word.

Table 4.8-1 serves as a quick look guide to the ADTA Mode/Status word. Systems Brief 4.0 contains detailed discussions of the built in tests used to drive the BITE conditions.

TABLE 4.17-1: ADTA BITE MODE STATUS WORD QUICK LOOK

BIT #	BITE	STAT [1]	NOM IND	NOM HEX	BFS ↓	POSSIBLE IMPACTS AND ACTIONS
1	ADTA GOOD	0FFC	1	8	N	Drives crew status indicator on OPS8 SPEC 41 and OPS9 SPEC 102, indicates fail when bits 2, 5-10, or 12-16 indicate fail.
2	ADTA RADIATE CIRCUIT GOOD	4FFC	0		Y	Indicates radiation circumvention circuitry failed to act on Single Event Latch-up (SEL) condition. Impacts vary depending on circuit affected, but may indicate erroneous pressure data.
3	HIGH TEST MODE	AFFC	0		N/A	Set high when high test in progress in OPS8 or OPS9
4	LOW TEST MODE	9FFC	0		N/A	Set high when low test in progress in OPS8 or OPS9
5	PaL TRANSDUCER GOOD	07FC	1	F	Y	Indicates PaL (P1) transducer test outputs are out of tolerance. Potential indication of erroneous pressure data.
6	PaU TRANSDUCER GOOD	0BFC	1		Y	Indicates PaU (P2) transducer test outputs are out of tolerance. Potential indication of erroneous pressure data.
7	PaC TRANSDUCER GOOD	0DFC	1		Y	Indicates PaC (P3) transducer test outputs are out of tolerance. Potential indication of erroneous pressure data.
8	Ps TRANSDUCER GOOD	0EFC	1		Y	Indicates PS (P4) transducer test outputs are out of tolerance. Potential indication of erroneous pressure data.
9	A/D CONVERTER GOOD	0F7C	1	F	N	Selected A/D Converter voltages are out of tolerance. Loss of selected Power Supply, Pressure (pressure BITES can be driven by other tests), and Electronics BITE. Self-test can verify health of circuits with lost insight.
10	ADTA ELECTRONICS GOOD	0FBC	1		Y	Possible Watchdog Timer, NVM, oscillator, Manchester, or power supply problem. Potential indication of erroneous pressure data.
11	ADTA TEMP CIRCUIT GOOD	8FDC	1		N	Not Used. Temp circuit tests are performed but will not announce this BITE (should always read 1).
12	ADTA CODE MEMORY CRC	0FEC	1		Y	Cyclic Redundancy Check (CRC) test verifies NVM and ROM address locations. Potential indication of erroneous pressure data.
13	ADTA POWER SUPPLY GOOD	0FF4	1	C	Y	+5, ±10 and ±15 volt power supplies voltage out of tolerance. Potential indication of erroneous pressure data. A/D Converter BITE will inhibit this BITE, but no commfault and completion of self-test indicate good power supply.
14	ADTA DISCRETE INPUTS GOOD	0FF8	1		N	No impact. Possible loss of self-test. BITE may be cleared with multiple HI/LO self test commands (OPS 8 and 9). If BITE occurs during FCS C/O, do not DES affected ADTA (✓MCC in procedure included for this case).
15	ADTA RAM MEMORY GOOD	0FFE	0		Y	Write/Read-back of static and external RAM. Only performed at power-up. Potential indication of erroneous pressure data.
16	ADTA F/D GOOD	0FFD	0		N	Only performed at power-up. Potential indication of erroneous pressure data, however Pressure BITES will be set if F/D converter BITE is real.

NOTE [1]: Mode Status Word will indicate value shown if indicated BITE is the only BITE present.

TITLE

GPS YETI MONITORING

PURPOSE

The purpose of this SCP is document the YETI scenario, how to monitor GPS for YETI, and workarounds in the event the GPS is affected by a YETI.

BACKGROUND

YETI DEFINITION:

YETI is Y-Code Erroneous Tracking Incident that can cause the GPS to have difficulty tracking satellites. This is a known DR(110646) in the MAGR software. An affected GPS receiver hardware channel will not be able to acquire Y-code signals.

IN FLIGHT AND GROUND TESTING HISTORY:

The first time a YETI event was detected was during ground testing with a rooftop antenna at the Rockwell-Collins facility in Cedar Rapids, Iowa. During this test, a MAGR-3S became unable to acquire Y-code signals.

During STS-112, just after GMT 284/02:09:37 on MAGR s/n X, hardware channel 4 stopped tracking Y-code signals, indicating the first in-flight YETI event. Once the problem was detected, the problem was cleared by commanding the MAGR to initialization (INIT) mode and then back to navigation (NAV) mode. During the YETI, performance degradation was observed.

After these two events, two long duration ground tests were performed to try and capture data and test possible fixes for the YETI condition. The first test was performed during 2004 at Rockwell-Collins. During this test, three MAGRs were run simultaneously against live sky satellites. MAGR s/n 18 was an un-modified MAGR and it shared a rooftop antenna with s/n 19, which had modified software to capture YETI event data. The third MAGR, s/n 6, was modified with hardware test points and used a different, nearby antenna. During the approximately five month test, six YETI events were recorded on different receivers, none at the same time. One of the YETI occurrences on s/n 6 was not cleared for six weeks in order to observe the effects of the YETI. The Figure of Merit (FOM) from this MAGR was slightly elevated at 2 or better for the duration of the YETI condition.

The second test was run in October and November 2005 after a software fix was identified that would, in theory, fix the YETI. Two MAGRs contained the software fix and one did not. Unfortunately, one of the MAGRs with the software fix experienced a YETI. After Collins verified that the software fix was implemented correctly they concluded that their theory about the YETI was not correct.

At this time (10/06), the cause of the YETI is still not known.

PROCEDURE

YETI DETECTION:

A YETI can be detected when an affected GPS receiver hardware channel can not acquire Y-code signals. The following behaviors may be observed during a YETI:

- Failed Y-code acquisitions
- Failed C/A to Y-code handovers
- Failed ionospheric delay and channel calibration measurements
 - Ionospheric delay measurements are characterized by the peripheral channel tracking the same satellite as a navigation channel but on a different frequency.
 - Channel calibration measurements are characterized by the peripheral channel tracking the same satellite as a navigation channel in the same code and frequency.

Performance degradation may also occur. The primary evidence of degraded performance will be elevated FOM and Geometric Dilution of Precision (GDOP) values. Degradation will be the result of C/A-code tracking on a navigation channel, inability to perform ionospheric delay and channel calibration measurements, and inability to switch requested satellites into the navigation constellation.

YETI MONITORING:

GNC has three ATOM comps to track the performance of the GPS hardware channels and alert the user if the receiver has experienced a YETI. The user will start the comps (GNC>>APPS>>YETI 1(2,3)>>START), usually during the first Orbit 2 shift, to begin monitoring the GPS performance for each of the three units. The comp will run in the background and if a YETI is detected a YETI ALERT message will be issued in ELOG as well as an ALERT flag published on the GPS Status Display only for a GPS 2 YETI (see picture below) and the Three String GPS Summary page for GPS 1, 2 or 3.

F/V xxx / 0 OGMT 000:00:00:00 OMET 000:00:00:00 GPS STATUS v1.6(0127)										MM	0	TFL	GNC	SM	BFS								
T HOMGEN YES GPS T 000:00:00:00										NAV CHAN		1	2	3	4	5	GPS2 VS GND		GPS COMPARISONS				
TFOM 0										HW CHAN		0	0	0	0	0	U	0.0	BRG RNG				
HARDWARE STATUS										SAT #		0	0	0	0	0	V	0.0	TAC1 0.00 0.00				
DES		P/L STBY	ON							STATE		0	0	0	0	0	W	0.0	TAC2 0.00 0.00				
GPS BYPASS	YES	NAV MODE	PPS							C/N RATIO		0	0	0	0	0	UD	0.00	TAC3 0.00 0.00				
D/G FLAG		FILT MODE	INS							CODE		P	P	P	P	P	VD	0.00	GPS2 0.00 0.00				
R/P MODE	TEST	FILT RESET	YES							FREQUENCY		L2	L2	L2	L2	L2	WD	0.00					
BIT IN PROG	YES	RP AUTO RESET	YES							FAULT							T	0.000000	GPS VS BRG RNG				
S/TEST FAIL		REANCHOR COMP	YES							ANTENNA		UPP	UPP	UPP	UPP	UPP	QA2	POS	RAT	0.0	TAC1	0.00	0.00
<4 SATS	YES	INIT STATES SET	YES							EPHEMERIS		D/L	D/L	D/L	D/L	D/L	QA2	VEL	RAT	0.0	TAC2	0.00	0.00
R/P FAIL	YES	UTC VALID								FAIL POS VEL							QA2	VEL	RAT	0.0	TAC3	0.00	0.00
BATT LOW	YES	LEVER ARM CORR	YES							GPS TO NAV		A	F				QA3	POS	RAT	0.0	GPS ALT 0.0		
RCVR KEYED	YES									GPS TO G&C		A	A				QA3	VEL	RAT	0.0	NAV ALT 0.0		
GDOP	0									LAST UPDATE							QA3	VEL	RAT	0.0	GND ALT 0.0		
QA1 (FOM)	0																	VEL	RES	0.0	LAT 0.0		
																					LONG 0.0		

YETI ALERT STATUS for Single String Flights

The GPS Status Display will show which hardware channel is experiencing the YETI while the ELOG message is a generic alert that a YETI has been detected.

YETI TROUBLESHOOTING:

If a YETI alert is annunciated in ELOG, verify the YETI is real by checking for the behavior described above. If the YETI is confirmed, the receiver can be recovered by keyboard command of the receiver to INIT and then back to NAV.

Do not perform this troubleshooting during a critical flight phase unless degraded performance is observed. If receiver performance is degraded to the point of an out-of-service condition, recover the receiver as described above. Be aware the receiver recovery time may exceed out-of service constraints (2.3 minutes for entry), but likely will not.

Do not command INIT-NAV mode transitions during GPS signal blackout during entry (~335kft to 230kft); this may result in an extended recovery time.

Once the GPS has been recovered by INIT-NAV the YETI comp for that unit will need to be stopped (GNC>>APPS>>YETI 1 (2,3)>>STOP) and restarted (GNC>>APPS>>YETI 1 (2,3)>>START) in order to monitor for a reoccurrence of the YETI scenario.

REFERENCES

[MAGR-S/3S Program Note/OPS Note for DR 110646 \(click for link\)](#)

[FSW DR Management form for DR 110646 \(click for link\)](#)

STS-112 Post Flight Report (pending completion)

STS-112 Console Data Book

[GPS YETI Status Ray Nuss Summary dated 5/11/2006 \(click for link\)](#)

TITLE

GPS TIME COMPENSATION

PURPOSE

WARNING: This procedure is governed by FCOH SOP 3.1, COMMAND POLICY FOR MOD, and cannot be modified without prior approval of the FOIG or the Flight Director (during real-time operations). Safety critical steps are marked by a box.

The GPS Delta Time command (DSM 398) modifies the way the GPS SOP calculates time. This can be used to account for changes in the GPS time basis that are not accounted for in the ILOADS; for example, if a leap second was added between ILOAD delivery and launch, or if the launch year changes (Year End Roll Over).

This command can also be used to account for the differences between the GPC time and GPS time. If a difference between the GPS time and GPC time exists, the difference must be compensated for or the GPS may reject the aiding data from the GPCs and downmode from INS (aided) to PVA (unaided) mode. Additionally, a difference between GPS and GPC times will cause the Navigation Flight Software to erroneously introduce propagation error into the GPS state vector. The GPS is not certified for operation in PVA mode. This command uplink modifies the GPS to GMT Time Adjustment parameter in the GPS SOP.

Restrictions:

OI Load: OI-30 and subs.

OPS mode: PASS (OPS 1/6, OPS 3, OPS 9 and MM 201 of OPS 2)
BFS (OPS 1/6 and OPS 3)

Major Function: GNC

Vehicles: all

Crew/MCC coordination: information only

Time Constraints: none

Hazardous: This load replaces the values of T_GPS_TO_GMT_ADJ (V91W0035C) in the PASS and LEAP_LZRD in the BFS (V98W0016C). Incorrect uplink could cause GPS aiding data to be invalid, which would mode the GPS to PVA (unaided mode). **Incorrect uplink will affect all GPS LRUs.**

Require safing: no

Minimum value: -31,626,000 seconds

Maximum value: +31,626,000 seconds.

COMMAND RESPONSIBILITIES

GNC is responsible for this uplink in the event of an MTU failure, or if the prelaunch uplink must be performed again due to GPC failure, and the GPO is not available (see below for FDF procedures requiring this uplink).

The Guidance officer will be responsible for this uplink prelaunch and for Year End Roll Over (YERO) (ref. DM-CH-5, Flight Dynamics Command Procedures).

BACKGROUND

The GPS to GPC Time Adjust is uplinked to the PASS and BFS by the Guidance Officer prior to launch. The nav018 product (commonly referred to as the ONAV/GPO OPS Memo) contains the values for prelaunch uplink. Typically this value will be 0.0, but it may not be if there is a difference between the launch time for which the ILOADS were designed and the actual launch time. A leap second that was added between I-load delivery and launch would be one example. Since this uplink is simply a way to bias the GPS to GPC time calculations, it can also be used to fix any discrepancy between GPS and GPC time.

GPS Aiding data must be no more than 2 seconds in the past or more than 5 milliseconds (ms) in the future. If the aiding data falls outside this range, the GPS will transition to PVA mode. If aiding data is between 400 ms and 2 seconds in the past, process noise is added to the covariance of the aiding data, and navigation performance may be degraded (reference ONAV GPS Memo dated 5/2001). Additionally, a phenomenon called Nearly Repeated Time Tag (NRTT) occurs at latencies greater 400 ms. NRTTs will not occur when the Age of Aiding is less than approximately 240 ms. NRTTs will occur at 1 Hz rate when the Age of Aiding is in excess of 400 ms. Latencies greater than 400 ms result in the MAGR "anticipating" entering PVA mode, so the MAGR only applies 70% of acceleration to the propagated high rate solution over 160 ms time frame (GPC receives the high rate solution). Therefore, NRTTs can result in velocity spikes up to 30% of vehicle acceleration. QA3 will protect spikes greater than 5 fps (I-load). Other, possibly unknown, MAGR side effects may exist when the Age of Aiding is greater than 400 ms. NRTT was not discovered until an analysis was performed to explain flight data signatures. The vendor (Collins) does not endorse and has not performed comprehensive assessment operating at latencies greater than 400 ms.

Due to the above described conditions, it can be seen that the difference in time between the GPS and the GPCs (GPS-GPC) must maintained between 400 ms and -5 ms to avoid degraded performance, and between 2000 ms and -5 ms to avoid downmoding from INS mode to PVA mode.

Additionally, the GPS SOP will not output a GPS vector for use in Nav unless the IMU bracketing constraints are met, and the difference between the GPS state vector time and the current orbiter time is less than GPS_QA_TIME_THRESH (I-loaded to 1.9 sec.). These constraints are summarized in Figure 1.

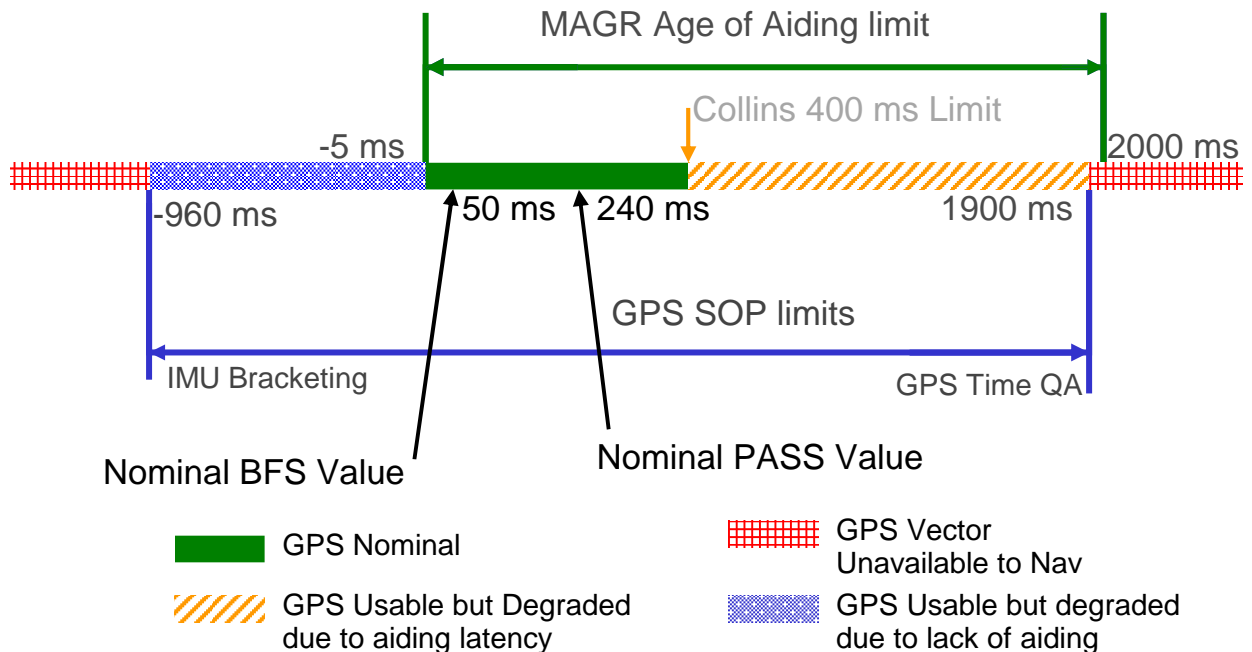


Figure 1: GPS to GPC time delta limits.

The GPS firmware calculates an Age of Aiding parameter that can be seen on the GPS Status Display (V74W3478B) and GPS BFS Status Display (V98U7282C). Typically the aiding data has a latency of 230 to 255 ms in the PASS and 40-50 ms in the BFS, post engage. Prior to engaging the GPS is being aided by the PASS so the BFS Age of Aiding will be the PASS value. If the GPC time were to drift, the Age of Aiding may fall outside the -5 to 2000 ms range. In this case an uplink will be required to keep the GPS from downmoding to PVA mode.

BFS Issues

There are three issues that make things more complicated on the BFS. First and foremost is the lack of insight to the BFS GPC drift rate. Prior to engaging the BFS, the GPS aiding state is provided to the MAGR from the PASS. The MAGR calculates Age of Aiding based on this aiding state and sends this value of Age of Aiding to both the PASS and BFS. As a result, the Age of Aiding downlisted by the BFS is actually the PASS Age of Aiding prior to engage. This means that Age of Aiding can not be used to provide insight to how the BFS GPC clock is performing. During prelaunch, the BFS spends a significant amount of time in standalone, on its internal clock. This gives DPS time to measure the drift rate of the BFS GPC. DPS has agreed to measure this drift rate and provide it to GNC prelaunch.

The second issue of concern for the BFS is the nominal value of Age of Aiding (post engage). Since the BFS aiding data is nominally less latent (lower Age of Aiding) than the PASS (see Figure 1), the BFS is more susceptible to a fast GPC clock. For a GPC clock speeding up at spec drift rate, the BFS can lose aiding in as little as 11 minutes. This means that a loss of the MTU during ascent could present a problem for a subsequent Abort on the BFS. To prepare for this case, some assumptions can be made and a GPS delta time command can be built prelaunch to maintain aiding for this case.

Third, prior to engage, an uplink to the BFS essentially “double books” the GPC drift, since the PASS GPC drift will be accounted for in the PASS uplink, and the BFS drift will be accounted for a second time with the BFS uplink. This will cause error in the BFS state vector due to the timing error. This error will be larger at higher velocities, due to these errors GPS should not be taken to the BFS above 130 kft when an uplink has been performed.

DPS MAL Procedures requiring this command

If the BFS GPC is re-IPLed or all PASS GNC GPCs are lost (IPL with no active GNC or Freeze Dry available), any previous uplink will need to be sent again.

For PASS, the uplinked data will reside in the GPC major function base (not the MMUs). If another running PASS GNC GPC is present and available or a Freeze Dried GNC GPC with current major function base is available, the GPC that is being recovered receives the GPS Time data via a GNC Set Expansion (software transfer). It is only the loss of all PASS GNC GPCs (GNC major function base) that requires the uplink. The uplinks for PASS (GNC) can be performed in Major Mode 201 or OPS 3.

If an uplink has been previously performed, the following FDF procedures will require a GPS Delta Time uplink via DSM 398:

1. DPS FRP-4 PASS Recovery After BFS Engage (Ascent/Orbit/Entry) – MAL
 Calls DPS SSR-8 GPC IPL (PASS) – MAL
2. BFS GPC IPL – APCL
3. DPS 5.1b BFS GPC Fail (BITE) (Orbit) – MAL
4. DPS FRP-1 Single GPC Fail for BFS case – MAL
5. DPS FRP-3 BFS GPC Fail Recovery (Entry) – MAL
6. DPS FRP-7 DPS Reconfig for Loss of Av Bay Cooling for Av Bay 2 Case (Ascent/Orbit) – MAL
7. DPS SSR-7 GPC IPL Menu Option (PASS/BFS) – MAL (called by 3, 4, and 5 above)

YERO procedures for STS-116 required an uplink of 31,536,001.0 seconds (1 year) after the GPC's were IPL'ed. With the new YERO capability in the FSW (OI-32), this time correction is implemented automatically and therefore the uplink is not required.

PROCEDURE

The Guidance Officer application GPS Time/RNP is used to generate the required command load.

A. DETERMINE NEW GPS DELTA TIME

1. If the uplink is required due to an MTU fail with a drifting GPC clock, perform the following steps. Otherwise the delta time for uplink will simply be the prelaunch value. In this case, skip to step B and use the command GPO built prelaunch from the NAV018 product.
2. Note which GPC is the current timing source (DPS can provide this information, typically this should be GPC 1). If this GPC fails, the drift rate will need to be re-evaluated, and a new uplink may need to be performed
3. Hardcopy the appropriate GPS Status display (PASS or BFS) with the current Age of Aiding displayed.
4. Using the RTPlot of Age of Aiding, determine the direction and magnitude of the GPC time drift. If the Age of Aiding parameter is decreasing, the GPC clock is fast and the Age of Aiding is drifting towards the -5 ms limit. If the Age of Aiding parameter is increasing, the GPC clock is slow and the Age of Aiding is drifting towards the +400 and +2000 ms limits.
5. The Age of Aiding data must be biased so that it will not violate the -5 or +400 ms limit. Typically the uplink will be performed at TIG-30 minutes, so the uplink will be calculated to protect the GPS for 1.5 hours of GPC drift.
6. Determine the desired value for the uplink. An XESS spreadsheet has been created to perform these computations (Apps->GPS Delta Time). The following calculations are included as a backup to the software and to document the computations.

- a. Determine the Age of Aiding post uplink:

$$\mathbf{AoA_post_uplink = AoA_td - [(GPC_drift) * (time_to_landing)]}$$

Where:

AoA_td = desired Age of Aiding at touchdown

GPC_drift = GPC time drift, negative for a fast GPC clock and positive for a slow GPC clock

Time_to_landing = time expected between uplink and landing.

Note: For a GPC speeding up at spec rate (~5 ms/min) and an uplink performed 90 minutes prior to landing the AoA_post_uplink would be 240 - (-5* 90) = 690. In this case it would take almost an hour for the GPC clock drift to get the Age of Aiding back into the desired -5 to 400 ms window. For this case, the desired Age of Aiding at touchdown can be decreased to avoid violating the 400 ms constraint at uplink. This case may require a second uplink to keep the GPS aided all the way to the

ground. A similar situation exists if the drift rate is slowing down at 5 ms/min. In this case the initial uplink could cause PVA due to the age of aiding post uplink being negative post uplink.

- b. Determine the new PASS GPS Delta Time for uplink:

$$\text{GPS Delta Time} = (\text{AoA_current} - \text{AoA_post_uplink}) + \text{previous_value}$$

Where:

AoA_current = current Age of Aiding from the GPS Status display

AoA_post_uplink = The desired value for Age of Aiding after the uplink is complete, calculated in step 4.

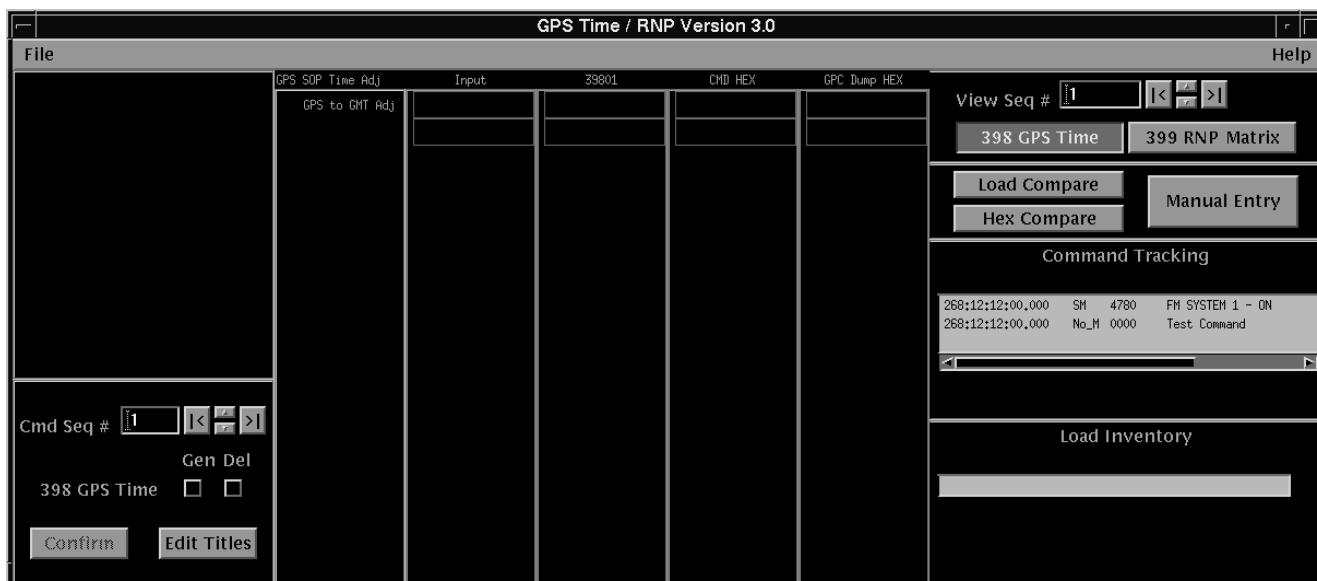
previous_value = value for GPS Delta Time uplinked by the Guidance officer prior to launch (From GPO/ONAV prelaunch product, Nav018) for an initial uplink. For subsequent uplinks, due to the drift rate changing, this will be the last command load value.

7. **Build the BFS Uplink:** Repeat the steps above using the prelaunch measured BFS GPC drift provided by DPS.

B. BUILDING AND LOADING THE COMMAND INTO THE COMMAND SERVER

NOTE: A Command Manager must be running on any workstation that runs command applications. Start or Stop a Command Manager from the Master DNAV, Global Apps, Command Server menu.

1. Launch the GPS Time/RNP application from the Master DNAV, Shuttle, Guidance (AEGPO), GPS Time/RNP (pictured below).



NOTE: Command Display inputs are not allowed when the Command Server is in checkpoint.

2. Push the 398 GPS Time button on upper right-hand corner of the application to access the DSM 398 command build menu.

3. If a prelaunch uplink was performed, DSM 39801 should be in the Command Server already; if not, build DSM 39801 with 0.0 for the GPS Delta Time to preserve capability to remove correction if necessary.
 - a. Select the desired DSM number in the using the Command Sequence and View Sequence scroll buttons.
 - b. Push the Manual Entry button to bring up the 398 GPS Time Manual Data Entry window.
 - c. Enter the desired GPS to GMT Time Adjust value in **SECONDS**.
 - d. Push the OK button to load the data in the Input Data column.
 - e. Edit the Command Load Title, if desired.
 - i. Push the Edit Titles button.
 - ii. Enter the desired command load title in the 398 GPS Time field only.
 - f. Push the OK button.
 - g. Push the Generate (Gen) button.
 - h. Push the Confirm button.
4. If this is simply an uplink of the prelaunch value, skip to step D below. Otherwise use the steps above to build DSM 39802 with the new GPS Delta Time correction calculated in step A.

D. VERIFICATION OF COMMAND SERVER LOAD

1. Verify the correct command has been loaded in the Command Server.
 - a. Select the command to verify using the View Sequence scroll buttons.
 - b. Verify the GPS to GMT Time Adjust Field.
 - c. Verify the DSM number and title in the Load Inventory field.
 - d. Hard copy the GPS Time/RNP display.
2. Launch the PASS GPS STATUS and BFS GPS STATUS displays in preparation for the confirmation of uplink.

E. NOTIFICATION AND APPROVAL

1. Advise the GNC FCR by DSM number that the load has been built, verified, and ready for uplink.
2. The GNC FCR will verify that the load is correct.
3. The GNC FCR will receive Flight Director approval to perform the uplink. The GNC FCR request to INCO for the uplink command will include a confirmation of Flight Director approval for uplink, the GPC major function destination, and the DSM number of the command.
4. The GNC FCR will monitor the INCO loop until all command actions are completed. INCO will notify the GNC FCR when the actions are completed. The GNC FCR will monitor Command Tracking displays to verify that the correct commands have been executed.

F. VERIFICATION OF UPLINK ONBOARD

1. Record Load number and uplink time in console log.
2. The GPS Delta Time parameter is not in the downlist so it can not be verified directly, however, the Age of Aiding can be used to verify the uplink. Verify the Age of Aiding on the GPS Status Displays (PASS or BFS as required) updates to the expected value.
 - For the MTU fail case this was calculated in step A.5 (AOA_post_uplink)
 - For an uplink of the prelaunch value, the Age of Aiding should be in the nominal range of 230 to 255 milliseconds after the uplink.

NOTE: If uplink causes erroneous GPS performance, request the previous DSM number to be uplinked to restore capability.
3. Observe the GPS to verify performance. The GPS should be in INS mode after the uplink.

G. TRACKING OF LOADS BUILT

1. Once the load has been uplinked and GPS performance has been verified, ensure that only the pre-launch and the most recent GPS compensation loads remain stored in the Command Server.
2. If this uplink was done on orbit, the BFS will need to be updated when it is brought up. Nominally this is done at deorbit burn minus 46 minutes per the entry checklist. The BFS uplink will be calculated based on the prelaunch GPC drift rate provided by DPS.

H. REFERENCES

Functional Subsystem Software Requirements (FSSR); Guidance, Navigation, and Control; Part E: Nav aids SOP, STS 83-0014V1, May 30, 2003, Section 4.17.

Backup Flight System (BFS) GN&C Hardware Interface Program Requirements Document (PRD). MG038106-30, May 29, 2001. Section 3.2.5.2.4.

GNC Systems Briefs (JSC-12843), Section 20, Global Positioning System (GPS).

Flight Dynamics Command Procedures. DM-CH-05. Revision D. November 1, 2006

Ascent/Entry Onboard Navigation Console Handbook USA004831 Rev. B. June 2005

Ascent/Entry GPO Console Handbook, Volume 1: Checklists, DM-CH-10 Basic, April 2005.

TITLE

ORBITER VENT AND ACCELERATION CALCULATIONS (ANGACL)

PURPOSE

To describe the ANGACL program which calculates Orbiter vehicle angular and linear accelerations for any given force or number of different forces such as external vents, reaction control system (RCS), Space Shuttle main engine (SSME) dumps, etc. Equations are also presented to calculate centripetal accelerations along with tables containing data on inertial measurement unit (IMU) locations, RCS, SSME, orbital maneuvering system (OMS), and solid rocket booster (SRB) thrusts and locations.

DESCRIPTION

The program is called ANGACL. The program inputs are

- A. Moments of inertia IXX, IYY, IZZ (SLUG-FT²).
- B. Products of inertia IXY, IXZ, IYZ (SLUG-FT²).
- C. Vehicle C.G. X, Y, Z location (in inches in the X₀ COORD system defined in the SODB Vol. II Mass Prop Book).
- D. Vehicle weight (lb).
- E. Force vector (in X, Y, Z force components in LB-F or as a total force in LB-F and the rho, gamma angles in degrees which define the force direction as pitch/yaw euler rotations from a position along the Orbiter plus X (VEH DYN COORD system).
- F. Location of force (in inches from the X₀ coordinate system reference as defined in the SODB Vol. II Mass Prop Book).
- G. Any number of force vectors can be entered.

The program outputs are

- A. A printout of the input data.
- B. The total force vector data.
- C. Angular accelerations X, Y, Z of the vehicle in deg/sec².
- D. Linear accelerations X, Y, Z of the vehicle in ft/sec².

The basic equations used in this program are:

For the linear acceleration:

$$F = Ma$$
$$a = F/M$$

Where: F = net force (lbf)
M = mass (slug) = weight (lb)/32.17
a = linear acceleration (ft/sec²)

For the angular acceleration, torques are computed first:

$$T = F \times r$$

Where: T = torque (ft-lb)
F = net force (lbf)
r = distance from force to C.G. (ft)

The inverse of the inertia matrix [I] (after it is converted to the Orbiter Dynamic COORD system) is multiplied by the torque and then converted to deg/sec² from rad/sec²:

$$A = [I]^{-1} T (180/\pi)$$

Where: A = X, Y, Z accelerations in deg/sec²
[I]⁻¹ = inverse of inertia matrix in ORB DYN COORD system
 $\pi = 3.1416$

CENTRIPETAL ACCELERATION

Neither program calculates centripetal acceleration but it can be calculated as follows:

$$A_c = l^2 r$$

Where: A_c = centripetal acceleration (ft/sec²)
l = VEH rate (deg/sec) x (1/180)
r = distance (in feet) from the c.g. to the point of interest such as an IMU location.

PROCEDURES

- The ANGACL program is entered through the GNC DNAV MENU under "Apps". Use the left mouse to select "Apps" then select the ANGACL option.

PROGRAM NOTES

- A. The default inertias, C.G., and vehicle weight can be used or overwritten.
- B. Once the mass properties are entered, additional computations can be made without re-entering the mass properties.

The mass property data IXX, IYY, IZZ, IXY, IXZ, IYZ, C.G. X, Y, Z locations, and vehicle weight can be found in the appropriate SODB Vol. II Mass Property Book Appendix.

REFERENCE

GNC Offline Program ANGACL Documentation Folder.

ANGACL PROG GNC SCP 5.1, ACCEL CALC, (5/14/85)

THIS PROGRAM CALCULATES ANGULAR AND TRANSLATIONAL ACCELERATIONS ON THE ORBITER DUE TO AN APPLIED FORCE--IT IS STORED ON CONTROL TAPES IN THE MCC AS-ANGACL, ANY NUMBER OF FORCE VECTORS CAN BE SUMMED.

FORCE VECTOR NO.=1

FORCE VECTOR $F_x = -28.000$ $F_y = 616.400$ $F_z = -639.500$
Roh = 92.507 $\Gamma = 43.919$ FORCE = 888.647
LOCATION $X = 333.800$ $Y = -61.400$ $Z = 357.000$

FORCE VECTOR NO.=2

FORCE VECTOR $F_x = -24.800$ $F_y = 612.600$ $F_z = -639.400$
Roh = 92.221 $\Gamma = 43.752$ FORCE = 885.848
LOCATION $X = 348.400$ $Y = -66.200$ $Z = 358.400$

CURRENT INERTIAS (SLUG-FT²):

$I_{xx} = 920734.9$
 $I_{yy} = 7101971.5$
 $I_{zz} = 7381760.4$
 $I_{xy} = -5492.6$
 $I_{xz} = 216457.4$
 $I_{yz} = 2405.8$

CURRENT C.G. (INCHES):

$X = 1110.0$
 $Y = 0.0$
 $Z = 375.9$

 $Wgt = 204701.9$

FOR A FORCE VECTOR (lbf):

$F_x = -52.800$
 $F_y = 1229.00$
 $F_z = -1278.900$

WITH RHO,GAMMA(DEG) AND FORCE(lbf) OF:

$Rho = 92.364$
 $\Gamma = 43.836$
FORCE = 1774.490

THE ANG ACCLS(DEG/SEC²) ARE:

$A_x = .45734$
 $A_y = .66060$
 $A_z = .62227$

THE TRANSLATIONAL ACCLS (FT/SEC²) ARE:

$X = -.00830$
 $Y = +.19314$
 $Z = -.20099$

VEHICLE TORQUES(FT-LBS) ARE:

$T_x = 4935.260$
 $T_y = 81865.312$
 $T_z = 78470.407$

NUMBER OF FORCE VECTORS = 2

Figure 5.1-1 - Angular and translational acceleration calculation example.

TABLE 5.1-I.-ORBITAL MANEUVERING SUBSYSTEM (OMS) DATA
[SODB, VOL I, PAR. 4.3.3.4.6, AND SODB, VOL II, FIGURE 4.1-2 TO 8]

	Thrust point location (inch)			Null position (deg)		Null offset (deg)	
	X ₀	Y ₀	Z ₀	Pitch/RHO	Yaw/GAM	Pitch	Yaw
L OMS	1518	-88	492	0/-15.824	0/+6.5	-15.824	+6.5
R OMS	1518	+88	492	0/-15.824	0/-6.5	-15.824	-6.5

- RHO = pitch trim + pitch offset
- GAM = yaw trim + yaw offset
- Approximate thrust force is 6000 lbf/engine
- OMS engine null offset positions are:
 L/R pitch = -15° 49' 28" (-15.824444 deg)
 L yaw = +6° 30' (+6.5 deg)
 R yaw = -6° 30' (-6.5 deg)

TABLE 5.1-II. - SPACE SHUTTLE MAIN ENGINE (SSME)DATA
[SODB, VOL I, PARAGRAPHS 4.3.1.1.T.1 AND 2]

	Thrust point location (inch)			Null position (deg)		Null offset (deg)	
	X ₀	Y ₀	Z ₀	Pitch/RHO	Yaw/GAM	Pitch	Yaw
SSME 1	1445.00	0	443.0	0/-16	0/0	-16.0	0.0
SSME 2	1468.17	-53	342.64	0/-10	0/+3.5	-10.0	+3.5
SSME 3	1468.17	+53	342.64	0/-10	0/-3.5	-10.0	-3.5

TABLE 5.1-III. - SPACE SHUTTLE MAIN ENGINE (SSME) DATA

	MPS dump position (deg) (I-load)*		MPS stow position (deg) (I-load)	
	Pitch/RHO	Yaw/GAM	Pitch	Yaw
SSME 1	10.0/-6	0/0	0/-16.0	0/0
SSME 2	10.5/.5	0/+3.5	-10/-20	-3.5/0
SSME 3	10.5/.5	0/-3.5	-10/-20	+3.5/0

- RHO = pitch + pitch offset
- GAM = yaw + yaw offset
- Approximate thrust force (LO2) during MPS dump is approximately 700 lbf/engine *

- LH2 dump location for norm mission is: $X_0 = 1453.06$
 $Y_0 = -116.83$
 $Z_0 = 392.30$
- Approximate thrust force (100 percent)
During engine burn is
 - (a) Sea level $375,000 \pm 6,000$ lbf
 - (b) Vacuum $470,000 \pm 6,000$ lbf

*For detailed information on MPS dumps, refer to SODB Vol. 1.

TABLE 5.1-IV.- SOLID ROCKET BOOSTER ENGINE (SRB) DATA
[SODB, VOL I, FIGURE 2-1]

	Thrust point location (inch)		
	X_0	Y_0	Z_0
L SRB	1671.0	-250.5	63.5
R SRB	1671.0	+250.5	63.5

SRB Thrust Per Engine:

Sea level = 2,650,000 lbf
Vacuum = 3,000,000 lbf

TABLE 5.1-V.- IMU LOCATIONS-INCHES (FT)
[SODB, VOL I, PARAGRAPH 4.5.1.2.3.B]

IMU	X_0	Y_0	Z_0
1	419.2 (34.9)	-13.75 (-1.2)	422 (35.2)
2	419.2 (34.9)	0.0	422 (35.2)
3	419.2 (34.9)	13.75 (1.2)	422 (35.2)

TABLE 5.1-VI.-RCS DATA
[X₀, Y₀, Z₀, and FX_b, FY_b, FZ_b=JET LOC (inch) and JET FORCE X, Y, Z, (LB)]
[SODB, Vol 1, Paragraph 4.3.2.4.1]

Thrust number	Thrust components, lb			Resultant thrust, lb	Thrust Location, inch		
	FX _b	FY _b	FZ _b		X ₀	Y ₀	Z ₀
F2F	-875.1	-26.2	148.0	887.9	306.72	14.65	392.96
F3F	-875.1	0.0	150.9	888.0	306.72	0.0	394.45
F1F	-875.1	26.2	148.0	887.9	306.72	-14.65	392.96
F1L	-26.3	873.6	18.2	874.2	362.67	-69.50	373.73
F3L	-21.0	870.3	0.5	870.6	364.71	-71.65	359.25
F2R	-26.3	-873.6	18.2	874.2	362.67	69.50	373.73
F4R	-21.0	-870.3	0.5	870.6	364.71	71.65	359.25
F2U	-32.3	-11.7	874.4	875.1	350.93	14.39	413.46
F3U	-31.9	0.0	873.5	874.1	350.92	0.0	414.53
F1U	-32.3	11.7	874.4	875.1	350.93	-14.39	413.46
F2D	-28.0	-616.4	-639.5	888.6	333.84	61.42	356.95
F1D	-28.0	616.4	-639.5	888.6	333.84	-61.42	356.95
F4D	-24.8	-612.6	-639.4	885.9	348.44	66.23	358.44
F3D	-24.8	612.6	-639.4	885.9	348.44	-66.23	358.44
F5R	-0.8	-17.0	-17.6	24.5	324.35	59.70	350.12
F5L	-0.8	17.0	-17.6	24.5	324.35	-59.70	350.12
R3A	856.8	0.0	151.1	870.0	1555.29	137.00	473.06
R1A	856.8	0.0	151.1	870.0	1555.29	124.00	473.06
L3A	856.8	0.0	151.1	870.0	1555.29	-137.00	473.06
L1A	856.8	0.0	151.1	870.0	1555.29	-124.00	473.06
L4L	0.0	870.5	-22.4	870.8	1516.00	-149.87	459.00
L2L	0.0	870.5	-22.4	870.8	1529.00	-149.87	459.00
L3L	0.0	870.5	-22.4	870.8	1542.00	-149.87	459.00
L1L	0.0	870.5	-22.4	870.8	1555.00	-149.87	459.00
R4R	0.0	-870.5	-22.4	870.8	1516.00	149.87	459.00
R2R	0.0	-870.5	-22.4	870.8	1529.00	149.87	459.00
R3R	0.0	-870.5	-22.4	870.8	1542.00	149.87	459.00
R1R	0.0	-870.5	-22.4	870.8	1555.00	149.87	459.00
L4U	0.0	0.0	870.0	870.0	1516.00	-132.00	480.50
L2U	0.0	0.0	870.0	870.0	1529.00	-132.00	480.50
L1U	0.0	0.0	870.0	870.0	1542.00	-132.00	480.50
R4U	0.0	0.0	870.0	870.0	1516.00	132.00	480.50
R2U	0.0	0.0	870.0	870.0	1529.00	132.00	480.50
R1U	0.0	0.0	870.0	870.0	1542.00	132.00	480.50
L4D	170.4	291.8	-801.7	870.0	1516.00	-111.95	437.40
L2D	170.4	291.8	-801.7	870.0	1529.00	-111.00	440.00
L3D	170.4	291.8	-801.7	870.0	1542.00	-110.06	442.60
R4D	170.4	-291.8	-801.7	870.0	1516.00	111.95	437.40
R2D	170.4	-291.8	-801.7	870.0	1529.00	111.00	440.00
R3D	170.4	-291.8	-801.7	870.0	1542.00	110.06	442.60
L5D	0.0	0.0	-24.0 ^d	24.0 ^d	1565.00	-118.00	455.44
R5D	0.0	0.0	-24.0 ^d	24.0 ^d	1565.00	118.00	455.44
L5L	0.0	24.0	-0.6	24.0	1565.00	-149.87	459.00
R5R	0.0	-24.0	-0.6	24.0	1565.00	149.87	459.00

ON-ORBIT VENTING

The forces and moments produced by the on-orbit venting of effluents can reduce navigation and pointing accuracies and affect the rate of RCS propellant consumption required to maintain attitude. There are three categories of on-orbit venting. They are scheduled, contingency, and failure. See figure 5.1-2 for an overview of venting locations.

A. SCHEDULED VENTING

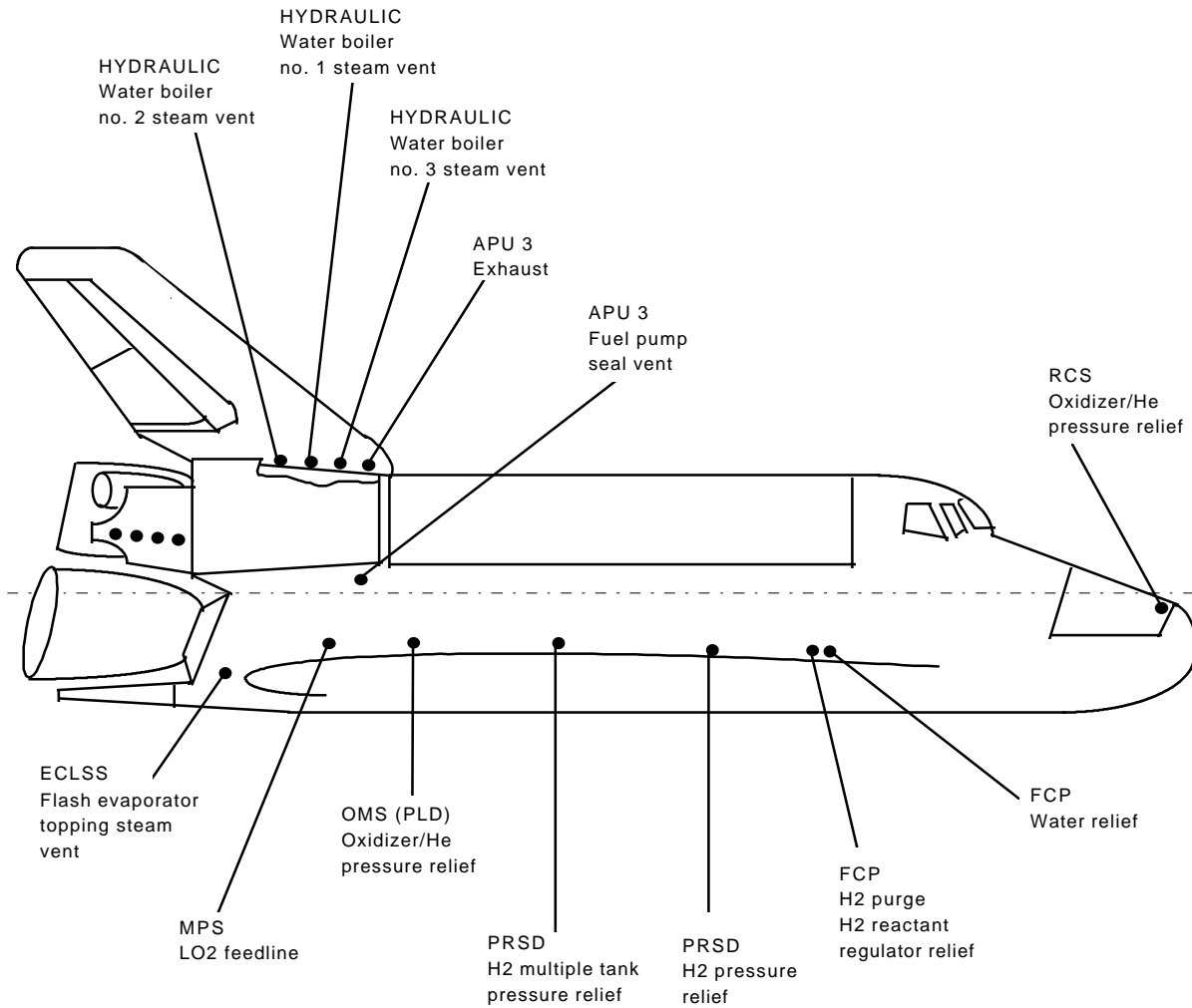
1. Thrust due to airlock depressurization
2. Flash evaporator in the full-up mode of operation
 - a. High-load nozzle
 - b. Impingement forces and moments
 - c. Topping nozzle
3. Flash evaporator in the topping mode of operation
4. FCP purge thrust
5. Hydraulics water-boiler thrust
 - a. WSB nozzle thrust vs. water flow rate (single WSB)
 - b. Steady-state WSB nozzle thrust force (one nozzle) vs. percent of full APU power
 - c. APU/hydraulic water boiler steam flowrate vs. percent APU shaft horsepower
 - d. WSB thrust force vs. time (single nozzle)
6. APU thrust
7. MPS liquid hydrogen propellant dumping thrust, forces and moments due to impingement

B. CONTINGENCY VENTING

1. APU/WSB, AOA on-orbit thrust

C. FAILURE VENTING

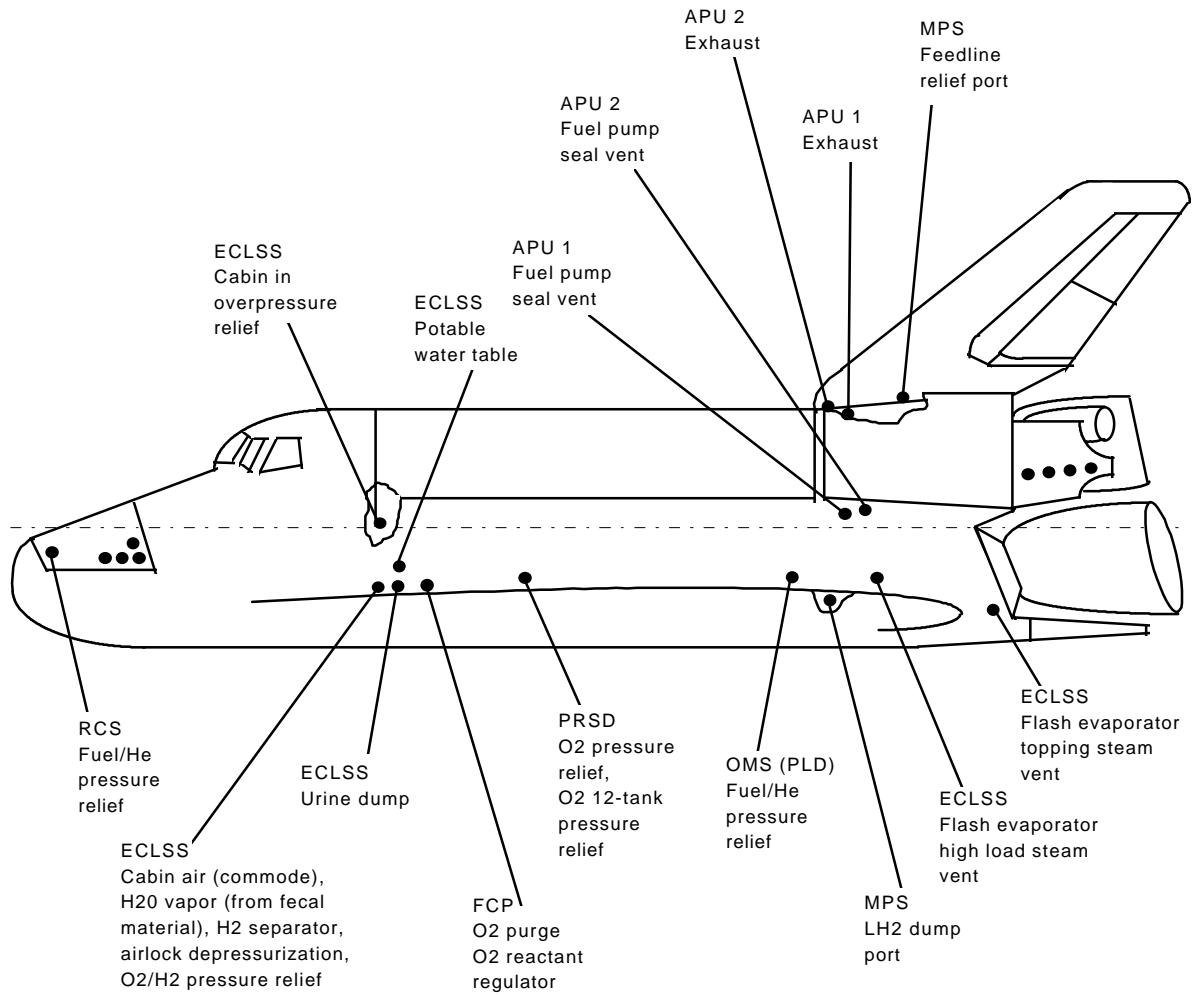
1. RCS thrust
2. FCP reactant regulator relief thrust



(a) Right side

Note: See SODB, vol, I, paragraph 4.1.4.6, On-orbit Venting, for detail vent force, and location data.

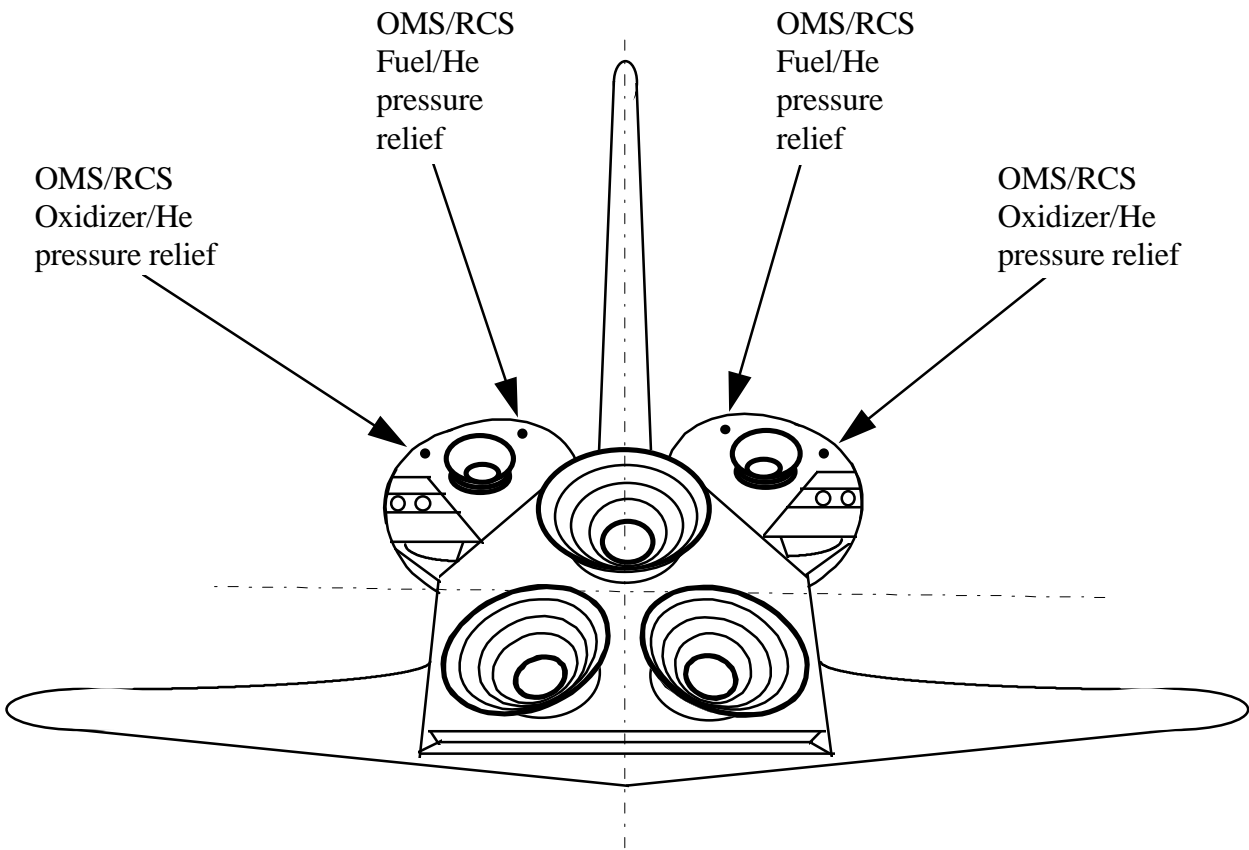
Figure 5.1-2.- Overview of on-orbit venting locations.



(b) Left side

Note: See SODB, vol, I, paragraph 4.1.4.6, On-orbit Venting, for detail vent force, and location data.

Figure 5.1-2.-Continued.



(c) Rear view

Note: See SODB, vol, I, paragraph 4.1.4.6, On-orbit Venting, for detail vent force, and location data.

Figure 5.1-2.-Concluded

Table 5.1-VII - SCHEDULED VENTING

Source	Location			Effluent	Thrust, lb	Vector			Duration	Remarks
	X0	Y0	Z0			FXB	FYB	FZB		
ECLSS Cabin air (commode)	602.0	-105.5	335.965	Air	Negligible	0	1	0	2 sec, 4 to 14 times per 24 hr	Depends on number of people
Water vapor from fecal material	602.0	-105.5	335.965	H ₂ O	Negligible	0	1	0	Continuous	Flow rate 2 x 10 ⁻⁷ lb/sec
H ₂ O separator (FCP water)	602.0	-105.5	335.965	H ₂	Negligible	0	1	0	Continuous	
Airlock depressurization ^a	602.0	-105.5	335.965	Air	1.0 to 4.75	0	1	0	8 minutes, three times per mission	
Waste water dump	620.0	-105.5	335.965	Urine Humidity condensation	0.093	0	1	0	4.5 hr per week-mission < 7 days	
Potable water dump	620.0	-105.5	342.4	Water	0.093	0	1	0	3 hr per day	Dependent on fuel cell H ₂ O production rate.
Flash evaporator topping 1 and 2 ^a	1505.7	±128.4	304.8 ^b	H ₂ O (steam)	0.21 max Full-up mode Topping mode	-0.1102	0.9916	0.0677	10 hr/day average	Dependent on fuel cell H ₂ O production rate. Supplements radiators during orbital operations.
High load ^a	1390.3	-113.8	326.8	H ₂ O (steam)	2.08 max Full-up mode	-0.1031	0.9943	0.0284	Operational during ascent above 140,000 ft and after payload bay door closure down to 100,000 ft.	Supplements radiators during orbital operations.
Fuel cell H ₂ purge ^a	640.9	105.4	339.2	H ₂ (g)		0	-1	0	Normal mode: 2 minutes per FCP every 8 hr	
O ₂ purge ^a	640.9	-105.4	339.2	O ₂ (g)		0	1	0	Concurrent with H2 purge	

^a See SODDB vol. 1 paragraph 4.1.4.6 for additional data.

^b OV-102

Table 5.1-VII - CONCLUDED

Source	Location			Effluent	Thrust, lb	Vector			Duration	Remarks
	X0	Y0	Z0			FXB	FYB	FZB		
Hydraulics water boiler Number 1 ^a Number 2 ^a Number 3 ^a	1375.7	16.3	508.1	H ₂ O (g)	3.0 max	0	0	1	15 minutes ascent, 5 minutes checkout, & 65 minutes entry	Ascent, On-orbit APU checkout, Deorbit burn and entry
	1385.7	16.3	510.5	H ₂ O (g)	3.0 max	0	0	1		
	1355.7	16.4	505.8	H ₂ O (g)	3.0 max	0	0	1		
APU exhaust APU 1 ^a APU 2 ^a APU 3 ^a	1327.9	-15.9	502.5	N ₂ (g)	23.0 max	0	0	1	15 minutes ascent, 5 minutes checkout, & 65 minutes entry	Ascent, On-orbit APU checkout, Deorbit burn and entry
	1318.7	-15.7	501.3	H ₂ (g)	23.0 max	0	0	1		
	1327.9	15.9	502.5	NH ₃ (g)	23.0 max	0	0	1		
MPS LH ₂ LO ₂ LH ₂	1453.1	-116.8	372.3	LH ₂		0	0.989	-0.017	c	Normal and TAL abort
	Through engines 1334	-108	315.4	LO ₂ LH ₂	c c				c c	Typical RTLS

^a See SODB vol. 1 paragraph 4.1.4.6 for additional data.

^c See SODB vol. 1 paragraph 4.3.1.10 for additional data.

Table 5.1-VIII - CONTINGENCY VENTING

Source	Location			Effluent	Thrust, lb	Vector			Duration	Remarks
	X0	Y0	Z0			FXB	FYB	FZB		
Fuel cell water relief	631.1	105.4	339.2	Water (l)	< 0.01	0	-1	0	Can be continuous	Occurs only if ECLSS cannot accept FCP water.
Hydraulics water boiler Number 1 ^a Number 2 ^a Number 3 ^a	1375.7	16.3	508.1	H ₂ O (g)		0	0	1	AOA from MECO to EI	
	1395.7	16.3	510.5	H ₂ O (g)		0	0	1		
	1395.7	16.4	505.8	H ₂ O (g)		0	0	1		
APU exhaust APU 1 ^a APU 2 ^a APU 3 ^a	1327.9	-15.9	502.5	N ₂ (g)		0	0	1	AOA from MECO to EI	
	1318.7	-15.7	501.3	H ₂ (g)		0	0	1		
	1327.9	15.9	502.5	NH ₃ (g)		0	0	1		

^a See SODB vol.1 paragraph 4.1.4.6 for additional data

Table 5.1-IX - FAILURE VENTING

Source	Location			Effluent	Thrust, lb	Vector			Duration	Remarks
	X0	Y0	Z0			FXB	FYB	FZB		
RCS pressure relief ^a										
Fwd oxidizer	285.5	40.6	361.4	He+	19.8 max	-0.4520	-0.8103	0.3729	30 sec max	Occurs only if open failure of both primary and secondary regulators.
Fwd fuel	285.5	-40.6	361.4	N ₂ O ₄	19.8 max	-0.4520	0.8103	0.3729		
Aft oxidizer (RHS)	1507.7	128.1	510.1	MMH	19.8 max	0.9986	-0.0379	0.0366		
Aft fuel (RHS)	1509.4	65.7	529.9	N ₂ O ₄	19.8 max	0.9986	-0.0379	0.0366		
Aft oxidizer (LHS)	1507.2	-128.1	510.1	MMH	19.8 max	0.9986	0.0379	0.0366		
Aft fuel (LHS)	1509.4	-65.7	529.9	N ₂ O ₄	19.8 max	0.9986	0.0379	0.0366		
MMH										
OMS pressure relief				He+					3 minutes max	Occurs if open failure of both primary and secondary regulator stages, excessive regulator/isolation valve leakage or prop tank over-temperature.
Oxidizer (RHS)	1507.7	128.1	510.1	N ₂ O ₄	12.35	0.9986	-0.0379	0.0366		
Fuel (RHS)	1509.4	65.7	529.9	MMH	12.35	0.9986	-0.0379	0.0366		
Oxidizer (LHS)	1507.2	-128.1	510.1	N ₂ O ₄	12.35	0.9986	-0.0379	0.0366		
Fuel (LHS)	1509.4	-65.7	529.9	MMH	12.35	0.9986	-0.0379	0.0366		
APU fuel pump seal										
APU 1	1343.3	-107.8	413.3	N ₂ H ₄	3.5	0	1	0	9 minute max	3 kits Failure of fuel pump seal ring only
APU 2	1349.9	-108.3	413.6	N ₂ H ₄	3.5	0	1	0	Leakage stops at crew initiated shutdown	
APU 3	1343.3	107.8	413.3	N ₂ H ₄	3.5	0	-1	0		
ECLSS										
O ₂	602.0	-105.5	335.965	O ₂ (g)	4.6	0	1	0	10 minutes maximum (deplete one tank)	Single failure of pressure regulators
N ₂	602.0	-105.5	335.965	N ₂ (g)	4.9	0	1	0	16 minutes (deplete two of four tanks)	
Cabin overpressure relief valves ^b										
	576.0	-67.7	394.4	Air	53	-1	0	0	Flow stops at crew-initiated shutdown	Opens at 15.5 psi cabin pressure
	576.0	-74.2	394.4		53 (nozzle thrust) ^{bc}	-1	0	0		

^a See SODB vol. 1 paragraph 4.1.4.6 for additional data.

^b Plume impingement within PLB will change magnitude and direction of thrust vector.

^c Regulator or line failure resulting inflow through both valves.

Table 5.1-IX - CONCLUDED

Source	Location			Effluent	Thrust, lb	Vector			Duration	Remarks
	X0	Y0	Z0			FXB	FYB	FZB		
PRSD H ₂ relief (fwd) ^a H ₂ relief (aft) ^a O ₂ relief ^a	822.2	105.4	342.5	H ₂ (g)	0.10/tank	0	-1	0	Total venting time (each tank) in 17 hr: ~20min in cycles < 10 sec Total venting time (each tank) in 16 hr: ~2.4hr in cycles ≤100 sec	Occurs due to tank overheat; heaters failed ON most likely cause.
	990.0	105.4	342.5	H ₂ (g)	0.07/tank	0	-1	0		
	760.0	-105.4	355.5	O ₂ (g)	0.57/tank	0	1	0		
Fuel Cell ^a H ₂ reactant regulator O ₂ reactant regulator	640.9	105.4	339.2	H ₂ (g)		0	-1	0	Flow stops at crew-initiated isolation.	Failure of FCP reactant regulator.
	640.9	-105.4	339.2	O ₂ (g)		0	1	0		
Hydraulic water boiler ^a Number 1 Number 2 Number 3	1375.7	16.3	508.1	H ₂ O (g)	3.0 max	0	0	1	No venting if hydraulic system fails.	
	1385.7	16.3	510.5	H ₂ O (g)	3.0 max	0	0	1		
	1355.7	16.4	505.8	H ₂ O (g)	3.0 max	0	0	1		

^a See SODB vol. 1 paragraph 4.1.4.6 for additional data.

TITLE

UNIVERSAL POINTING BODY VECTOR OMICRON/LVLH ATTITUDE CALCULATION (PYOM)

PURPOSE

To describe the procedure for calculating the spacecraft body vector (pitch, yaw, omicron) used with onboard universal pointing display OPS 2011 when given the local vertical local horizontal (LVLH) attitude (X, Y, Z) that will point the body vector toward the center of the Earth and the converse; i.e., calculate the LVLH attitude when given the body vector and omicron. This procedure also includes the calculations for determining the ORBITAL PERIOD, the ORB RATE, and the LVLH AVERAGE VEHICLE body rates. A computer program is available for these calculations and is described below.

BACKGROUND

This procedure is used to support the Mission Control Center (MCC) GNC/ CONTROL positions responsible for maintaining the optimum spacecraft attitude during gravity gradient (GG) maintenance operations. The S/C LVLH attitude during GG operations is analyzed by flight controllers to determine if a new body vector/omicron needs to be uplinked to the crew to optimize S/C attitude control.

PROGRAM DESCRIPTION

The program consists of three separate subprograms: A, B, and C.

- A. Program A computes the pitch, yaw body vector, and omicron for a roll, pitch, yaw LVLH attitude input.
- B. Program B computes the LVLH roll, pitch, yaw attitude for a pitch, yaw body vector, and omicron input (converse of program A).
- C. Program C computes the Orbiter roll, pitch, and yaw body rates, the orbital period, and the orbital rate for any LVLH attitude and apogee/perigee input.

NOTE: There are "singularity" points with this program as follows:

- When the dot product of VEC BOD and RR BOD is +1 (i.e., when body vec yaw = +90°), the omicron is redefined by using S/C -Z axis instead of +Y axis for RR BOD.
- When VEC M50 (target vector) is along the -H (momentum vector). This case does not apply with this program since the target vector is always 90° from -H vector (LVLH ref definition).
- When the LVLH ATT is near +90° yaw, the X (roll) is made = 0.

- The user should always use program "B" to verify LVLH ATT and body vector to ensure correct understanding of data in view of above singularity conditions.

The math and algorithms for this program are as follows:

A. PROGRAM B DESCRIPTION

1. Inputs: Pitch, yaw, omicron (body vector)
2. Outputs: LVLH attitude X, Y, Z to point body vector to center of Earth
3. The direction cosine matrix transformation from the LVLH system to the required body system (M_LVLH RBD) is computed as follows:

$$\begin{aligned} \bar{Y}N &= \text{UNIT} (\text{VEC_}\bar{B}OD \times \text{RR_}\bar{B}OD) \\ \bar{Y}T &= \text{UNIT} (\text{VEC_}M50 \times \text{RR_}M50) _ \text{SIN} (\text{ROLL}) \\ &\quad - \text{VEC_}M50 \times \text{UNIT} (\text{VEC_}M50 \times \text{RR_}M50) _ \text{COS} (\text{ROLL}) \\ \text{MTP} &= [\text{MATRIX} (\text{VEC_}\bar{B}OD, \text{VEC_}\bar{B}OD \times \bar{Y}N, -\bar{Y}N)] T_x \\ &\quad [\text{MATRIX} (\text{VEC_}M50, \text{VEC_}M50 \times \bar{Y}T, -\bar{Y}T)] \end{aligned}$$

Where: $\text{VEC_}\bar{B}OD = (\text{CPCY}, \text{SY}, -\text{SPCY})$

Y = YAW BODY VEC
P = PITCH BODY VEC

$\text{RR_}BOD = \text{BODY ROLL REF} = (0, 1, 0)$ when $|\text{SIN YAW BODY VEC}| \leq .999848$

$\text{RR_}BOD = (0, 0, -1)$ when $|\text{SIN YAW BODY VEC}| > .999848$

$\text{VEC_}M50 = \text{TARGET VECTOR} = (0, 0, 1)$

$\text{ROLL} = \text{OMICRON} + 90$

$\text{RR_}M50 = - \text{unit} (\text{RORB} \times \text{VORB}) = (0,1,0)$

4. The required LVLH attitude (P, Y, R Euler order) is then extracted from the matrix $M_{LVLH RBD}$:

$$M_{LVLH RBD} = \begin{bmatrix} CPCY & SY & -SPCY \\ -CPSYCR & CYCR & SPSYCR \\ +SPSR & & +CPSR \\ CPSYSR & -CYSR & -SPSYSR \\ +SPCR & & +CPCR \end{bmatrix}$$

$$= \begin{bmatrix} A11 & A12 & A13 \\ A21 & A22 & A23 \\ A31 & A32 & A33 \end{bmatrix}$$

LVLH ATT is:

$$(Z) \text{ YAW} = \text{SIN}^{-1} (A12) \text{ constrained to } \pm 90^\circ$$

$$(Y) \text{ PITCH} = \text{TAN}^{-1} (-A13/A11)^*$$

$$(X) \text{ ROLL} = \text{TAN}^{-1} (-A32/A22)^*$$

IF $|\text{COS YAW}| < 0.005$, THEN ROLL is made = 0, and
(Y) $\text{PITCH} = \text{TAN}^{-1} (A31/A33)^*$

B. PROGRAM A DESCRIPTION

This program is the converse of PROG B.

1. Inputs: LVLH attitude X, Y, Z to point body vector to center of Earth.
2. Outputs: Pitch, yaw, omicron (body vector) from direction cosine matrix transformation same as in step 4 preceding.

$$\text{PITCH BODY VEC} = \text{TAN}^{-1} (-A33/A13)^*$$

$$\text{YAW BODY VEC} = \text{SIN}^{-1} (A23)$$

$$\text{OMICRON} = \text{TAN}^{-1} (-A21/A22)^* \text{ when } |\text{SIN YAW BODY VEC}| \leq .999848$$

$$\text{OMICRON} = \text{TAN}^{-1} (A31/-A32)^* \text{ when } |\text{SIN YAW BODY VEC}| > .999848$$

* ARCTAN2 function resolves quadrant according to signs of the arguments.

C. PROGRAM C DESCRIPTION

1. Inputs: Roll, pitch, yaw LVLH attitude (deg) apogee/perigee (n.mi.)
2. Outputs: Body rates RDOT, PDOT, YDOT (deg/sec), orbital period (min), orbit rate (deg/sec)

D. ORBITAL PERIOD

$$p = \frac{2\pi a^{3/2}}{\sqrt{\mu}}$$

Where: a = Earth radius + h (feet)

$$h = (\text{apogee} + \text{perigee})/2$$

$$\mu = 1.407646882 \times 10^{16} \text{ (ft}^3/\text{s}^2\text{)}$$

p = orbital period (sec)

Earth radius = 3963.195563 statute miles

Statute mile = 5280 ft

Nautical-to-statute mile conversion = (n.mi.) * 1.150779448

E. ORBITAL RATE

$$\text{ORBRATE} = \frac{\sqrt{\mu a}}{a^2} * \left(\frac{180}{p} \right)$$

Where: a and μ are as above and ORB RATE is in deg/sec

F. BODY RATES

$$\text{RDOT} = - (\text{ORB RATE}) * \text{SIN (YAW)}$$

$$\text{PDOT} = - (\text{ORB RATE}) * \text{COS (YAW)} * \text{COS (ROLL)}$$

$$\text{YDOT} = - (\text{ORB RATE}) * (-\text{COS (YAW)} * \text{SIN (ROLL)})$$

Where: roll, yaw = roll, yaw LVLH attitude

G. PROCEDURE

1. In the MCC, select PYOM from the GNC DNAV MENU under "Apps".
2. Select desired option and follow the program prompts.

REFERENCES

1. Guidance, Navigation, and Control, FSSR STS81-0003A, Part A, Guidance On-Orbit/Deorbit, June 1985.
2. Bate, Roger R.; Mueller, Donald D.; and White, Jerry E.: Fundamentals of Astrodynamics, Dover Publications Inc., 1971.
3. GNC Offline Program PYOM Documentation Folder.

TITLE

ATTITUDE MANEUVER CALCULATIONS (ATTMNV)

PURPOSE

To describe a procedure for calculating spacecraft maneuver body rates, attitude errors, maneuver commands, and maneuver times for planned spacecraft maneuvers.

BACKGROUND

The Space Shuttle Orbiter vehicle has the capability to perform automatic and manual attitude maneuvers about its three-axis body coordinate system. Numerous attitude maneuvers are planned and performed during a Shuttle flight. Automatic maneuvers are performed by executing a vehicle rotation about an Eigen axis at a prescribed rate for a certain length of time to attain a predefined three-axis attitude. This procedure, through the use of a computer program, will provide flight controllers with useful calculated data in connection with planned spacecraft maneuvers.

DESCRIPTION

A. THE PROGRAM INPUTS ARE:

1. Current vehicle attitude X, Y, Z (deg)
2. Required vehicle attitude X, Y, Z (deg)
3. The desired vehicle maneuver rate (deg/sec)

B. OUTPUTS:

1. Total errors (fly-to) X, Y, Z (deg)
2. ADI errors (fly-from) X, Y, Z (deg) [small angle approximation]
3. Euler maneuver commands X, Y, Z (deg) in the pitch, yaw, roll Euler order
4. Vehicle body rates during Eigen maneuver X, Y, Z (deg/sec)
5. Total Eigen axis rotation (deg)
6. Maneuver time (seconds)
7. Eigen vector in P, Y body coordinates (deg) P, Y, order

C. EQUATIONS:

1. Quaternions are formed from the current and required attitude inputs as follows:

$$Q_I = \begin{bmatrix} s \\ v1 \\ v2 \\ v3 \end{bmatrix} = \begin{bmatrix} +(C_{\frac{x}{2}})(C_{\frac{y}{2}})(C_{\frac{z}{2}}) - (S_{\frac{x}{2}})(S_{\frac{y}{2}})(S_{\frac{z}{2}}) \\ -(S_{\frac{x}{2}})(C_{\frac{y}{2}})(C_{\frac{z}{2}}) - (C_{\frac{x}{2}})(S_{\frac{y}{2}})(S_{\frac{z}{2}}) \\ -(C_{\frac{x}{2}})(S_{\frac{y}{2}})(C_{\frac{z}{2}}) - (S_{\frac{x}{2}})(C_{\frac{y}{2}})(S_{\frac{z}{2}}) \\ -(C_{\frac{x}{2}})(C_{\frac{y}{2}})(S_{\frac{z}{2}}) + (S_{\frac{x}{2}})(S_{\frac{y}{2}})(C_{\frac{z}{2}}) \end{bmatrix}$$

where: I = curr or reqd
C = cosine
S = sine

2. The current attitude and required attitude quaternions are then multiplied to obtain the error quaternion as follows:

$$Q_{curr}^* = \text{conjugate of } Q_{curr}$$

$$Q_{err} = \begin{bmatrix} s \\ v1 \\ v2 \\ v3 \end{bmatrix} = [Q_{reqd}][Q_{curr}^*]$$

$$= \begin{bmatrix} QR_s QC_s - QR_{v1} QC_{v1} - QR_{v2} QC_{v2} - QR_{v3} QC_{v3} \\ QR_s QC_{v1} + QR_{v1} QC_s + QR_{v2} QC_{v3} - QR_{v3} QC_{v2} \\ QR_s QC_{v2} - QR_{v1} QC_{v3} + QR_{v2} QC_s + QR_{v3} QC_{v1} \\ QR_s QC_{v3} + QR_{v1} QC_{v2} - QR_{v2} QC_{v1} + QR_{v3} QC_s \end{bmatrix}$$

where: QR = Q_{reqd}

QC = Q_{curr}*

If Q_s < 0, then change sign of all four elements of Q_{err}

3. Outputs are extracted from the error quaternion Q_{err} (QE=Q_{err}) as follows:

$$\text{Total error } X = \frac{-2(QE_{v1}) \cos^{-1}(QE_s)}{\sqrt{1 - (QE_s)^2}}$$

$$\text{Total error } Y = \frac{-2(QE_{v2}) \cos^{-1}(QE_s)}{\sqrt{1 - (QE_s)^2}}$$

$$\text{Total error } Z = \frac{-2(QE_{v3}) \cos^{-1}(QE_s)}{\sqrt{1 - (QE_s)^2}}$$

$$\text{ADI error } X = 2(180 / p)(QE_{v1})$$

$$\text{ADI error } Y = 2(180 / p)(QE_{v2})$$

$$\text{ADI error } Z = 2(180 / p)(QE_{v3})$$

$$\text{Euler mnvr cmd } X = \arctan 2 \left(-2(QE_{v2}QE_{v3} + QE_{v1}QE_s), 1 - 2(QE_{v1}^2 + QE_{v3}^2) \right)$$

$$\text{Euler mnvr cmd } Y = \arctan 2 \left(-2(QE_{v1}QE_{v3} + QE_{v2}QE_s), 1 - 2(QE_{v1}^2 + QE_{v3}^2) \right)$$

$$\text{Euler mnvr cmd } Z = \arctan 2 \left(-2(QE_{v1}QE_{v2} - QE_{v3}QE_s), \sqrt{1 - 2(QE_{v1}QE_{v2} - QE_{v3}QE_s)^2} \right)$$

$$\text{Total Eigen axis rot} = 2 \cos^{-1}(QE_s) = q$$

$$\text{Maneuver time} = q/\text{des mnvr rate}$$

$$\text{Body rate } X = \text{Total error } X/\text{mnvr time}$$

$$\text{Body rate } Y = \text{Total error } Y/\text{mnvr time}$$

$$\text{Body rate } Z = \text{Total error } Z/\text{mnvr time}$$

$$\text{Eigen vector YAW} = \sin^{-1}(\cos \text{beta})$$

$$\text{Eigen vector PITCH} = -\tan^{-1}(\cos \text{gam}/\cos \text{alpha})$$

Where:

$$\text{alpha} = \cos^{-1} \left(\frac{-QE_{v1}}{\sin(q/2)} \right)$$

$$\text{beta} = \cos^{-1} \left(\frac{-QE_{v2}}{\sin(q/2)} \right)$$

$$\text{gam} = \cos^{-1} \left(\frac{-QE_{v3}}{\sin(q/2)} \right)$$

PROCEDURE

In the MCC, select ATTMNV from the GNC DNAV MENU under "Apps". The program will prompt you for inputs.

REFERENCES

1. Guidance, Navigation, and Control, FSSR STS81-0003A, Part A, Guidance On-Orbit/Deorbit, Universal Pointing Principal Function, June 1985.
2. GNC Offline Program ATTMNV Documentation Folder.

TITLE

ADI ATTITUDE CALCULATIONS FROM TLM (ADIATT)

PURPOSE

To describe a program that will calculate the three +X, -X, and -Z Orbiter ADI attitudes when given only one ADI attitude, the two RELQUAT's from TLM (Q_M50REF and Q_M50LVLH) and the Q_M50INRTL RELQUAT.

DESCRIPTION

The program is called "ADIATT". The program inputs are:

- ADI +X INERTIAL, REF, or LVLH attitude from the GNC ORBIT Display
- The INRTL RELQUAT
- Two RELQUAT's (REF and LVLH) from TLM in HBR or LBR.

The program outputs are:

- A printout of the input data
- The three ADI +X, -X, and -Z INERTIAL, REF, and LVLH attitudes
- The M50 (QBI) attitude which is the pitch, yaw, roll (euler order) angles (extracted from QBI) that define the spacecraft body axis system with respect to M50 reference when rotated from the M50 reference system.
- The quaternion QBI (S, V1, V2, V3) as it would appear on TLM

The program uses the appropriate RELQUAT in conjunction with the input attitude to calculate the quaternion QBI. QBI is then used in conjunction with the appropriate RELQUAT's to calculate the other two ADI attitudes. The +X ADI attitudes are then used to calculate the aft ADI -X and -Z attitudes.

The basic equations used for calculating the ADI LVLH attitude are given here as an example.

$$Q_BI = Q_BODYADIREF Q_M50INRTL^{-1}$$

$$Q_BODYADIREF = Q_BI Q_M50LVLH$$

Where: Q_BI is the body wrt M50 quaternion

Q_BODY ADIREF is derived from the ADI attitude input angles (ADI inertial attitude in this example)

Q_M50 INRTL is the INRTL RELQUAT (S/C I-LOAD 1, 0, 0, 0 for "M50" and 0.707107, 0.707107, 0, 0 for "STAR BALL")

Q_M50LVLH is an input from TLM

The ADI LVLH attitude angles (pitch, yaw, roll euler order) are extracted from the calculated quaternion Q_BODYADIREF.

PROCEDURE

In the MCC, select ADIATT from the GNC DNAV MENU under "Apps" and follow the program prompts.

PROGRAM APPLICATIONS

This program can be used to calculate all required attitudes in the event the MCC ADI attitude computation is not running such as for playback data.

This program can be used to calculate attitude data for postmission analysis when the desired attitude may not be on TLM.

The program can also calculate the right ascension (RA) and declination (DEC) of the orbiter +X axis for a given ADI +X inertial attitude input and the default RELQUATS. The output ADI +X REF output pitch will = RA and yaw = DEC. Conversely, the pitch and yaw inertial attitude can be calculated for a given RA and DEC. Input the RA and DEC as pitch and yaw ADI +X REF attitude using the default RELQUATS and read out the ADI +X inertial pitch and yaw angles.

NOTE: The orbiter on-board software will freeze the last value of pitch and roll when the cosine (yaw) is less than 0.03, which occurs when yaw is within 1.72° of 90 or 270 (singularity).

The ADIATT program will allow a yaw angle within approximately 0.0001° of 90 or 270 singularity but will warn the user if the yaw angle is within 1.72° of the 90/270 singularity.

REFERENCES

1. GNC Systems Console Handbook, JSC-12843, app. C, latest version.
2. GNC Offline Program ADIATT Documentation Folder.
3. The detail equations for the euler angle to quaternion, quaternion multi-ply and quaternion to euler angles conversion are contained in the Functional Subsystem Software Requirements (FSSR) Guidance, Navigation, and Control, Part C, Flight Control Orbit DAP, STS 83-0009B, June 30, 1987.

TITLE

GRAVITY GRADIENT OPERATIONS

PURPOSE

The purpose of this SCP is to describe the use of the Gravity Gradient (GG) program. This program will calculate the starting attitude for the orbiter when given either an atmospheric density or a standard atmospheric altitude. With a density input, the program will generate the proper attitude and the corresponding altitude. Likewise, with an altitude input, the program will generate the proper attitude and corresponding density.

BACKGROUND

During orbit operations, the shuttle may be configured into a free drift mode to minimize RCS propellant consumption and vehicle accelerations. In order to minimize attitude rates and errors, the shuttle is maneuvered to an initial gravity gradient attitude. The maneuver to and initialization of the GG free drift attitude may be performed using vernier or ALT DAP. The vernier DAP is preferred due to its ability to achieve lower rates. The vernier configuration for the initiation of the GG free drift attitude is:

VERN ROT RATE:	0.0080
VERN ATT DB:	0.070
VERN RATE DB:	.010
VERN ROT PLS:	0.010
VERN COMP:	.000
VERN CNTL ACC:	0

A DRAPER study shows that the most effective ALT DAP configuration for the initiation of the GG free drift attitude is:

Jet Selection:	Dot Product or Minimum angle
PRI ATT DB:	0.3 (minimum allowable)
ALT RATE DB:	0.07
ALT JET OPT:	Any (Low Z, All, Tail)
ALT # JETS:	1
ALT DELAY:	0

Currently, the Orbit Operations Checklist GG Free Drift procedure includes the appropriate item entries to ensure the GG A3 ALT DAP parameters are configured properly. The I-loaded A3 DAP contains the proper vernier configuration but not the correct ALT configuration because the I-loads were defined before the ALT configuration was determined. These DAP changes should be included in future updates to DAP A1-A8 I-loads.

The necessary release attitude is dependent upon the magnitude of the atmospheric density. This relationship between attitude and density has been obtained from a model developed by personnel in the On-Orbit FCS Section of the Navigation Control and Aeronautics Division of the Engineering Directorate (EG23).

DESCRIPTION

To convert a given standard atmospheric altitude to density, the program uses equations developed according to the 1962 Standard Atmosphere. To convert a given density to altitude, the program uses equations generated from a curve fit. These equations can be found in the Supplemental Information section of the GG Program Certification Folder. The values for pitch, yaw, and omicron are stored in variable arrays within the program for each orbiter configuration. When an altitude or density is read, the program will search the arrays for the proper boundary conditions. The proper GG starting attitude is found by interpolation between the boundary conditions.

PROCEDURE

In the following user's guide, program outputs to the screen are contained in boxes.

1. Obtain from the Flight Dynamics Officer (FDO) the current atmospheric density in slugs/ft³ for the Orbiter's current altitude.
2. The following options are displayed when the GG program is executed.

Enter the desired Shuttle orientation:
1) Nose Down Bay North
2) Nose Down Bay South
3) Nose Down Bay to RAM
4) Tail Down Bay North
5) Tail Down Bay South
6) Tail Down Bay to RAM
7) Exit program
Enter 1, 2, 3, 4, 5, 6 or 7:

3. Enter the desired shuttle orientation (items 1 thru 6), or item 7 to exit the program. If any other input is made, the program will announce "Unknown command" and then terminate operation.

Select a density or altitude input:
1) Density
2) Altitude
Enter 1 or 2:

4. Enter the desired option (1 or 2).

Enter the density in units of slugs/cubic foot:

or

Enter the altitude in units of nautical miles:

- a. If option 1 is selected, enter the density in slugs/cubic feet. The density input range is $1.0e-15 < \text{density} < 1.0e-12$.
- b. If option 2 is selected, enter the average altitude in nautical miles. The program computes a density from the standard atmosphere model for the input altitude and is therefore less precise than entering the current orbital altitude density as obtained from FDO. The altitude input range is $98 < \text{altitude} < 320$.

Gravity Gradient Operations
The orientation you chose is Nose Down Bay North. The density is 8.750000E-014 slugs/cubic foot. The corresponding altitude is 152.31 nautical miles. The GG starting attitude is: pitch = 357.59 degrees yaw = 0.74 degrees omicron = 243.98 degrees

5. The output of the program will be displayed on the screen. If in DOS, use the page up, page down, and ESC keys to view the data. If in UNIX, use the space bar to move through the data.

Do you wish to printout (y/n)?

6. Enter y/n if a hardcopy is desired.

Do you wish to view the GG datafiles (y/n)?

7. Enter y/n if the GG datafiles are to be viewed or printed.

Enter the desired Shuttle orientation:

- 1) Nose Down Bay North
- 2) Nose Down Bay South
- 3) Nose Down Bay to RAM
- 4) Tail Down Bay North
- 5) Tail Down Bay South
- 6) Tail Down Bay to RAM
- 7) Exit program

Enter 1, 2, 3, 4, 5, 6 or 7:

8. Enter the desired option (items 1 thru 7).

Do you wish a printout (y/n)?

9. Enter y/n if a hardcopy is desired.

Do you wish to run another case (y/n)?

10. Enter y/n if another case is to be executed. If no other cases are to be run, the program will terminate operation. The program output files are stored in the current working directory. Output files containing the calculated GG initial attitude are stored in the file "gg.out" and the data files containing the GG density and attitude data are stored in "ggdata.dat".

MANUAL METHOD

If for any reason the GG program is unable to execute, the following procedure should be used.

1. Obtain from the Flight Dynamics Officer (FDO) the current atmospheric density in slugs/ft³ for the Orbiter's current altitude.

2. To find the initial attitude for a given orientation, the following relationships can be used. Using the current atmospheric density, select the corresponding pitch, yaw, and omicron angles from the Nose Down Bay South (NDBS) graphs (Figures 1, 2, and 3). The initial attitudes for the other orientations can be found as follows:

Nose Down Bay North (NDBN):

pitch = NDBS
yaw = 360 - NDBS
omicron = 360 - NDBS

Nose Down Bay to RAM (NDBTR):

pitch = NDBS
yaw = 0.0
omicron = 0.0

Tail Down Bay North (TDBN):

pitch = NDBS - 180
yaw = 360 - NDBS
omicron = 180 - NDBS

Tail Down Bay South (TDBS):

pitch = NDBS - 180
yaw = NDBS
omicron = 180 + NDBS

Tail Down Bay to RAM (TDBTR):

pitch = NDBS - 180
yaw = 0.0
omicron = 180

ERROR HANDLING

The following table lists what the program does when an erroneous input is made for the different options.

OPTION	RESPONSE TO INCORRECT INPUT
Shuttle orientation	'UNKNOWN COMMAND' HIT <return> TO CONTINUE exits program
Density or altitude	'OUT OF RANGE' if out of range HIT <return> TO CONTINUE exits program
Print	defaults to 'n' if the response is not 'y'
View GG Data files	defaults to 'n' if the response is not 'y'
Run another case	defaults to 'y' if the response is not 'n'

REFERENCES

1. Memorandum from FM5/Advanced Mission Design Branch: Analytical Atmosphere Density Model

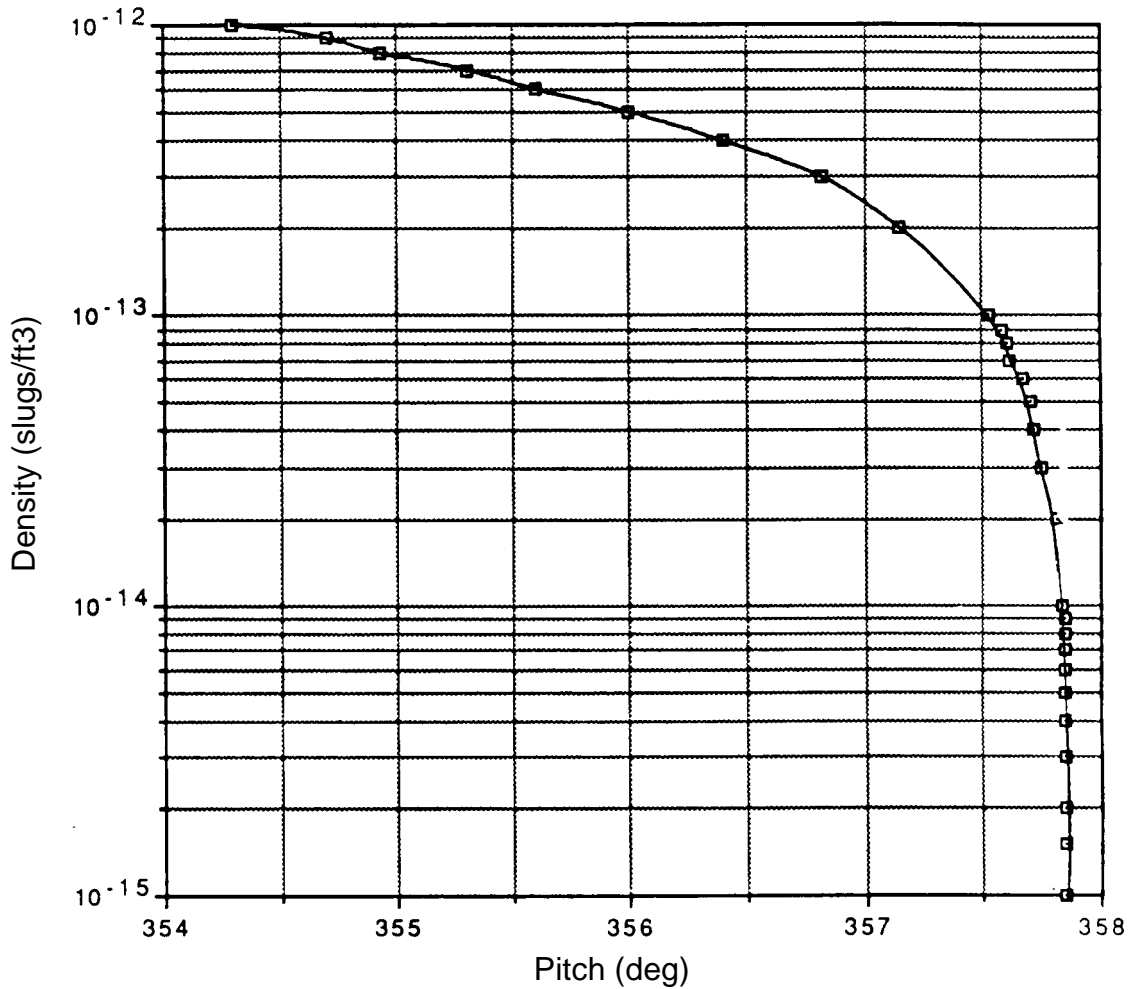


Figure 5.5-1. - Nose down, bay South - Pitch

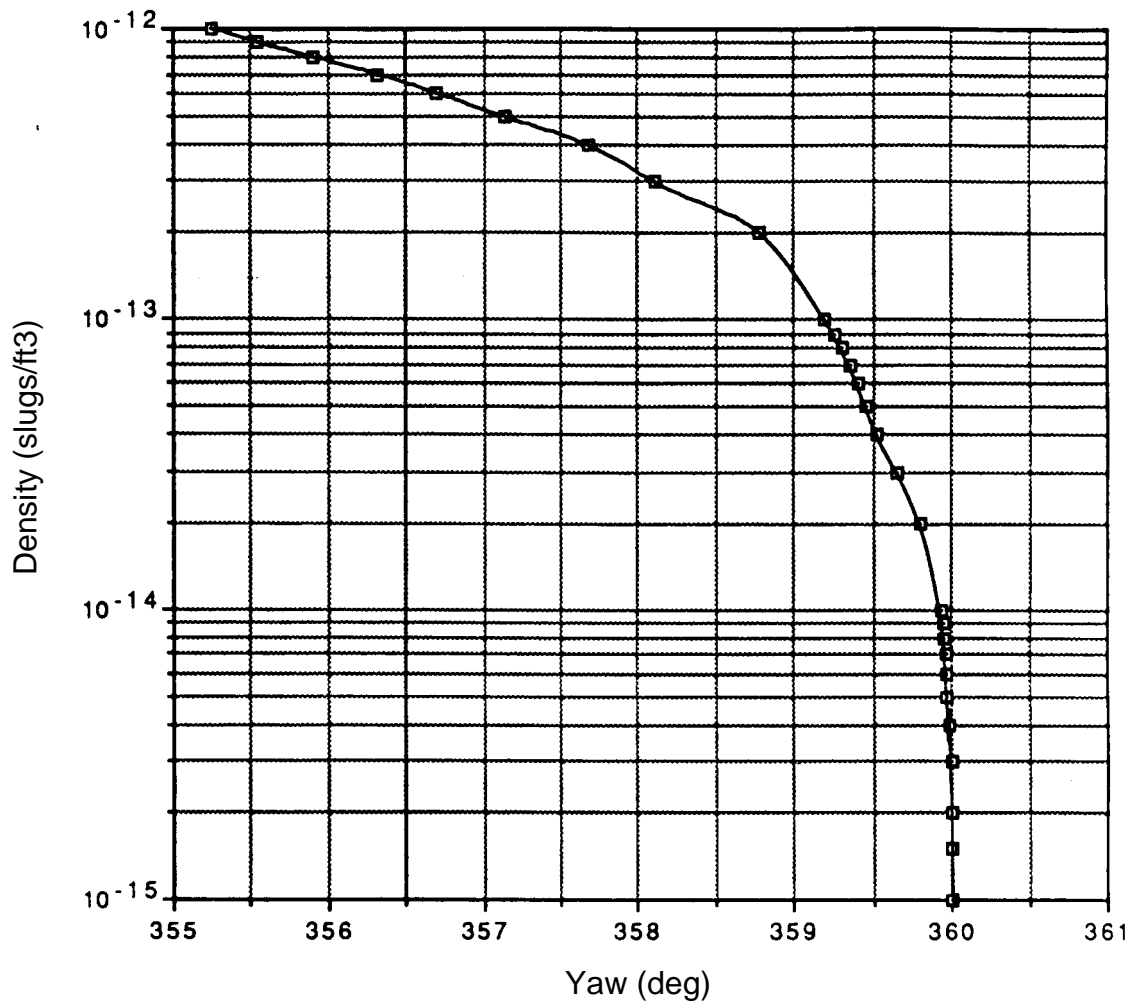


Figure 5.5-2. - Nose down, bay South - Yaw

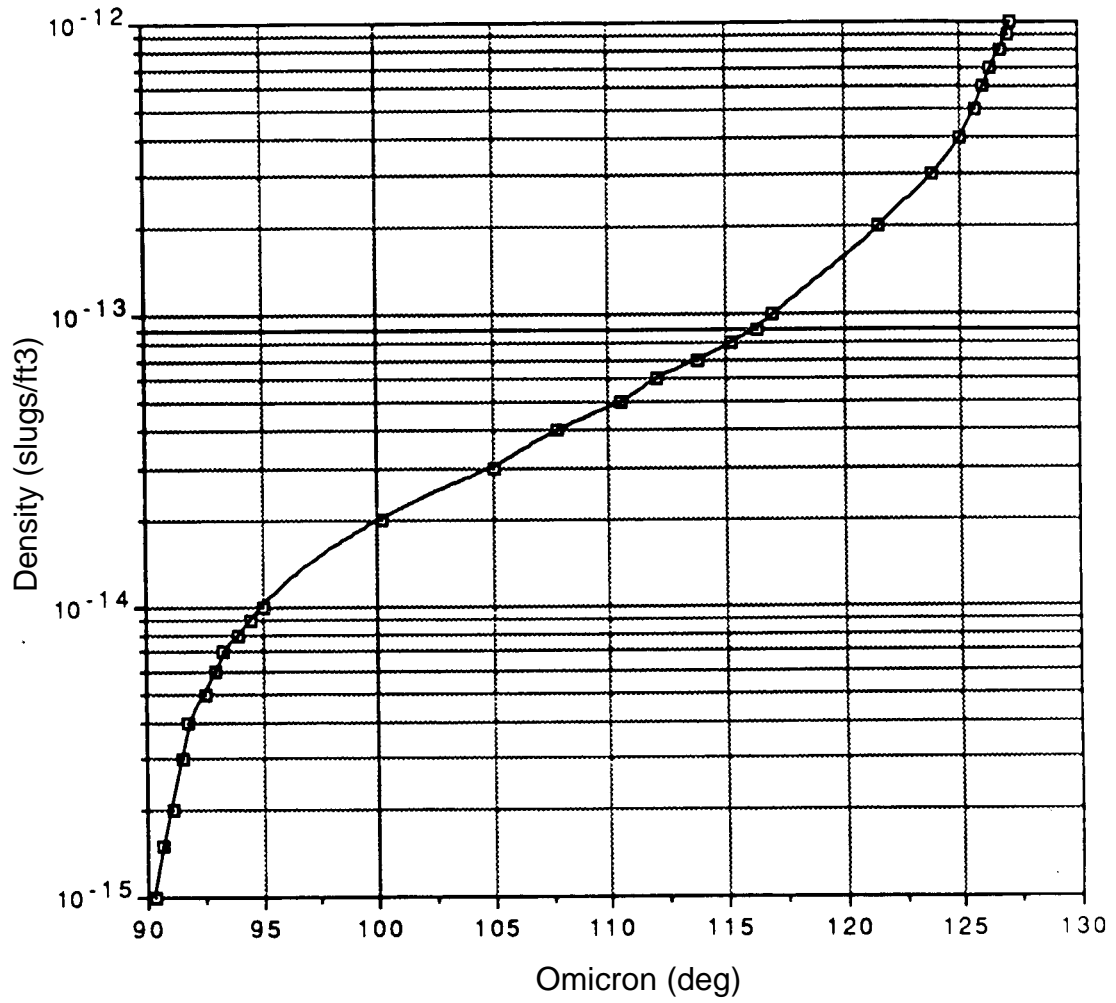


Figure 5.5-3. - Nose down, bay South - Omicron

TITLE

MANEUVER COMP (MNVR_COMP)

PURPOSE

The purpose of this SCP is to describe the maneuver comp program which runs as a background process to convert the various down-listed maneuver related quantities into more readable formats. It also calculates the rotations and completion times for down-listed required and/or desired maneuvers. The maneuver comp does not require manual inputs (all inputs come from the down-listed data) or display outputs. Instead, it reads ISP data and makes its outputs available (via ISP) to be displayed or utilized by other programs.

BACKGROUND

The maneuver comp program makes possible real time calculations that are too time consuming to do continuously throughout a flight. The outputs are utilized by console display programs (such as the MSK displays) to provide status information to the flight control teams.

As a clarification to the user, the desired maneuvers referred to in this comp are those input by the crew on either the Universal Pointing or Maneuver CRT displays. Required maneuvers are those computed by the GPC on the Universal Pointing CRT display.)

PROGRAM DESCRIPTION

The program is called mnvr_comp. The program inputs are:

V95J7482C	Current Option Indicator
V95J7483C	Future Option Indicator
V93W6801C	Day of Maneuver Start
V93W6802C	Hour of Maneuver Start
V93W6803C	Minute of Maneuver Start
V93W6804C	Second of Maneuver Start
V90O8001C	Major Mode
V90U2787C	DAP Maneuver Rate
V90U2240C	Element 0 of M50 to Body Quaternion
V90U2241C	Element 1 of M50 to Body Quaternion
V90U2242C	Element 2 of M50 to Body Quaternion
V90U2243C	Element 3 of M50 to Body Quaternion
V95H7468C	Required Inertial Pitch Angle
V95H7484C	Required Inertial Roll Angle
V95H7467C	Required Inertial Yaw Angle
V93H6838C	Desired Inertial Pitch Angle
V93H6839C	Desired Inertial Roll Angle
V93H6837C	Desired Inertial Yaw Angle

V93U6909C	Desired ADI Inertial Pitch Angle
V93U6911C	Desired ADI Inertial Roll Angle
V93U6910C	Desired ADI Inertial Yaw Angle

The program outputs the following quantities:

W01G2400R	Current Option Indicator
W02G2400R	Future Option Indicator
FUTURE_MNVR_TIME	Maneuver Start Time
TIMEREQ	Required Maneuver Completion Time
ROTREQ	Eigen rotation to required attitude
PITCHREQ	Euler pitch to required attitude
YAWREQ	Euler yaw to required attitude
ROLLREQ	Euler roll to required attitude
TIMEDES	Desired Maneuver Completion Time
ROTDES	Eigen rotation to desired attitude
PITCHDES	Euler pitch to desired attitude
YAWDES	Euler yaw to desired attitude
ROLLDES	Euler roll to desired attitude

(Note that all angles are in units of degrees.)

The program calculates the current-to-required (track) and current-to-desired (maneuver) quaternions and then calculates the Eigen rotations and Euler angles in PYR order from the appropriate quaternion. Finally, the maneuver completion times are calculated based on the Eigen rotations and DAP maneuver rate. (Be aware that the DAP maneuver rate is a constant with a value of 0.5 in major modes 104-106 and 301-303, but is retrieved from the downlist in major modes 201, 202, and 801.)

Some of the calculated data is valid only in certain major modes. In any major mode where the data is not valid, the output statuses for invalid maneuver rotations and completion times shall be set to dead. The comp is not active in Major Modes 101-103, 304, 305, or in OPS 6 and 9.

The Euler angles for the required attitude are valid only in major modes 201, 202 and 801. It will utilize the required inertial angle inputs (V95H7467,68,84C MSIDs) in its calculations.

The Euler angles for the desired attitude are valid in major modes 104-106, 201, 202, 301-303 and 801. However, the inputs used to compute this data are different, depending on flight phase. In major modes 201 and 801, the desired inertial angles (V93H6837-39C MSIDs) are used in the equations. In the major modes 104-106, 202, and 301-303, the desired ADI Inertial Angles (V93U6909-11C MSIDs) are used for the calculations.

DESIRED AND REQUIRED ATTITUDES BY MAJOR MODE

Major Mode	COMP Not Available	MNVR/BURN (DESIRED)		TRACK (REQUIRED)
		INRTL MNVR	BURN ATT	Equiv Univ Ptg CMD INRTL ATT (INRTL MNVR, TRK, ROT)
101	X			
102	X			
103	X			
104			X	
105			X	
106			X	
201		X		X
202			X	X
301			X	
302			X	
303			X	
304	X			
305	X			
601	X			
602	X			
603	X			
801		X		X
901	X			

Note: In MM 202 and 801, whatever was commanded in MM 201 continues to be processed but no additional changes may be made.

PROCEDURES

There is no user interface for the maneuver comp. The program runs in the background and continuously monitors the down-listed data, generating the appropriate outputs real-time via ISP. Other programs (i.e. MSK-View) display the resulting data.

In normal operation, this program will be automatically executed during console login, so it will not be necessary to manually execute the program. However, assuming the correct path to the executable is in the current path, the computation can be executed directly from the Unix command line using the following syntax:

```
mnvr_comp -a -tnn &
```

The command line options in the above execution statement are from the ISP client library. The "a" option is used to cause the program to attempt to reconnect in the event of lost heartbeat from the ISP server. Without this option, the program will exit on this event.

The "t" option allows the user to set the number of heartbeats (nn) before ISP heartbeat is considered lost. The default is 10 heartbeats if this option is not used.

PROGRAM NOTES

This program is an ISP client and thus interfaces with an ISP server. Connection to the server is automatic upon start of the program, with no action required on the part of the user. If connection with the ISP server is lost at any time, the application will attempt to reconnect at reasonable intervals until a connection is reestablished.

REFERENCES

Ascent Checklist STS-90, Final, December 5, 1997

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DPS Dictionary, Generic, Rev J, June 13, 1997

Entry Checklist, Generic, Rev E, May 5, 1995

FSSR 20, Displays and Controls Vol 1, August 9, 1996

GNC Systems Briefs, Basic, Rev B, PCN-1, June 22, 1990

Maneuver Comp GNC Application Notebook

Orbit Operations Checklist, Generic, Rev F, March 31, 1995, JSC-48035

Consultations with GNC Personnel: Kevin Dunn, Eddie Trlica, Laura Stallard, and David Allega

TITLE

Single Auxiliary Power Unit (APU) Landing – Manual Speedbrake Setting

PURPOSE

To describe the procedure for manually setting the speedbrake when the Shuttle lands with only a single APU operating.

BACKGROUND

The Shuttle software is designed to allow a landing with only one of three APUs operating. It does this by reducing the aerosurface drive rates to values that can be supported by a single APU. The software responsible for this function is called priority rate limiting software (PRL) and is discussed in detail in SCP 9.10, PRL MANAGEMENT. When this software was developed it was understood that single APU landings involved risk because they required that the remaining APU perform at its operational limits. However, it was believed that with the software in place a successful landing could be accomplished.

Studies conducted at the Ames Vertical Motion Simulator in April of 1998 to support APU hardware upgrades revealed serious flaws in the existing PRL software. It was discovered that the software consistently allowed APU overdemands in excess of 20 gallons per minute (gpm) during certain flight phases. Severe hydraulic system pressure drops (and probably loss of vehicle control) were expected under these circumstances. Most of these overdemands occurred after Shuttle weight-on-wheels (WOW) but some (less significant) problems were also identified during gear deploy.

Three primary culprits were identified as the causes of the overdemands:

1. Sluggish speedbrake (SB)
2. PRL did not account for all post-landing system flow demands
3. In-air landing gear deploy hydraulic flow was underestimated.

SLUGGISH SPEEDBRAKE (SB)

The sluggish SB problem is a result of two independent factors. First, with a single hydraulic system (and therefore a single hydraulic motor), SB responsiveness is significantly reduced. When the PRL software commands the SB to drive at a given rate, the SB does not achieve this rate immediately but takes 1-2 seconds to build up to it. This results in a command/position delta, with the actual SB position trailing the command position. This means that the SB will continue to move for 1-2 seconds after the software command stops in order to “catch up”. While SB lag is present even during 3 APU operation, it only becomes a factor during single APU operation. The other aerosurfaces also experience increased sluggishness during single APU operation but to a much smaller degree. Their lag is on the order of 0.3 seconds or less.

The second contributing factor to the SB sluggishness (although of less importance), is that the SB can not always achieve the drive rate commanded by PRL with a single hydraulic motor. Prior to OI-29, PRL software always commanded a SB open rate of 6.1 deg/sec and a close rate of 10.86 deg/sec, regardless of how many hydraulic systems were available. When only a single APU is operating, the SB may not be able to open at a rate of 6.1 deg/sec if the Shuttle is in a high qbar region where it must overcome large aerodynamic forces. The drive rate may be reduced, for example, to 5.7 deg/sec. Shuttle Engineering simulator data has also indicated that the SB cannot achieve a 10.86 deg/sec drive rate in the closed direction, even in a high Qbar region where aerodynamic forces assist the motion. The data indicates that a drive rate of only about 7.7 deg/sec can be achieved. The effect of this is to cause the SB to lag even further behind the command and further increase the command/position delta.

The SB lag can create significant hydraulic over-demands during periods of peak system operation. During these periods, the PRL software attempts to reduce hydraulic system flow by reducing aerosurface drive rates according to specific priorities. It first attempts to reduce hydraulic system demands by terminating SB motion. It does this by "freezing" the SB position command to whatever value is present when peak hydraulic demands are detected. In this way it reserves all of the available hydraulic flow for higher priority aerosurfaces including the elevons, rudder and body flap. If this is inadequate to bring hydraulic flow within limits, PRL next reduces elevon, rudder and body flap drive rates across-the-board to keep hydraulic demands within the capability of a single APU. Unfortunately, when PRL freezes the SB command, the SB continues to move for 1-2 seconds in order to "catch up" with the command. During this 1-2 second period, the SB uses hydraulic system flow (approximately 18 gpm) which the PRL software does not take into account. PRL is not a feedback system and assumes that the aerosurfaces follow commands exactly. In an attempt to reduce the hydraulic demand of the SB during a single APU entry, the rates were further reduced via additional software logic and I-loads to 6.06 deg/sec closing, and 5.43 deg/sec opening (CR's 92422 and 02384) and are discussed in more detail later.

HYDRAULIC OVERDEMANDS

Simulations run over a wide range of conditions demonstrated that there were three regions between the deorbit burn and wheel stop where the SB command/position delta problem could create hydraulic system overdemands. The first occurred at an altitude of 300ft when the main gear was being deployed. The second occurred between WOW and weight-on-nose-gear (WONG) and the third was immediately following WONG.

When the WOW flag is set, the SB is commanded by the AUTO system to open to 100% to provide aerodynamic braking. This is also a time when the elevons and rudder are very active controlling bounce, maintaining centerline, and executing Orbiter derotation. The elevons are often commanded to drive at their maximum rate of 13.9 deg/sec during this period. Four elevons driving at full rate consume nearly all of the hydraulic capacity of a single APU. Under these circumstances, PRL freezes the SB command and divides the available hydraulic flow between the elevons and rudder (the body flap is not active in this timeframe). Unfortunately, the SB does not stop moving when the command is frozen because it lags behind. This results in an 18 gpm overdemand for 1-2 seconds immediately following WOW. The same situation occurs at WONG, when the elevons are commanded to the full down position at maximum drive rates in order to provide load relief for the tires. If in AUTO, the SB is still in the process of opening to 100% at this time and will again cause system overdemands for 1-2 seconds. In addition, there are new flow demands placed on the hydraulic system following WONG which

are not accounted for by PRL software. These include post WONG leakage, brake flow and nose wheel steering flow. These flows add approximately 6 gpm of demand on the hydraulic system. The in-air overdemand which can occur during gear deploy is a much less likely source of overdemand than those which occurs near WOW and WONG. In this case, overdemand will only develop if the SB is moving during gear deploy and the vehicle is also encountering vehicle dynamics which require significant activity of the elevons and rudder. Such situations are uncommon.

Based on test data, an average APU can provide approximately 72 gpm of hydraulic flow at 3000 psi (PRL assumes 69gpm in high speed). As flow demands increase above this value, hydraulic system steady state pressure drops off drastically. When flow demands reach 80gpm, overall system performance becomes unpredictable. The pressure could drop low enough to engage the rudder hydraulic brake, freezing the rudder position. The elevons could become sluggish or begin to stall. They might also experience unequal hydraulic flow and become unbalanced. All of these events would leave the rudder and elevons in undesired positions and result in large command/position deltas. As the hydraulic system began to recover from the pressure drop, the large command/position deltas would further tax the hydraulic system by asking for large rudder/elevon position changes. All of these events would introduce vehicle control problems and further contribute to demands on the hydraulic system. Vehicle loss of control is a possibility.

WORKAROUNDS: OI-27

Several solutions were considered to eliminate the sluggish SB problem, including adding SB position feedback to PRL. Due to internal timing problems, this and other options proved unworkable (See Asc/Ent Flight Techniques Panel #154, Single APU Landing Study Status). The best solution identified was to eliminate SB motion during gear deploy, WOW to WONG, and throughout rollout by manually setting the SB to a fixed position prior to landing. This requires a manual SB procedure.

While the manual SB procedure was being developed, an unexpected problem was identified. This problem was caused by a difference between the SB in-air minimum limits and the post-WOW minimum limits. For OI-27 and earlier flights, the SB minimum allowable setting in the air was 15% and the minimum post-WOW setting was 25% (these values were specified by software K-loads). The 10% difference between the in-air and post-WOW K-load values created a problem because it meant that the SB would open to 25% at WOW whenever the in-air setting was less than this value. This motion occurred even if manual SB was selected. Opening from 15% to 25% left the hydraulic system vulnerable to system overdemands after WOW for a time period of approximately 2 seconds [time for SB to open from 15 to 25 percent = $[(25-15 \text{ deg})/(6.1 \text{ deg/sec})] = 1.6 \text{ sec}$. SB sluggishness would increase the length of this time to approximately 2 seconds].

One way to avoid SB motion at WOW would be to limit the manual in-air SB setting to 25% or greater. However, this would have the negative impact of reducing landing energy for cases when the true desired setting was 15%. Requiring a minimum setting of 25% would also add complication to the crew manual SB procedure. This was highly undesirable because this procedure is performed near touchdown and the crew's attention should be focused on landing. It was decided at the Ascent/Entry Flight Techniques Panel #154 (January 17, 1999) that it was best to set the SB to the desired setting at 3000 feet (even if it was less than 25%) in order to minimize landing energy impacts and procedural complexity. The risk introduced to the

hydraulic system by allowing the SB to open from 15% to 25% at WOW was considered the lesser of the two evils.

WORKAROUNDS : K-load Changes in OI-28

The reason for the difference between the in-air SB minimum setting and the post-WOW setting is interesting and has to do with the SB/rudder hardware design. The SB/Rud consists of two panels held in place by a conical seal as shown in Figure 1. When the two panels move in unison they provide a rudder function and when they move in opposition they provide a SB function. The panels are rotated by a mechanism within the seal. To allow maximum range of rotation of the panels, a notch was cut into the conical seal which allowed the rotary actuator arm of the trailing panel to slide into it. Unfortunately, the notch in the conical seal was not made large enough to accept the panel's rotary actuator arm. This situation was not discovered until after the vertical tail, along with the SB/Rud, had already been assembled.

Rather than disassembling the vertical tail and re-machining the conical seal notch (an expensive proposition), it was decided to accept the hardware as it was. This meant that software limits had to be imposed on the SB/Rud system to ensure that the rotary actuator arm was never driven into the conical seal notch. If this were to occur, the Rud/SB would probably still function but the thermal seal would be damaged. Without a healthy seal, significant thermal damage could result to the Rud/SB mechanism during early phases of the entry (thermal damage would probably not be of great concern late in the landing profile). At the very least it would be extremely expensive to repair the damaged seal.

The trailing panel will contact the conical seal when it is commanded to a value greater than 20 degrees. The panel position is a combination of the SB and Rud commands as shown in Figure 2. In order to protect the conical seal, software limits were imposed on both the SB and the rudder (CR 39590B, 7/18/81) to ensure that the resultant Rud/SB trailing panel command never exceeded 20 degrees (OPS 3 and OPS 6, PASS & BFS). There was also additional margin added to allow for 3 sigma RSS (root sum squared) hardware tolerances and a channel failed hard-over in the SB and the Rud. The values selected for the SB and Rud limits during the in-air phase of flight were slightly different from those selected for the post-WOW phase.

In the air, the SB minimum value was set to 15.0 degrees and the maximum rudder value was set to 24.1 degrees. This ensured that the trailing panel of the Rud/SB would never contact the conical seal. They allowed the greatest range of motion for the SB (15% to 100%) at the expense of some range of motion in the rudder (0 to 24.1 degrees). Since a rudder value greater than 24.1 degrees was never expected in the air, this was considered a good compromise. After WOW, however, the situation changes. The SB opens to 100% so a limit on the minimum setting is inconsequential. The rudder, on the other hand, becomes extremely important for maintaining directional control while the vehicle in the unstable two-point stance. Hence, the rudder capability was extended to 27.1 degrees and the SB capability was reduced by limiting its minimum value to 25%.

The values selected for the in-air and post-WOW SB/Rud limits made sense at the time they were selected but they created a problem for the single APU landing manual SB procedure. In order to remove the risk of the SB opening from 15% to 25% at WOW during a single APU landing, the AEFTP #154 decided to implement K-load changes in OI-28 (OPS 3 & 6, PASS and BFS). The in-air values will remain the same but the post-WOW values will be changed. The post-WOW SB minimum setting will become 15% and the maximum rudder setting will become 26.6deg. The rudder setting of 26.6 deg was derived by backing off of some of the

conservatism included in the in-air limit of 24.1 degrees. As mentioned above, the 24.1 degree limit protected for 3 sigma RSS hardware tolerances and a hardover channel failure in both the SB and rudder. The new value of 26.6 deg allows for 3 sigma RSS hardware tolerances but does not protect for any hardover channel failures.

Once the OI-28 K-load changes are implemented, the risk of SB motion at WOW will be completely eliminated and the majority of the single APU system overdemands will be corrected.

WORKAROUNDS : PRL UPGRADES in OI-29

To eliminate the remaining causes of hydraulic system overdemands, software upgrades were incorporated into PRL with OI-29. These changes include the following:

1. Increase gear deploy hydraulic flow from 6.64 gpm to 12.75 gpm
2. Add flows to account for post-WONG leakage (2.93 gpm), nose wheel steering flow (1.50 gpm) and brake flow (1.60 gpm).
3. Limit post-WONG elevator and aileron surface drive rates to 10.5 deg/sec (instead of 13.9 deg/sec).
4. Create new SB drive rate I-loads for single APU operation: 5.43 deg/sec (open); 6.06 deg/sec (close).

It is important to note that the 3K manual SB procedure is still required. Since attempts to incorporate aerosurface position feedback data into PRL failed (due to sampling rates and timing problems) it was not possible to fully eliminate hydraulic overdemands resulting from a sluggish SB with software changes alone. The new single APU SB drive rate I-loads of 5.43 deg/sec (open) and 6.06 deg/sec (close) reduce the magnitude of the SB command/position deltas which develop during SB motion but do not completely eliminate them. This means that overdemands due to SB motion can still occur during gear deploy and post-WOW unless the manual SB procedure is implemented.

The increase in gear deploy flow from 6.64 gpm to 12.75 gpm was made to bring the hydraulic flow value in line with current gear deploy estimates. Flight data shows that it takes approximately 5.6 seconds to deploy the landing gear. Since a fixed quantity of fluid is needed for gear deploy, the gpm during this time is calculated by taking this fixed quantity and dividing by the observed deploy time of 5.6 seconds. The original value of 6.64 gpm is believed to have been derived by using the spec value of 10 seconds for gear deploy. Since the actual deploy occurs much faster than the spec value, the gpm to deploy the gear was originally underestimated. The post WONG leakage of 2.93 gpm, brake flow of 1.60 gpm and nose wheel steering flow of 1.50 gpm were added to account for flow sources that were overlooked (or did not exist) when the PRL software was originally written. The reduction from 13.9 deg/sec to 10.5 deg/sec in elevator and aileron drive rates at WONG reduces elevon/aileron hydraulic flow demands and reserves greater flow for rudder activity. The rudder is extremely important for control authority during rollout since nose wheel steering may not be available when only a single APU is operating. The only negative aspect of reducing elevator and aileron limits is the possibility for a slight increase in tire and nose gear landing loads but these are acceptable.

The OI-29 software change which generated the most discussion involved the change in the SB drive rate. This change was implemented for two reasons. First, it minimizes the magnitude of the SB command/position deltas which can develop because it brings the commanded rate in closer agreement with the actual drive rate capability. Reducing the command/position delta reduces exposure to system overdemands while the Shuttle is in the air. Simulation data has not revealed any scenarios where a sluggish SB causes in-air overdemands (with the exception of the brief period during gear deploy) but this does not mean that such scenarios do not exist. The SB drive rate change provides increased protection from unexpected dynamics that could cause large hydraulic system demands during entry. Minimizing the SB command/position delta will also minimize the period of overdemand if such situations should develop.

The second, and primary reason, for reducing the SB drive rate for single APU operation is to protect the SB hardware. The certified drive rate for a single hydraulic motor is 5.43 deg/sec. The software prior to OI-29 commanded a single motor SB drive rate of 6.1 deg/sec in the open direction and 10.86 deg/sec in the closed direction. These values are clearly beyond the certified limit. While the "certified" value was not necessarily derived based on hardware capability, it represents a prudent limit for hardware operation. The OI-29 software changes were implemented to bring the single APU commanded drive rates closer to the certified values.

There were two competing issues which had to be considered when selecting the single APU SB drive rate. Reducing the drive rate to the certified limit would guarantee safe hardware operation but would have negative impacts on landing energy (because the SB would take longer to close at 3000 ft). A faster drive rate would improve landing energy impacts but might compromise hardware integrity. A value had to be selected which provided reasonable hardware protection while ensuring acceptable landing energy conditions.

The difference between the pre-OI-29 SB open drive rate of 6.1 deg/sec and the certified limit of 5.43 deg/sec was considered trivial so the certified limit was selected. No impacts on flight control or landing energy were identified for this change. Selection of the close drive rate proved to be a greater challenge. Data from the Shuttle Engineering simulator (SES) indicated that a single motor could probably only achieve a maximum SB closed rate of about 7.7 deg/sec. The fidelity of this simulator was unclear but represented the best available estimate of hardware capability. This placed an upper bound on the software close rate limit of 7.7 deg/sec.

The vendor, Hamilton Sunstrand, reported that the PDU hydraulic motor had a rated speed of 7000 rpm which corresponded to a 5.4 deg/sec drive rate. The suppliers performance data showed that the overspeed capability of the motor was 9900 rpm for up to ten minutes which corresponded to a drive rate of 7.7 deg/sec. However, there was no test data available to substantiate the performance data values. The only test data available which demonstrated that the SB motor could safely operate faster than 5.43 deg/sec was collected during hydraulic motor acceptance testing (AT). The data showed that a motor operated safely at a rate of 6.06 deg/sec for approximately 10 seconds.

The landing energy impacts of operating the SB at a close drive rate of 7.7 deg/sec vs. 6.06 deg/sec were examined using the landing conditions from ten selected shuttle flights. No significant impacts were identified on the Shuttle's ability to track the reference velocity on the outer glide slope. A reduction of about 200 feet of landing energy was observed in the worst case flight (STS-56). Based on this information, the AEFTP Splinter Meeting (February 8, 2000) decided to implement a drive rate of 6.06 deg/sec in the SB close direction. The Flight

Techniques Panel felt that the 200 feet of additional landing energy which could be realized by driving the SB at 7.7 deg/sec did not warrant the risk of operating the system outside of demonstrated limits. The new limits will be implemented in OI-29 and in the landing energy simulation used by the flight dynamics officer (FDO) to predict landing energy for single APU operations.

The manual SB procedure in conjunction with the OI-29 software changes should eliminate any serious hydraulic system overdemands. The worst-case flow overdemands are expected to occur between WOW and WONG and to be less than or equal to 75 gpm. Flow demands over 69gpm are expected to be limited to 1.5 seconds or less. The hydraulic system pressure drop associated with these worst-case overdemands is predicted to be on the order of 800psi. Any pressure drop in excess of 600 psi will generate a master alarm, illuminate the F7 panel light and generate a BFS "Hyd PRESS" fault message. Analysis of representative Ames vertical motion system overdemand cases show that transient pressure spikes due to waterhammer effects will approach or potentially slightly exceed the hydraulic system limits of 4500 psi (component proof pressure requirement) but should stay well below 6000 psi (tubing proof pressure requirement). Refer to the Orbiter Review Board (ORB) presentation of August 1, 1999, for more details.

All post-WONG over-demands are expected to be very short spikes (<160ms) due to nose wheel steering inputs. These short duration spikes are not expected to have a notable impact on system pressure. The in-air overdemands were predicted to be less than 0.2 seconds in duration and should also have a negligible effect on system pressure.

Unapproved OI-29 Software Changes

It should be noted that additional software changes were evaluated but not implemented when the OI-29 software changes were developed. These additional changes were intended to reduce flow demands between WOW and WONG and included the addition of a 2.93 gpm leakage term and a reduction in aileron & elevon rates from 13.9 deg/sec to 10.5 deg/sec at WOWLON. These changes were dropped because they were found to aggravate an undesirable bounce/oscillation condition at WOW. This phenomenon was first identified during testing in the vertical motion simulator at Ames Research Center. It was found to occur for all of the PRL configurations (including the original baseline configuration) but was encountered more frequently during landings with the changes implemented between WOW and WONG. It occurred in 15% of the landings with the WOW to WONG changes but only 4% of the baseline PRL landings. The increased bounce was primarily due to the reduced elevator rate capability and corresponding reduction in the control system's ability to damp the bounce oscillations. The magnitude of the oscillatory behavior was a function of several variables including mass properties, wind conditions, aerodynamics, sink rate, equivalent airspeed and touchdown pitch attitude. The AEFTP #158 determined that the lesser of two evils was to accept some hydraulic flow overdemand between WOW and WONG in order to avoid exciting the undesirable "bounce" effect.

MANUAL SB PROCEDURE

During nominal entries the SB is kept in AUTO for the entire entry profile. At an altitude of 3000 feet, the AUTO system commands the SB to a fixed position for landing. This position is a function of the Shuttle predicted landing energy. The SB stays at its 3K setting until an altitude of 500 feet, where a final adjustment is made by the AUTO system to ensure proper energy for landing. When the crew performs a single APU landing, the SB also remains in AUTO for most

of the entry profile. The only difference is that the 3K SB positioning is executed by the crew instead of by the AUTO system; and there is no 500ft adjustment.

When the manual SB procedure was being developed, two different options were considered for determining what value the crew should use when setting the SB. The first option considered was for the crew to match the on-board AUTO SB command at 3K. This option was found to be cumbersome because it was a challenge for crews to accurately match the AUTO setting in the short time available between 3K and gear deploy at 500 ft.. Of even greater significance was the fact that this technique was time consuming and distracted the pilot's attention from higher priority tasks associated with landing. A second option was developed in which the crew was given a 3K manual SB setting by the Flight Dynamics Officer (FDO) on the Entry DEL PAD, along with a reminder to use the manual SB procedure (if a single APU landing situation was expected). The SB setting was updated, if necessary, via the Capcom, during the final winds and weather update call as the Shuttle approached the heading alignment cone (HAC). In order to keep the procedure as simple as possible and thereby minimize crew distractions, the pilot set the speedbrake/thrust controller (SBTC) to the proper position using the cue card located next to the SBTC handle. Refer to the "Speed Brake Cmd vs. SBTC Trailing Edge" cue card in the Ascent Checklist. This action was performed during a quiescent period early in the entry profile in preparation for the manual 3K setting. The SB remained in AUTO during this time. At 3K, the pilot engaged the SBTC manual takeover push-button on the SBTC handle to invoke manual SB control. Since the SBTC was already properly positioned, the SB would be commanded to the correct setting. No further action was required by the crew other than to confirm that the SB was at the desired position using the surface position indicator (SPI) or CRT.

The FDO will round the preferred SB position to the nearest 5 degrees to make it easier for the crew to set the SB. The crew should make a best effort to achieve the proper position since any errors will have impacts on landing energy. However, they should not allow themselves to become distracted by attempting to fine tune the SB position. Not only would such activity divert the crew's attention from the higher priority activities of landing but it would also introduce the possibility of SB motion during gear deploy or close to the ground when the elevons are making last minute adjustments. In both cases, SB motion could result in hydraulic system overdemand. The most important objective for the crew should be to get the SB set reasonably close to the desired value and then leave it alone. Once the SB has been positioned to the 3K setting, the crew should not move it again until after wheel stop.

There may be landing scenarios where runway length is limited and opening the SB after touchdown to reduce rollout distance becomes highly desirable. This would only be a concern at selected contingency or transatlantic (TAL) abort sites with short runways. Since a single APU landing in combination with a contingency/TAL abort is extremely unlikely, the manual SB procedure was not developed to accommodate this scenario. However, if such a situation occurs, the crew may safely open the SB during rollout if they wait at least four seconds after WONG. A four second delay will ensure that the elevons have completed the movement from a full up position of -11.7 deg (typical during derotation) to a full down position of $+22.5$ deg (for load relief) and that system overdemand is no longer a threat. The crew should be especially careful not to move the SB between WOW and WONG since this is the period of greatest hydraulic system stress and of flight control instability.

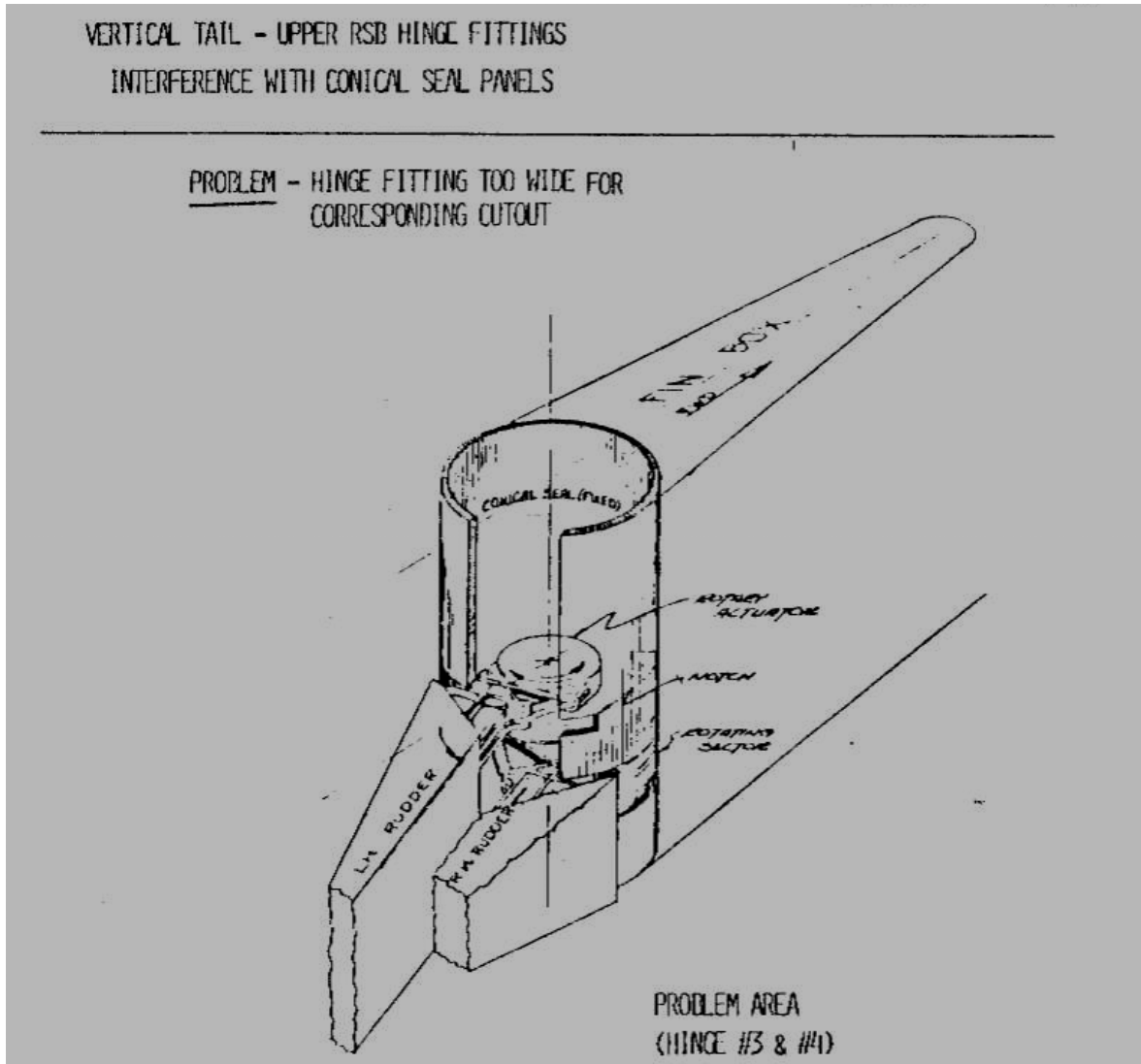


Figure 1: SB/RUD Conical Seal

$$\text{Rud Trailing Panel (TP) Pos} = \text{Rud cmd} - 1/2(\text{SB cmd}) < 20 \text{ deg}$$

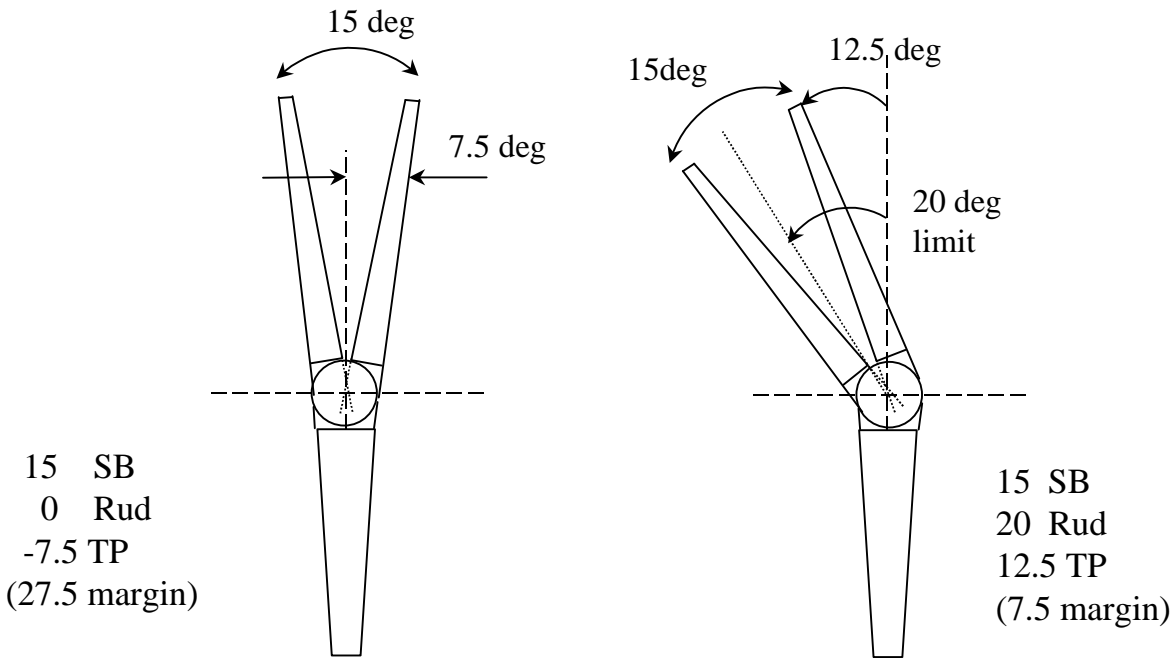


Figure 2: Trailing Panel Deflection

References:

1. ORB Presentation, August 3, 1999, "Feb-March '99 Ames Vertical Motion Simulator (VMS) Results (Kyle Cason)
2. Ascent/Entry Flight Techniques Panel #158, June 25, 1999, "Feb-March '99 Ames VMS Results (Kyle Cason, Bill McDermott, Ed Digon)
3. Ascent/Entry Flight Techniques Panel #154, January 27, 1999, "Single APU Landing" (Laura Kavanaugh)
4. Ascent/Entry Flight Techniques Panel Splinter, February 8, 2000, "Single APU Speedbrake Rate Limits" (Kyle Cason, Bill McDermott, Boeing); "A&L T/D Energy Concerns (Alan Hochstein)

TITLE

ENTRY FCS ACTUATOR FAILURE RESPONSE (RSB, BF, ELEVON)

PURPOSE

To summarize the Engineering analysis conducted in the 2002-2004 timeframe that studied the controllability of entry with a stuck FCS actuator. Specifically, the Engineering analysis studied stuck Rudder/Speedbrake, LOB Elevon, and Bodyflap actuators from EI to touchdown in various positions. The Engineering study results were summarized and presented to Ascent/Entry Flight Techniques Panel (AEFTP) #200 on 4/23/04.

DESCRIPTION

This SCP contains a detailed summary of the Entry FCS actuator study presented at AEFTP #200. This SCP actually contains more details than the AEFTP presentation because it lists each individual run conducted in the SES, Boeing-FDAX, and/or SDAP simulator, and the associated results. Specifically, the SCP is broken into the following areas:

SECTION 1 - STUCK RUDDER/SPEEDBRAKE CASES

SECTION 2 - STUCK BODYFLAP CASES

SECTION 3 - STUCK ELEVON CASES

This SCP provides recommended actions intended to improve the survivability of stuck Entry FCS actuator cases. It should be noted that that hardware causing the controllability cases are CRIT 1, and as a result some failed FCS actuator cases are unsurvivable, regardless of the course of action or operational procedures implemented. This SCP is simply intended to document the work completed to date, and to serve as a starting point in the event of an inflight occurrence.

The procedures documented in this SCP are considered contingency actions, and should not be considered operational. The procedures may not be usable for all flown vehicle configurations, Cg's, atmospheric conditions, FCS actuator failure modes, etc. To determine if an individual FCS actuator failure case is survivable, a full Engineering analysis must be conducted in an Engineering simulator. Do not use a training simulator like the SMS or GNS to determine the survivability of a failed FCS actuator case, because training simulators do not model (or model well) things such as structural loads, aerothermal, or atmospheric conditions. In addition, this study did not analyze all aspects of entry and landing, such as tail-scrrape at touchdown, nose gear slapdown rates, and aerosurface hinge moments.

This document provides the user with a quick reference tool for determining controllability of Entry FCS actuator cases failed at specific positions. All of the cases are based on limited Engineering analysis, and assumed nominal end of mission (NEOM) vehicle mass properties for the missions specified, and no aerodynamic or atmospheric uncertainties (unless otherwise specified). The cases listed in this SCP are the only documented cases studied of failed FCS actuators in Engineering simulators (as of April 2004), and as such do not constitute a full Monte Carlo analysis of the failed FCS actuators. **Failed FCS actuators are considered CRIT 1/1 failure modes**, and numerous FMEA/CILs document this fact. Table 5.8-5 contains a summary of the flight controls hardware that could lead to Loss of Crew and Vehicle (LOCV) as part of the Probable Risk Assessment (PRA) study conducted by the Safety and Mission Assurance Directorate in September 2003.

Prior to discussing the specific of the stuck actuator tests and analysis, it is important to understand the Aerojet DAP design. The Aerojet DAP functions during MM304/305, and MM602/603. **Only the Baseline DAP is available in MM602/603. The default setting on a TAL is the Baseline DAP although Wrap-DAP is available in a contingency (reference Flight Rule A8-19 YAW JET DOWNMODE. The Wrap-DAP is the default setting for Nominal End of Mission (NEOM).**

The Aerojet DAP is designed around a variable called the Lateral Control Departure Parameter (LCDP). The LCDP provides an indication of which way the vehicle will roll due to an aerosurface command.

Positive roll occurs when:

$$\text{Aileron LCDP} > 0 \text{Cn}\beta \cdot \text{Cl}\delta_a - \text{Cl}\beta \cdot \text{Cn}\delta_a$$

$$\text{Rudder LCDP} < 0 \quad \text{Cn}\beta \cdot \text{Cl}\delta_r - \text{Cl}\beta \cdot \text{Cn}\delta_r$$

If it is known that a control reversal exists, the flight control logic can be reversed so that the desired roll response will occur. The Shuttle uses this technique for aileron control above Mach 4 via a Mach scheduled aileron gain (GALR). **The flight control logic is governed by GALR in the following manner:**

GALR > 1: reverse aileron control

GALR < 1: normal aileron control

It should be noted that the **lateral directional control margin is reduced as aileron LCDP approaches zero and changes sign:**

When the aileron LCDP ~ 0: The rudder is required to maintain control

When the aileron LCDP > 0: The rudder is required for turn coordination and to minimize roll errors

The LCDP and GALR terms used for the Shuttle Aerojet DAP are shown graphically below in Figure 5.8-1.

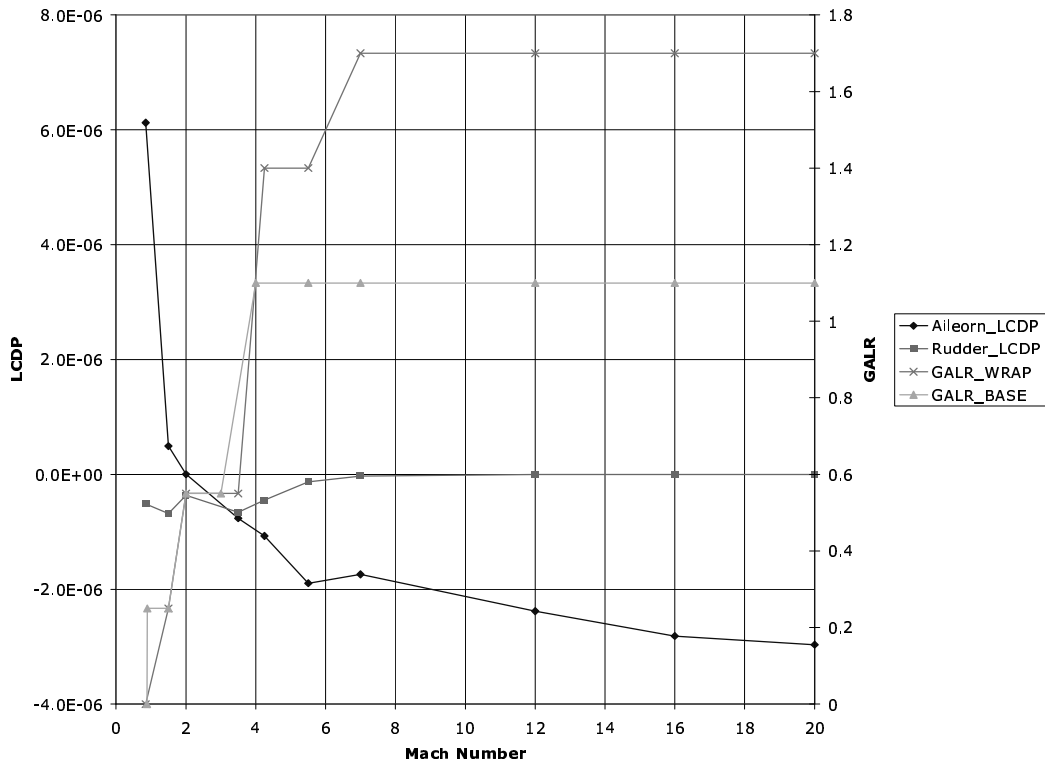


FIGURE 5.8-1 - ENTRY DAP GAIN SCHEDULE

PROCEDURE

SECTION 1: STUCK RUDDER/SPEEDBRAKE ACTUATOR

Table 5.8-1 is an executive summary of test cases completed in Engineering simulators (to date) with respect to a Rudder/Speedbrake actuator cases. The matrix contains the results of each test case run in the simulator, and in aft RCS used in lbs consumed from EI (noted in parens). Following Table 5.8-1 is a write-up of each stuck RSB t in the table (for completeness). *** - indicates that the run exceeded the Entry RCS redlines of 1175 lbs (i.e., the of aft RCS).

TABLE 5.8-1 - STUCK RUDDER/SPEEDBRAKE TEST SUMMARY

Failed RSBA Position		DAP CONFIGURATION			
Rudder Position	Speedbrake Position	Wrap-DAP in AUTO	Baseline DAP in AUTO	Baseline DAP in CSS	CSS Tech On Ba
0 deg	0%	LOC @ M=2.3 (RCS=620 lbs)	Crash on runway at 12500ft (RCS=660lbs)	TD @ 206 KEAS (no winds) TD @ 202 KEAS (w/winds) (no RCS data available)	M=0.95 gear deplo Flew outside HAC
0 deg	40%	LOC @ M=2.1 (RCS=700lbs)	Landed 3900ft short of runway (RCS=620lbs)	TD @ 180 KEAS (no winds) TD @ 206 KEAS (w/winds) (no RCS data available)	Flew outside HAC, Close-in Aimpoint
0 deg	81%	LOC @ M=1.9 (RCS=740lbs)	Landed 227ft short of runway (on underrun) (RCS=590lbs)	TD @ 205 KEAS (no winds) TD @ 195 KEAS (w/winds) (no RCS data available)	In TAEM bias GSI : HAC, Close-in Aim Late Gear Deploy (
0 deg	100%	Not performed	Not performed	TD @ 197 KEAS (no RCS data available)	In TAEM bias GSI : HAC w/high Alpha, Gear Deploy (200ft
0.5 deg	15%	LOC @ M=2.2 (RCS=640lbs)	Crash on runway at 7410ft (RCS=740lbs)	Not performed in CSS	N/A
4.0 deg	81%	LOC @ M=2.4 (RCS=790lbs)	Landed 343ft short of runway (on underrun) (RCS=1880lbs)***	Not performed in CSS	N/A
5.0 deg	10%	LOC @ M=2.6 (RCS=680lbs)	LOC @ M=2.1 (RCS=1320lbs)***	TD @ 176 KEAS (LOC @ TD) TD @ 200 KEAS(LOC @ TD) (no RCS data available)	Full RPTA deflectic Rudder (with yaw j input @ M=3

NOTE: All Stuck RSB runs were performed in the SES simulator using the OI-30 FSW with Cycle-2 I-loads, and the STS-114 NEOM Mass Properties where Cgx=1087.6 in., Cgy= +0.3 in., and WT=223,527 lbs

Stuck SB and Rudder @ 0.0 degrees from EI (using Wrap-DAP in AUTO):

LOC @ M=2.3 (due to roll-off), after using 620 lbs RCS (used 290 lbs up to M=5). This case simulates a stuck RSB during ascent, prior to FCS C/O.

Stuck SB and Rudder @ 0.0 degrees from EI (using Baseline DAP in AUTO):

Possible to land. Makes it through supersonic flight, then AUTO lofts the trajectory (following Ref Nz) until 5kft altitude, then dives at the runway and crashes on the runway at 12,500ft down the runway. Uses 660 lbs RCS. Manual techniques should do better than AUTO.

Stuck SB and Rudder @ 0.0 degrees from EI (using Baseline DAP in CSS):

Landed two CSS runs successfully. The first run was conducted without winds and landed at 206 KEAS. The second run was conducted with a 20 knot headwind and a 10 knot left crosswind and landed at 202 KEAS. No RCS data is available. Energy management techniques were utilized including selection of Close-in aimpoint, and flying outside the HAC to bleed off the excess vehicle energy induced by the stuck closed speedbrake.
.....

Stuck SB @ 40% and Rudder @ 0.0 degrees from M=10 (using Wrap-DAP in AUTO):

LOC @ M=2.1 (due to roll-off), after using 700 lbs RCS (used 290 lbs up to M=5). This case simulates a stuck RSB partially open during the SB ramp open at M=10.

Stuck SB @ 40% and Rudder @ 0.0 degrees from M=10 (using Baseline DAP in AUTO):

Possible to land. Makes it through the supersonic flight then AUTO lofts the trajectory (following Reference Nz) until 5kft altitude, then dives at the runway 3900ft short of desired touchdown point. Uses 620 lbs RCS (490 lbs to M=5). Manual techniques should do better than AUTO.

Stuck SB @ 40% and Rudder @ 0.0 degrees from M=10 (using Baseline DAP in CSS):

Landed two runs successfully. The first run was conducted without surface winds and landed at 180 KEAS. The second run was conducted with a 20 knot surface headwind and a 10 knot left crosswind and landed at 206 KEAS. No RCS data is available. Energy management techniques utilized included selection of close-in aimpoint, and flying outside the HAC with a 15 degree outer glideslope to bleed off the excess vehicle energy induced by the stuck speedbrake.
.....

Stuck SB @ 81% and Rudder @ 0.0 degrees from M=10 (using Wrap-DAP in AUTO):

LOC @ M=1.9 (due to roll-off), after using 740 lbs RCS (used 210 lbs up to M=5). This case simulates a stuck RSB at completion of SB ramp open at M=10.

Stuck SB @ 81% and Rudder @ 0.0 degrees from M=10 (using Baseline-DAP in AUTO):

Landed on the under-run (227 ft short), after using 590 lbs RCS (used 470 lbs up to M=5). Manual techniques should do better than AUTO to manage vehicle energy.

Stuck SB @ 81% and Rudder @ 0.0 degrees from M=10 (using Baseline DAP in CSS):

Landed two CSS runs successfully. The first run was conducted without surface winds and landed at 205 KEAS. The second run was conducted with a 20 knot headwind and a 10 knot left crosswind and landed at 195 KEAS. No RCS data is available. Energy management techniques utilized included selection of Close-in aimpoint, flying two dots high on the Glide-Slope Indicator (the GSI is located on the HSI), flying inside the HAC to gain vehicle energy (since the vehicle was short on energy due to the stuck open speedbrake), and a late gear deploy (at 200ft of altitude).

Stuck SB @ 100% and Rudder @ 0.0 degrees from M=10 (using Baseline DAP in CSS):

Landed one CSS run successfully at 197 KEAS (the run had no winds at touchdown). No RCS data is available. Energy management techniques utilized included selection of Close-in aimpoint, flying two dots high on the Glide-Slope Indicator (the GSI is located on the HSI), flying inside the HAC to gain vehicle energy (since the vehicle was short on energy due to the stuck open speedbrake), and a late gear deploy (at 200ft of altitude).

Stuck SB @ 15% at M=10 and Rudder @ 0.5 degrees at M=5 (using Wrap-DAP in AUTO):

LOC @ M=2.2 (due to roll-off), after using 640 lbs RCS (used 280 lbs up to M=5). This case simulates a stuck RSB where the SB jams partially open during the M=10 ramp open, and the rudder jams at M=5 activation with a small deflection.

Stuck SB @ 15% at M=10 and Rudder @ 0.5 degrees M=5 (using Baseline DAP in AUTO):

Possible to land. Makes it through supersonic flight then AUTO lofts the trajectory (following reference Nz) until 5kft altitude, then dives at runway and crashes 7410ft down the runway. Uses 740 lbs RCS (490 lbs up to M=5). Manual techniques should do better than AUTO.

Stuck SB @ 81% at M=10 and Rudder @ 4.0 degrees at M=5 (using Wrap-DAP in AUTO):

LOC @ M=2.4 (due to roll-off), after using 790 lbs RCS (used 290 lbs up to M=5). This case simulates a stuck RSB, where the SB jams at the M=10 ramp open position, and the Rudder jams when activated at M=5.

Stuck SB @ 81% at M=10 and Rudder @ 4.0 degrees from M=5 (using Baseline-DAP in AUTO):

Landed on the runway under-run (343 ft short), after using 1880 lbs RCS (used 500 lbs up to M=5). Exceeded aft RCS redlines limit of 1175 lbs at M=1.7. Manual techniques should do better than AUTO in terms of energy management, but may result in higher RCS usage.

Stuck SB @ 10% and Rudder @ 5.0 degrees from EI (using Wrap-DAP in AUTO):

LOC @ M=2.6 (due to roll-off), after using 680 lbs RCS (used 310 lbs up to M=5). This case simulates a stuck RSB at the "drive stop position" which is commanded at completion of the aerosurface drive portion of FCS C/O.

Stuck SB @ 10% and Rudder @ 5.0 degrees from EI (using Baseline DAP in AUTO):

LOC @ M=2.1 (due to roll-off), after using 1320 lbs RCS (used 420 lbs up to M=5).

Stuck SB @ 10% and Rudder @ 5.0 degrees from EI (using Baseline DAP in CSS):

Landed both runs, but departed the runway to the left while still in the 2-point stance (*almost* successfully landed). The first run was conducted without winds and landed at 176 KEAS with a M=0.95 gear deploy to reduce vehicle energy. The second run was conducted with a 20 knot headwind and a 10 knot left crosswind and landed at 200 KEAS (with a nominal gear deploy). No RCS data is available. To maintain control, it is required to input a steady RPTA deflection (up to a full deflection at times), or use the Yaw Panel Trim switch in combination with RPTA deflections to command the yaw jets on. The yaw jet firings are necessary to counter the roll/yaw moment induced by the stuck rudder, and are enough to maintain control in the low Mach region (M=3 to 1) with the stuck Rudder at a non-zero position, but used all of the aft RCS (usually broke the aft RCS redline by M=2). The lateral control was very marginal in the M=3 to M=2 region, but improved around M=1 and on the HAC. Due to the large amount of drag induced by the deflected rudder, and trimmed elevons, no energy management techniques are recommended for this case. At main-gear touchdown, the vehicle departed the runway to the left before weight-on-nose gear (WONG). This case is likely only survivable in CSS, and on a lakebed runway (i.e., NORTHROP!!!)

CONCLUSIONS OF STUCK RSB STUDY:

- I. **Baseline DAP is required to maintain control.** Use of the Wrap-DAP allows larger roll errors (and consequently a larger beta angle), which are characteristics that when combined with the low lateral directional control margin in the M=5 to M=1 region lead to loss of control (without the rudder available). The baseline DAP uses tighter aft RCS deadbands, and as a result maintains a smaller roll angle/beta angle and consequently maintains control in the M=5 to 1 region where the yaw jets are the only control effectors available to account for the loss of the rudder (by maintaining a positive lateral directional control margin).
- II. **Contingency Energy Management Techniques are required** to maintain adequate energy for touchdown (see Table 5.8-2 for An Executive Summary of Contingency Stuck RSB Energy Management actions). For cases where the SB is stuck open greater than 40% and the rudder is at trail (0.0 degrees), the vehicle is going to be low on energy, and techniques such as selecting close-in aimpoint, flying inside the HAC, etc are required to ensure that the vehicle has enough energy to reach the runway. For cases where the SB is stuck open less than 40% and the rudder is at trail (0.0 degrees), the vehicle is going to be high on energy, and techniques such as flying outside the HAC, or deploying the gear at M=0.95 are required to bleed off the excess energy prior to touchdown to prevent from landing too fast or too far down the runway. For cases where the SB is stuck and the rudder is deflected, the vehicle will most likely be low on energy due to the drag created by the SB, deflected rudder, and trimmed elevons (to counteract the rudder), but a real-time determination should be made and the appropriate techniques should be used to ensure safe touchdown conditions.
- III. **Cases where the rudder was deflected more than 4 degrees requires CSS below M=5 and full yaw jet control authority** to preclude an LOC in AUTO. With nominal aerodynamic and atmospheric conditions, AUTO has just enough margin to maintain control for a stuck rudder at 4 degrees of deflection, but loses control when the rudder is stuck at 5 or more degrees. In CSS, with modified piloting techniques, the crew is able to fly with a rudder stuck at 5 degrees, but with a very high level of difficulty and using large amount of aft RCS (if not all the aft RCS). It is also worth noting that even if the crew is able to make the runway with 5 degrees of rudder deflection, the touchdown will likely be single main-gear at initial touchdown (due to the large roll angle that the stuck rudder induces), and will lead to runway departure once in the two point stance (due to the yaw moment that the rudder creates). The main-gear touchdown, nose gear slap-down moment, and lateral gear/tire loads were not analyzed for this case, and may result in an LOC once on the runway (at main gear touchdown, in the 2-point stance, or at nose-gear touchdown).
- IV. **Cases where the RSB sticks below M=5 require immediate action** to invoke the Baseline DAP. Even if the Baseline DAP is invoked in time, an LOC may still result regardless of the course of action. During the Engineering simulator tests with the pilot-in-the-loop, two M=3 run start tests were attempted with the Rudder stuck at 5 degrees and Speedbrake stuck at 10% on Wrap-DAP, and both runs resulted in a LOC before the Baseline DAP could be manually invoked on SPEC 51 (via the ITEM 45). The conclusion taken from this was that even if you know the very instant that the RSB fails and sticks, if the rudder is deflected at the time of the actuator failure, and the failure occurs between M=5 and M=1, an LOC will likely result, regardless of the course of action.

TABLE 5.8-2 - CONTINGENCY STUCK RSB ENERGY MGMT PROC:

- (1) At M=5.1 on G51, WRAP MODE - ITEM 45 (INH), to invoke the Baseline DAP, then
 (2) Use the STUCK SPEEDBRAKE PROCEDURE as follows (Depending on the stuck SB position):

SB POSITION (STUCK at XX%)	TAEM ACTIONS	A/L ACTIONS	AIMPOINT
> 60 *	Fly 1-2 dots Hi on GSI ** Throughout TAEM	<220 klbs: 25 OGS (#) >220 klbs: 21 OGS (#)	4000' ***
40-60	AUTO P, R/Y	Fly needles	CLSE
30-40	Fly 1-2 dots Lo on GSI Keep EAS < 300	15 OGS (#)	CLSE
< 30	AUTO P, R/Y At M<.95, deploy gear	Fly needles	CLSE

- * If up-elevons causing control problems, drive BF up manually.
- ** TAEM: 2 dots = 5000 ft (Full GSI deflection)
A/L: 2 dots = 1000 ft (Full GSI deflection)
- ***1/2 way between 7500' (nominal) aimpoint and threshold.
- # Use HUD flight path indicator to fly OGS, if out of PAPI range

NOTE: A full explanation (including rationale) of this procedure appears at the end of this SCP.

SECTION 2: STUCK BODYFLAP ACTUATOR:

Table 5.8-3 is an executive summary of test cases completed in Engineering simulators (to date) with respect to a stuck body flap actuator. The matrix contains the results of each test case run in the simulator, and includes the total aft RCS used and consumed from EI (noted in parens). Following the Table 5.8-3 is a full write-up of each test case (for complete details see the test case write-up).

TABLE 5.8-3 - STUCK BODYFLAP TEST SUMMARY

Failed BF Position		DAP CONFIGURATION	
Degrees	% Deflection	Wrap-DAP in AUTO	Baseline DAP in AI
-11.7	0.0%	Landed on Runway (107) - No RCS data Landed on Runway @ 1598ft (114)-RCS=330lbs	Not performed (107) - No RCS data Landed on Runway @ 1593ft (114) -
0.0	34.2%	Landed on Runway (107) - No RCS data Landed on Runway @ 2180ft (114)-RCS=320lbs	Not performed (107) - No RCS data Landed on Runway @ 2170ft (114) -
6.0	51.7%	Landed on Runway (107) - No RCS data Not performed (114) - No RCS data	Not performed (107) - No RCS data Not performed (114) - No RCS data
7.0	54.7%	Landed on Runway (107) - No RCS data Not performed (114) - No RCS data	Not performed (107) - No RCS data Not performed (114) - No RCS data
8.0	57.6%	Landed on Runway (107) - No RCS data Not performed (114) - No RCS data	Not performed (107) - No RCS data Not performed (114) - No RCS data
9.0	60.5%	Landed on Runway (107) - No RCS data Not performed (114) - No RCS data	Not performed (107) - No RCS data Not performed (114) - No RCS data
10.0	63.4%	Landed on Runway (107) - No RCS data Landed on Runway @ 2381ft (114)-RCS=335lbs	Not performed (107) - No RCS data Landed on runway @ 2376ft (114) - f
11.0	66.3%	Landed on Runway (107) - No RCS data Not performed (114) - No RCS data	Not performed (107) - No RCS data Not performed (114) - No RCS data
12.0	69.3%	Landed on Runway (107) - No RCS data Not performed (114) - No RCS data	Not performed (107) - No RCS data Not performed (114) - No RCS data
13.0	72.2%	LOC @ M-8 (107) - No RCS data Not performed (114) - No RCS data	Not performed (107) - No RCS data Not performed (114) - No RCS data
14.0	75.1%	LOC @ M-8 (107) - No RCS data Not performed (114) - No RCS data	Not performed (107) - No RCS data Not performed (114) - No RCS data
15.0	78.0%	LOC @ M-8 (107) - No RCS data Landed on Runway @ 2290ft (114)-RCS=375lbs	Not performed (107) - No RCS data Landed on runway @ 2310ft (114) - f

TABLE 5.8-3 - STUCK BODYFLAP TEST SUMMARY (CONTINUED)

Failed BF Position		DAP CONFIGURATION	
Degrees	% Deflection	Wrap-DAP in AUTO	Baseline DAP in Al
22.5	100.0%	LOC @ M=8 (107) - No RCS data LOC @ M=7.5 (114) - RCS=2400lbs***	Not performed (107) - No RCS data LOC @ M=8 (114) - RCS=2590lbs***

NOTES:

(107) - Indicates use of STS-107 NEOM Mass Properties where Cgx=1078.2 in., Cgy=+0.1 in., WT=TBS lbs in the FDAX Engineering Entry Simulator.

(114) - Indicates use of STS-114 NEOM Mass Properties where Cgx=1087.6 in., Cgy= +0.3 in., and WT=223,527 FSW with Cycle-2 I-loads in the SES Simulator.

*** - Exceeds the Entry RCS Redlines (normally protect of 1175 lbs total aft RCS (Left + Right RCS)). Case most RCS somewhere between 1175 and 1400 lbs of RCS. 1175 lbs is the minimum required per Flight Rule A6-305 / REDLINES. 1400 lbs is the average amount of aft RCS available based on flight history (from STS-105 through 5

Stuck BF full up @ 0% (-11.7 deg) from EI (using Wrap-DAP in AUTO and STS-107 NEOM mass properties):

Lands on runway. No RCS Data available.

Stuck BF full up @ 0% (-11.7 deg) from EI (using Wrap-DAP in AUTO and STS-114 NEOM mass properties):

Lands on runway at 1598ft, using 330lbs RCS (310lbs up to M=5).

Stuck BF full up @ 0% (-11.7 deg) from EI (using Baseline-DAP in AUTO and STS-114 NEOM mass properties):

Lands on runway at 1593ft, using 570lbs RCS (520lbs up to M=5).

Stuck BF at trail @ 34% (0.0 deg) from EI (using Wrap-DAP in AUTO and STS-107 NEOM mass properties):

Lands on runway. No RCS data available.

Stuck BF at trail @ 34% (0.0 deg) from EI (using Wrap-DAP in AUTO and STS-114 NEOM mass properties):

Lands on runway at 2180ft, using 320lbs RCS (310lbs up to M=5).

Stuck BF at trail @ 34% (0.0 deg) from EI (using Baseline-DAP in AUTO and STS-114 NEOM mass properties):

Lands on runway at 2170ft, using 510lbs RCS (480lbs up to M=5).

Stuck BF partly down @ 51.7% (6.0 deg) from EI (using Wrap-DAP in AUTO and STS-107 NEOM mass properties):

Lands on runway. No RCS data available.

Stuck BF partly down @ 54.7% (7.0 deg) from EI (using Wrap-DAP in AUTO and STS-107 NEOM mass properties):

Lands on runway. No RCS data available.

Stuck BF partly down @ 57.6% (8.0 deg) from EI (using Wrap-DAP in AUTO and STS-107 NEOM mass properties):

Lands on runway. No RCS data available.

Stuck BF partly down @ 60.5% (9.0 deg) from EI (using Wrap-DAP in AUTO and STS-107 NEOM mass properties):

Lands on runway. No RCS data available.

Stuck BF partly down @ 63.4% (10.0 deg) from EI (using Wrap-DAP in AUTO and STS-107 NEOM mass properties):

Lands on runway. No RCS data available.

Stuck BF partly down @ 63.4% (+10.0 deg) from EI (using Wrap-DAP in AUTO and STS-114 NEOM mass properties):

Lands on runway at 2381ft, using 335lbs RCS (320lbs up to M=5).

Stuck BF partly down @ 63.4% (+10.0 deg) from EI (using Baseline-DAP in AUTO and STS-114 NEOM mass properties):

Lands on runway at 2376ft, using 570lbs RCS (520lbs up to M=5).

Stuck BF mostly down @ 66.3% (11.0 deg) from EI (using Wrap-DAP in AUTO and STS-107 NEOM mass properties):

Lands on runway. No RCS data available.

Stuck BF mostly down @ 69.3% (12.0 deg) from EI (using Wrap-DAP in AUTO and STS-107 NEOM mass properties):

Lands on runway. No RCS data available.

Stuck BF mostly down @ 72.2% (13.0 deg) from EI (using Wrap-DAP in AUTO and STS-107 NEOM mass properties):

LOC at M=8. No RCS data available.

Stuck BF mostly down @ 75.1% (14.0 deg) from EI (using Wrap-DAP in AUTO and STS-107 NEOM mass properties):

LOC at M=8. No RCS data available.

Stuck BF mostly down @ 78.0% (15.0 deg) from EI (using Wrap-DAP in AUTO and STS-107 NEOM mass properties):

LOC at M=8. No RCS data available.

Stuck BF mostly down @ 78% (+15.0 deg) from EI (using Wrap-DAP in AUTO and STS-114 NEOM mass properties):

Lands on runway at 2290ft, using 375lbs RCS (360lbs up to M=5).

Stuck BF mostly down @ 78% (+15.0 deg) from EI (using Baseline-DAP in AUTO and STS-114 NEOM mass properties):

Lands on runway at 2310ft, using 580lbs RCS (540lbs up to M=5).

Stuck BF full down @ 100% (+22.5 deg) from EI (using Wrap-DAP in AUTO and STS-114 NEOM mass properties):

LOC at M=7.5 after running out of aft RCS (used 2400lbs total before LOC). Breaks aft RCS redline of 1175 lbs at M=10, with the yaw jets on solid. Heavy yaw jet limit cycling starts at M=11.

Stuck BF full down @ 100% (+22.5 deg) from EI (using Baseline-DAP in AUTO and STS-114 NEOM mass properties):

LOC at M=8 after running out of aft RCS (used 2590 lbs total before LOC). Breaks aft RCS redline of 1175 lbs at M=13. Yaw jets start heavy limit cycling at M=12.5.

CONCLUSIONS OF STUCK BF STUDY:

- I. **Wrap-DAP provides the most control margin and should be used for stuck BF cases, or for cases where the BF function is temporarily lost.** Use of the Wrap-DAP allows larger aileron trim and trim rates to compensate for the loss of BF trim capability. Baseline DAP with the smaller aileron trim and trim rates will lose control quicker than Wrap-DAP.
- II. Loss of control will likely occur for a BF stuck full down at a high Mach number (Mach 7+). For cases where the BF is stuck down more than ~15 degrees (~66%), survivability is XCg dependent. For a more forward XCg (i.e., STS-107 with an Xcg=1078.2 in.) an LOC will occur for BF stuck at or below ~13 degrees down, for a more aft XCg (i.e., STS-114 with an Xcg=1087.6 in.) an LOC will likely occur if the BF is stuck more than 15 degrees down from trail.
- III. **Stuck BF positions down from trail (more than 34%) are concern for tail-scrape at touchdown. Most likely tail-scrape will not occur unless the BF is stuck down more than 50% (+5 degrees) for a nominal touchdown theta,** but this should be analyzed on a case-by-case basis using the predicted touchdown conditions (i.e., predicted touchdown airspeed, predicted wind direction on runway surface, etc).
- IV. Use of full open speedbrake to attempt to increase the longitudinal control margin provides virtually no help for cases where the BF is full/mostly down. The region the LOC is most likely to occur for a stuck down BF is in the M=9 to 7 region, where the SB is open already, but partially blanketed by the orbiter due to the alpha profile flown in the region. As a result, no manual speedbrake actions are recommended for this case, as they will provide marginal benefit.

SECTION 3: STUCK ELEVON ACTUATOR (LOB)

Table 5.8-4 is an executive summary of test cases completed in Engineering simulators (to date) with respect to a actuator cases. The matrix contains the results of each test case run in the simulator, and includes the total aft R consumed from EI (noted in parens). Following Table 5.8-4 is a detailed write-up of each test case (for complete stuck LOB elevon positions or elevon actuators (LIB, RIB, or ROB) were studied.

TABLE 5.8-4 - STUCK LOB AILERON TEST SUMMARY

Failed LOB Position	DAP CONFIGURATION			CSS Techniq
	Wrap-DAP in AUTO	Baseline DAP in AUTO	Wrap-DAP DAP in CSS	
-20 deg (up)	LOC on HAC (130 deg to go) RCS=1740lbs***	LOC @ M=19 RCS=1830lbs***	Run start @ M=3 LOC at touchdown	L Overhead H MAN BF @ 28 Full Rudder d
-10 deg (up)	LOC on final approach RCS=480lbs	LOC on final approach RCS=905lbs	Run start @ M=10 Landed on runway @ 200 KEAS (Likely tail-scrape)	L Overhead H MAN BF (100°
0 deg (trail)	Landed on runway @ 2223ft RCS=330lbs)	Landed on runway @ 2207ft RCS=710lbs	Not performed	N/A
+10 deg (down)	Landed on runway @ 1801ft RCS=1280lbs***	LOC @ M=11 RCS=1830lbs***	Not performed	N/A
+18 deg (down)	Exceeds NZ limit (4.5g) @ M=22 RCS=1890lbs***	LOC @ M=23 RCS=1880lbs***	Run start @ EI LOC @ M=16 (exceeded NZ limit)	MAN BF (0%) Ran out of RC Selected No-1

*** - Exceeds the Entry RCS Redlines normally protected (1175 lbs total aft RCS = Left + Right RCS). Case out of RCS somewhere between 1175 and 1400 lbs of RCS. 1175 lbs is the minimum required per Flight R RCS REDLINES. 1400 lbs is the average amount of aft RCS available for control based on flight history fro

NOTE: All Stuck LOB elevon runs were performed in the SES simulator using the OI-30 FSW with Cycle-2 I-loads, and the STS-114 NEOM Mass Properties where $C_{gx}=1087.6$ in., $C_{gy}=+0.3$ in., and $WT=223,527$ lbs. No other LOB elevon positions or actuators (i.e., LIB, RIB, ROB) were analyzed.

LOB stuck mostly up (-20 deg) from EI (using Wrap-DAP in AUTO):

LOC on the HAC at about 20kft. With about 130 degrees to go on the HAC (a Left Overhead HAC), the orbiter attempts to pitch down, but loses roll effectiveness with the elevons near their position saturation limit, and slowly rolls over and then nose dives. The BF is still active when the LOC occurs, and is in the full down position (100%). Uses 1740 lbs RCS (1660 up to $M=5$), breaking in the aft RCS redline of 1175 lbs at $M=17$. This case may easily run out of aft RCS for slight aerodynamic or atmospheric disturbances, which none of these runs used (they all used nominal aero with a benign atmosphere).

LOB stuck mostly up (-20 deg) from EI (using Wrap-DAP in CSS):

Landed on the runway, but lost control while in the 2-point stance (departed the runway to the left). The run started at $M=3$. Manual BF was selected at 28Kft of altitude, and the BF was driven full down (100%). The case flew a Left Overhead HAC, and was marginally controllable throughout the subsonic region. Even with the BF full down, the pilot needed to input a full rudder deflection to maintain a straight glide path angle while on final approach. The stuck LOB elevon with the full rudder deflection induced a roll angle that was present all the way through final approach and touchdown. Main gear touchdown was on the right main gear only, then during left main gear touchdown the vehicle quickly departed the runway (to the left) while in the 2-point stance. Because the bodyflap was left in the full down position, the case likely resulted in tailscape. It is also likely that the elevons and/or BF exceeded hinge moments while flying around the HAC. No aft RCS usage numbers were available from the run, but this case may easily run out of aft RCS if run with the stuck elevon from EI.

LOB stuck mostly up (-20.0 deg) from EI (using Baseline DAP in AUTO):

LOC at $M=19$ after running out of aft RCS. Uses 1830 lbs RCS prior to LOC, and breaks the aft RCS redline limit of 1175 lbs at $M=23$.

LOB stuck partially up (-10.0 deg) from EI (using Wrap-DAP in AUTO):

LOC after 10kft when the BF retracted to trail (when the guidance Approach & Land flag is set true). When the BF is retracted to trail, the remaining good elevons saturated to maintain pitch trim, and as a result were unable to compensate for the stuck LOB elevon, and a slow roll-off results. Uses 480 lbs RCS total (460 lbs up to $M=5$).

LOB stuck partially up (-10.0 deg) from EI (using Wrap-DAP in CSS):

Landed on the runway at 200 KEAS (no touchdown point data was available). The run started at M=10 and flew a left overhead HAC. CSS was selected at M=0.95. While in AUTO the BF was full down. At 11kft of altitude manual bodyflap was selected (leaving the bodyflap full down). Control was adequate throughout the run, but the case likely resulted in tail-scrape at touchdown, and possibly exceeded elevon and/or bodyflap hinge moments while flying the HAC. The case was controllable on the runway in the 2-point stance, during derotation, and weight on nose gear (WONG).

LOB stuck partially up (-10.0 deg) from EI (using Baseline DAP in AUTO):

LOC after 10kft when the BF retracted to trail (when the A&L flag is set). When the BF retracts to trail, the elevons saturate to maintain pitch trim, and are unable to compensate for the stuck LOB elevon, and a roll-off results. Uses 905 lbs RCS (850lbs up to M=5).

LOB stuck @ trail (0.0 deg) from EI (using Wrap-DAP in AUTO):

Lands on runway at 2223ft, using 330lbs RCS (315lbs up to M=5).

LOB stuck @ trail (0.0 deg) from EI (using Baseline DAP in AUTO):

Lands on runway at 2207ft, using 710lbs RCS (660lbs up to M=5).

LOB stuck partially down (+10.0 deg) from EI (using Wrap-DAP in AUTO):

Lands on the runway at 1801ft. Uses 1280 lbs RCS (1260 lbs up to M=5).

LOB stuck partially down (+10.0 deg) from EI (using Baseline DAP in AUTO):

LOC at M=11 after running out of RCS fuel. Uses 1830 lbs prior to LOC (breaks the aft RCS redline limits of 1175 lbs at M=19).

LOB stuck mostly down (+18.0 deg) from EI (using Wrap-DAP in AUTO):

Breaks the Nz limit of 4.5 g's at M=22. Uses 1890 lbs prior to over-g, and breaks the aft RCS redline limit of 1175 lbs at M=24. All 4 yaw jets are on solid at M=22, and eventually enters a deep pitch down with a small roll rate.

LOB stuck mostly down (+18.0 deg) from EI (using Wrap-DAP in CSS):

LOC at M=16 after running out of aft RCS. The run started at EI. At M=25, manual bodyflap was selected and driven full up (0%). Ran out of aft RCS at M=19, and selected No-Yaw-Jet. At M=16 a rolloff occurred (LOC). No RCS usage data was available.

LOB stuck mostly down (+18.0 deg) from EI (using Baseline DAP in AUTO):

LOC at M=19 after running out of RCS. Uses 1880 lbs RCS prior to LOC, and breaks the aft RCS redline limit of 1175 lbs at M=24.5.

CONCLUSIONS OF STUCK LOB ELEVON STUDY:

- I. **Wrap-DAP provides the most control margin and should be used** for stuck elevon cases. Use of the Wrap-DAP allows larger aileron trim and trim rates to compensate for the stuck LOB elevon. Baseline DAP with the smaller aileron trim and trim rates will lose control quicker than Wrap-DAP.
- II. **Driving the BF manually in a direction opposite the direction of the stuck elevon**, will balance the rolling moment induced by the stuck elevon. By driving the BF in a direction opposite to the stuck elevon, the BF will force the remaining good elevons to all move towards the stuck elevon. This balances the rolling moment induced by the stuck elevon, but gives up longitudinal (pitch) axis trim authority.
- III. **If an Elevon is stuck at trail, it is likely survivable** (but should be analyzed on a case-by-case basis due to Cg variations, aerodynamic conditions, etc). If an elevon is stuck partially up or down (less than or equal to +/- 10 degrees), the case *may* be survivable with manual BF actions (assuming the risk of tail-scrape or elevon scrape at touchdown is acceptable). For cases where the elevon is stuck more than +/- 10 degrees, the case is *not likely* to be survivable.

The next two pages outline a draft real-time flight rule CR that should be submitted in the event that a stuck/failed FCS actuator is discovered during ascent or while on-orbit. The actions outlined in the draft flight rule CR manage on-orbit propellant priorities and entry landing site selection to maximize the probability of surviving an entry with a stuck/failed FCS actuator. The draft rule was coordinated in the May, 2004 timeframe with Prop, GNC, FDO, and the Flight Director Office, but was never submitted as a formal flight rule CR due to the the fact that a problem of this nature would consistute an ISS safe-haven scenario. The actions outlined in the rule assume that ISS safe-haven is not an option, and that the suspect FCS actuator problem was discovered prior to the D/O burn, and that time and propellant are available to reduce the risk of re-entry with the stuck/failed FCS actuator.

A2-210 ENTRY FCS ACTUATOR SYSTEMS MANAGEMENT [CIL]

FOR A SUSPECT/FAILED ENTRY FCS ACTUATOR FAILURE, THE FOLLOWING ACTIONS WILL BE TAKEN PRIOR TO COMMIT TO DEORBIT TO MAXIMIZE THE PROBABILITY OF SAFE ENTRY:

- A. PERFORM THE AEROSURFACE DRIVE TEST AS SOON AS POSSIBLE (PER FLIGHT RULE A8-104) TO CONFIRM THE ACTUATOR FAILURE MODE, AND DETERMINE THE ACTUATOR RANGE OF MOTION (IF ANY). THE AEROSURFACE DRIVE TEST MUST BE PERFORMED DURING AOS TO ALLOW THE MCC TO EVALUATE THE DATA.
- B. CONSERVE THE AVAILABLE AFT RCS PROPELLANT FOR USE FROM EI TO M=1 USING THE FOLLOWING METHODS:
 1. ALL ATTITUDE HOLD AND MANEUVERS OCCURRING PRIOR TO EI SHALL USE AVAILABLE OMS PROPELLANT. AFT RCS PROPELLANT USE IS ONLY ALLOWED FOR THOSE ITEMS OUTLINED IN PART B.4 OF THIS RULE.
 2. DELETE ALL MISSION OBJECTIVES THAT REQUIRE AFT RCS CONSUMPTION
 3. UTILIZE AFT RCS PROPELLANT CONSERVATION TECHNIQUES SPECIFIED IN FLIGHT RULE A6-359.
 4. IT IS ACCEPTABLE TO UTILIZE AFT RCS PROPELLANT FOR ENTRY CRITICAL ACTIONS SUCH AS FCS C/O, RCS HOTFIRE, ENTRY IMU ALIGNMENT AND VERIFICATION, AND A NOMINAL DEORBIT PREP.
- A. TO MAXIMIZE THE ENTRY CONTROL MARGIN, MANAGE THE CG VIA THE FOLLOWING ACTIONS:
 1. SHIFT THE XCG AS FAR FORWARD/AFT AS POSSIBLE WITHIN THE CERTIFIED CG ENVELOPE AS SPECIFIED IN RULE A4-153.
 2. SHIFT THE YCG AS FAR LEFT/RIGHT AS POSSIBLE WITHIN THE CERTIFIED YCG ENVELOPE SPECIFIED IN FLIGHT RULE A4-153.

3. FOR CASES WHERE THE NOMINAL CERTIFIED CG ENVELOPE RESULTS IN A PREDICTED NEGATIVE ENTRY CONTROL MARGIN, THE CONTINGENCY CG ENVELOPE MAY BE USED AS OUTLINE IN FLIGHT RULE A4-153.
4. PARTS B AND C OF THIS RULE ARE ALLOWED EXCEPTIONS TO FLIGHT RULES A2-108, A4-158, A4-207, AND A6-353.
 - A. TARGET DEORBIT BURN AND LANDING SITE PER FLIGHT RULE A2-207, PARAGRAPH D.
 - B. SELECT THE HAC CONFIGURATION THAT PROVIDES THE MOST BENIGN FLIGHT CONDITIONS WITH RESPECT TO THE FLIGHT CONTROL SYSTEM, WHILE PRESERVING THE GREATEST AMOUNT OF ENERGY DOWNMODE OPTIONS, GREATEST RUNWAY MARGIN TO MANAGE FLIGHT CONTROL SYSTEM ISSUES AFTER TOUCHDOWN, AND THE MOST FAVORABLE ATMOSPHERIC CONDITIONS DURING FINAL APPROACH AND ROLLOUT (INCLUDING CROSS WIND SELECTION).
 - C. SELECT THE ENTRY AEROJET DAP CONFIGURATION AS SPECIFIED IN FLIGHT RULE A8-116.
 - D. PER FLIGHT RULE A2-102, STAY ON ORBIT UNTIL A FULL ENGINEERING ANALYSIS OF THE EXPECTED ENTRY CONFIGURATION IS PERFORMED. THE ANALYSIS SHOULD USE THE EXPECTED ENTRY RCS PROPELLANT MARGIN, EXPECTED ENTRY VEHICLE MASS PROPERTIES, FORECASTED LANDING SITE ATMOSPHERIC CONDITIONS, AND PREDICTED TAEM CONFIGURATION/HAC SELECTION, AND PREDICTED TOUCHDOWN CONDITIONS. ONCE THE ANALYSIS IS COMPLETE, PROVIDE THE CREW WITH RECOMMENDED PILOTING TECHNIQUES BASED ON THE ENGINEERING ANALYSIS RESULTS.
 - E. PROVIDE FULL UP CRASH AND RESCUE FORCES AT THE TARGETED LANDING SITE. DEORBIT MAY BE DELAYED UNTIL NECESSARY GROUND FORCES ARE AVAILABLE AT THE TARGETED LANDING SITE.

TABLE 5.8-5 - PROBABLE RISK ASSESSMENT (PRA) STUDY
TOP ENTRY CONTRIBUTORS (OVER ALL CONTRIBUTION 1-IN-980 LOCV (1.02X10-3))

RANK	%*	PROBABILITY	DESCRIPTION OF CAUSE OF LOCV DURING ENTRY
1	27.5	3,571	Max Sink rate exceeded (CREW ACTION)
2	54.9	3,571	Crew improperly performs pre flare
3	75.5	4,762	Crew activates WONG too early
4	78.2	35,714	Crew action failure to de-rotate
5	81.0	35,714	Crew does not line up to centerline properly
6	83.7	35,714	Crew improperly follows guidance on HAC
7	86.5	35,714	Crew bumps stick leading to LOCV
8	87.4	106,975	RUD/SPB MIXER GEARBOX JAMS
9	88.3	106,975	RUDDER GEAR BOX FAILS
10	89.3	106,975	SPEEDBRAKE GEARBOX FAILS
11	90.2	106,975	EBOYD FLAP GEAR BOX JAMS
12	91.1	106,975	MOTOR BRAKE SLIPS ANY 1 OF 3
13	92.0	106,975	RUD/SPB MECHANICAL ACT JAM ANY 1 OF 4
14	92.7	146,349	FAILURE OF LIE SUM ACT
15	93.4	146,349	FAILURE OF LOE SUM ACT
16	94.0	146,349	FAILURE OF RIE SUM ACT
17	94.7	146,349	FAILURE OF ROE SUM ACT
18	95.3	166,945	FAILURE OF LIE PRI ACT
19	95.9	166,945	FAILURE OF LOE PRI ACT
20	96.5	166,945	FAILURE OF RIE PRI ACT
21	97.1	166,945	FAILURE OF ROE PRI ACT
22	97.6	195,580	BODY FLAP HYD ACT 2 FAILS NO OUTPUT
23	98.1	195,580	BODY FLAP HYD ACT 1 FAILS NO OUTPUT
24	98.6	195,580	BODY FLAP HYD ACT 3 FAILS NO OUTPUT
25	98.7	1,069,748	STRUCTURAL FAILURE OF PORT SIDE RUD/SPB
26	98.8	1,069,748	RUD/SPB PORT DRIVE SHAFT STRUCTURAL FL
27	98.9	1,069,748	STRUCTURAL FAILURE OF STB SIDE RUD/SPB
28	99.0	1,069,748	RUD/SPB STB DRIVE SHAFT STRUCTURAL FL
29	99.1	1,069,748	RUDDER TRIPLEX POWER VALVE JAMS
30	99.2	1,069,748	SPB TRIPLEX POWER VALVE JAMS
31	99.3	1,069,748	STRUCTURAL FAILURE OF BODY FLAP
32	99.4	1,069,748	STRUCTURAL FAILURE OF BDF DRIVE SHAFT
33	99.5	1,069,748	STRUCTURAL FAILURE OF ROE
34	99.6	1,069,748	STRUCTURAL FAILURE OF RIE
35	99.7	1,069,748	STRUCTURAL FAILURE OF LIE
36	99.8	1,069,748	STRUCTURAL FAILURE OF LOE
37	99.9	1,108,525	BODY FLAP ACT NUMBER 1 JAMS
38	99.9	1,108,525	BODY FLAP ACT NUMBER 2 JAMS
39	100.0	1,108,525	BODY FLAP ACT NUMBER 3 JAMS
40	100.0	1,108,525	BODY FLAP ACT NUMBER 4 JAMS

NOTES:

- I. A rank of #1 indicates most probable event to result in LOCV during entry alone.
- II. * -Indicates the cumulative percent contribution to 1-in-980 probability of LOCV during entry alone.
- III. Probability indicates the likelihood of LOCV during entry alone due to specified failure (on a per flight basis). Example: Failure Mode Rank #1 has a probability of occurrence of 1-in-3,571 flights.
- IV. **Bold** indicates FCS actuator hardware failure modes documented in the FMEA/CILs
- V. All failure modes are assumed to result in LOCV, and procedural workarounds or crew actions are not considered available to prevent the LOCV.
- VI. Data is based on the results of the September 2003 PRA Data Summit hosted by JSC/S&MA.

The following is a copy of **GPO SCP 2.8.21, which contains Stuck Speedbrake Contingency Energy Management procedures**

GPO SCP 2.8.21

Purpose: To define procedures for off nominal speedbrake positions

Procedures and Background:

STUCK SPEEDBRAKE

RSOC analysis has shown that a stuck speedbrake in MM 304 has very little impact on the trajectory or TAEM interface. The current procedures were developed without regards to winds or other perturbations in TAEM and were evaluated in the SMS. The STA cannot simulate a speedbrake stuck open greater than 50%, so there is some concern over how well some of these procedures can be fully tested and trained for in a real flight environment. Additionally, the present procedures have not been evaluated using the latest Approach and Land I-loads (18°- 20° glideslope and higher airspeed) or the most recent changes to the speedbrake logic in the flight software (OI-22). Neither change is expected to impact the existing procedures. From a systems standpoint, the most likely failure positions are 15 and 81%. Four separate procedures have been established for the entire range of speedbrake settings. This represents a compromise between the desire to minimize the number of techniques and reestablishing the correct energy for a variety of speedbrake positions.

SB SETTING (STUCK)	TAEM	A/L	AIMPOINT
> 60 *	Fly 1-2 dots Hi on GSI ** Throughout TAEM	<220 klbs: 25° OGS (#) >220 klbs: 21° OGS (#)	4000' ***

* If SB stuck open and up-elevons causing control problems, drive BF up manually.

** TAEM: 2 dots = 5000 ft (Full GSI deflection)

A/L: 2 dots = 1000 ft (Full GSI deflection)

Use HUD flight path indicator to fly OGS, if out of PAPI range

*** ½ way between 7500' (nominal) aimpoint and threshold

The procedure covers a speedbrake stuck from 100% to 60%. Although, the speedbrake is never commanded greater than 81% in MM304, it is possible for the speedbrake to go full open (100%) in TAEM and then stick. Throughout TAEM the orbiter is flown 1 to 2 dots high. This is accomplished by flying higher α and lower airspeed to better "stretch" glide capability. The 2500-5000 ft of additional altitude is used to obtain a steeper glideslope, which is required to achieve enough airspeed for preflare. A 4000 ft aimpoint is used since the vehicle is decelerating faster than normal throughout preflare due to the open speedbrake. Both Close-in and Nominal aimpoints are too far down the runway to provide a reasonable chance of touchdown past the threshold.

SB SETTING (STUCK)	TAEM	A/L	AIMPOINT
40-60	AUTO P, R/Y	Fly needles	CLSE

Stuck speedbrake in the midrange most closely resembles the nominal configuration, in terms of energy, for approach and land in the higher region. Hence, the procedure is to basically fly the needles. Since the speedbrake will not retract at 3000 ft, Close in aimpoint is selected to compensate for the increased drag.

SB SETTING (STUCK)	TAEM	A/L	AIMPOINT
30-40	Fly 1-2 dots Lo on GSI Keep EAS < 300	15° OGS (#)	CLSE

Use HUD flight path indicator to fly OGS, if out of PAPI range

With the speedbrake fixed between 30 and 40%, the energy is slightly higher than nominal. Throughout TAEM the vehicle is flown 1 to 2 dots low to dump some of the energy. This is accomplished by flying lower α and higher than nominal airspeed. There is a possibility that HAC shrink may be triggered since the vehicle is below the nominal glideslope. The lower altitude is used to allow a shallower glideslope (15°) and thus maintain close to nominal airspeed. Without the shallow glideslope, excessive airspeed on final could result with the speedbrake partially retracted. Close in aimpoint falls out of the shallow glideslope and airspeed required.

SB SETTING (STUCK)	TAEM	A/L	AIMPOINT
< 30	AUTO P, R/Y At M<.95, deploy gear	Fly needles	CLSE

For speedbrake stuck closed (or nearly closed) there will again be too much airspeed on A/L. The gear is deployed early to increase drag. The gear is not lowered earlier than subsonic (312 KEAS) due to excessive dynamic pressure. Also, at mach < .95, the typical speed brake is around 65%, so lowering the gear emulates the nominal configuration. Close in aimpoint is required since the vehicle will be decelerating faster than nominal through the preflare with an equivalent speedbrake setting (gear) of 60%.

SLOW SPEEDBRAKE

- 1) When M < 0.95: Set manually between 40%-60%.
- 2) Select CLOSE in aimpoint.
- 3) Fly nominal guidance needles around HAC and A/L
- 4) Based on energy conditions on final, crew can manually adjust speedbrake as needed.
Remember slow response of speedbrake.

For a slow speedbrake, the accepted procedure is to "fix" it at the midrange value and then follow the stuck (40-60%) speedbrake procedures. This avoids having the speedbrake lag the desired command from guidance and places it in a configuration most closely resembling the "average" value normally seen on the HAC. The crew can still manually adjust the setting for energy control if they can account for the delay.

EARLY GEAR DEPLOY

- 1) Select CLOSE in aimpoint
- 2) Fly nominal guidance needles around HAC and A/L

For some combinations of failures, the landing gear may be deliberately lowered early to ensure that it does in fact extend. This action should be avoided until subsonic due to dynamic pressure concerns. Inadvertent firing of the backup pyros or other failures could also lead to an unintentional early deploy. The extended gear is roughly equivalent to a 60% speedbrake setting, so essentially the midrange (40%-60%) stuck speedbrake procedures are utilized. The speedbrake should react to the increased drag from the gear and close automatically.

PAPI NOTES:

4 White	GS \geq 23°
1 Red 3 White	GS 21 - 23°
2 Red 2 White	GS 19 - 21°
3 Red 1 White	GS 17 - 19°
4 Red	GS \leq 17°

The glideslope desired for the specific procedure can be called out in terms of the PAPI light configuration to aid the crew. For the 25° GS used with stuck speedbrake greater than 60% and lightweight vehicle, the PAPIs are not useful.

REFERENCES

Ascent/Entry Flight Techniques #200, "Entry DAP Mode for FCS Failures" presented by DF62/M.L. Sarafin, dated 4/23/04.

Memorandum AC5-03-35, "Every Space Shuttle Mission Is A Test Flight", authored by AC5/J. Young, dated 10/17/03.

"Entry DAP Mode Recommendations" presentation in response to Memorandum AC5-03-35, authored by BNA-Houston/Milt Reed and EG/Mark Hammerschmidt, dated 12/3/03.

"STS-107 Entry Longitudinal Aerodynamic Trim Analysis with Body Flap Bounds", authored by BNA-Houston/Goergi Ushev, dated 4/7/04.

Space Shuttle Operational Flight Rules, Volume A, All Flights:

- Flight Rule A8-19 - YAW JET DOWNMODE
- Flight Rule A8-116- AEROJET DAP SYSTEMS MANAGEMENT

Shuttle Operations Data Book (SODB), Volume 1, Section 3.4.1.3.8 Thermal Protection Subsystem, Elevon/Bodyflap Limits.

Probable Risk Assessment (PRA) Data Summit results, conducted by the Safety and Mission Assurance (S&MA) Directorate in September 2003.

NSTS-08399 "SSP CIL LISTING" website @ <http://usahoud4.unitedspacealliance.com/ssp/cil/cil-1.cfm> which was last updated 5/11/04. Specifically, the FMEA/CILs affecting Entry FCS Actuators include:

- Elevon Failure Modes FMEA/CILs:
 - 02-2C-C01-CR-A01; 02-2C-C01-CV-C08; 02-2C-C01-CV-C09; 02-2C-C01-ES-C06; 02-2C-C01-FE-B08; 02-2C-C01-PP-A06; 02-2C-C01-PP-A07; 02-2C-C01-PV-B05; 02-2C-C01-SP-01; 02-2C-C01-ST-A02; 02-2C-C01-SV-B01; 02-2C-C01-SW-C02; and 02-2C-C01-SW-C03.
- Rudder/Speedbrake Failure Modes FMEA/CILs:
 - 02-2A-011-10001; 02-2A-011-10003; 02-2A-011-10101; 02-2A-011-10102; 02-2A-011-10202; 02-2A-011-10401; 02-2A-011-10601; 02-2A-011-10802; 02-2A-011-11001; 02-2A-011-11002; 02-2A-011-11003; 02-2A-011-11201; 02-2A-011-11202; 02-2A-011-11205; 02-2A-011-11402; 02-2A-011-20001; and 02-2A-011-30001.
- BodyFlap Failure Mode FMEA/CILs:
 - 02-2A-021-10001; 02-2A-021-10401; 02-2A-021-10502; 02-2A-021-10902; 02-2A-021-11001; 02-2A-021-11002; 02-2A-021-11003; 02-2A-021-11101; 02-2A-021-11102; 02-2A-021-11105; 02-2A-021-11302; 02-2A-021-11402; 02-2A-021-11601; 02-2A-021-20001; and 02-2A-021-30001.

Ascent/Entry GPO Console Handbook, Volume 1, Checklists and Rationale, SCP 2.8.21, Rev B, dated 2/2002:

- Nickelson, J. L., RSOC STF SSDD-DFD-91-520-043, TAEM Stuck Speedbrake Analysis, May 13, 1991.
- Deger, D., Manofsky, L. and Welch, D., Entry Automon 3101 Class Notes Handout.

TITLE

BFS STANDALONE BLACK ZONE

PURPOSE

To aid ascent/entry GNC operators in vehicle controllability in the event of PASS failure during various stages of dynamic flight. In particular, this document deals with the ability of the BFS to regain control of the vehicle after PASS failure when there is a short delay between PASS failure and BFS engage.

BACKGROUND

When the PASS system fails, the BFS immediately enters a mode called "standalone" where it does not receive any data from sensors and no commands are issued to vehicle hardware. Simulations of this phenomenon were conducted by Rockwell in 1991 and this SCP presents a brief overview of these results for quick reference (see the full Rockwell report for more details, referenced at the end of this document).

BLACK ZONE DEFINITION

"Black zones" are defined as vehicle loss of control for the following:

First Stage: Pad/Tower recontact, exceeding structural loads, exceeding angle of attack heating limits, or exceeding SRB separation limits.

Second Stage: Roll, pitch or yaw body rates exceeding 20°/sec, or catastrophic delay of MECO command.

Entry/TAEM/GRTLs: Dynamic pressure > 600 psf, normal acceleration greater than 2.5 g's, navigation errors too large to enable crew to find the runway, or energy state too high or low to allow system to make runway.

GRAY ZONE DEFINITION

In addition to the black zones, the following gray zones are defined in second stage ascent and unpowered atmospheric flight:

Second Stage: Highly undesirable vehicle rates or attitudes, significant violations of design requirements, recontact with the external tank, or unacceptable conditions for the subsequent flight phase.

Entry/TAEM/GRTLs: Dynamic pressure between 500 and 600 psf, or inability to make the runway barring extremely off-nominal procedures by the crew.

FIRST STAGE ASCENT

The Rockwell study found that during first stage ascent, the effects of BFS engage result in trajectory deviations that exceed certification limits approximately 60-70% of the time, however the severity of the constraint violations are a function of the length of time of the standalone period after PASS failure and prior to BFS engage (10 seconds assumed for study). See Figure 1 for a graphical representation of first stage black zones.

SECOND STAGE ASCENT

(See Figure 2).

Post-SRB Separation Attitude Hold: Black

Alpha Limiting: Gray (excessive alpha/beta buildup)

Constant Thrust: White

Constant Acceleration: First 23 seconds are white; remainder is gray due to large vehicle rates and accelerations exceeding 3 g's.

Fine Count: Black (due to possible catastrophic delay of MECO command).

POWERED RTLS

(See Figure 3).

Post-SRB Separation: White

Fuel Dissipation: Eight seconds following RTLS abort selection are gray due to excessive rates and angle of attack, remainder is white until PPA.

Powered Pitcharound (PPA): The ten seconds following PPA initiation are black.

Flyback: White until PPD-10, which is gray

Powered Pitchdown (PPD): Black.

ET SEPARATION

Nominal/TAL Mated Coast: White

Nominal/TAL Separation: Separation through separation +0.24 sec (OI-21) is black for recontact.

RTLS Mated Coast: All of mated coast for qbar between 5 psf and 10 psf is black

RTLS Separation: Separation through separation + 2 seconds is black; if Qbar = 5psf, further analysis required; if Qbar = 10psf, separation +4 seconds through separation +6 seconds is black.

ENTRY/TAEM/GRTL

OPS 3: No black zones for <15 sec standalone time.

OPS 6, GRTL: Black zones at 20 seconds after MM 602 transition and at alpha transition (see Figure 4).

FIGURES & TABLES

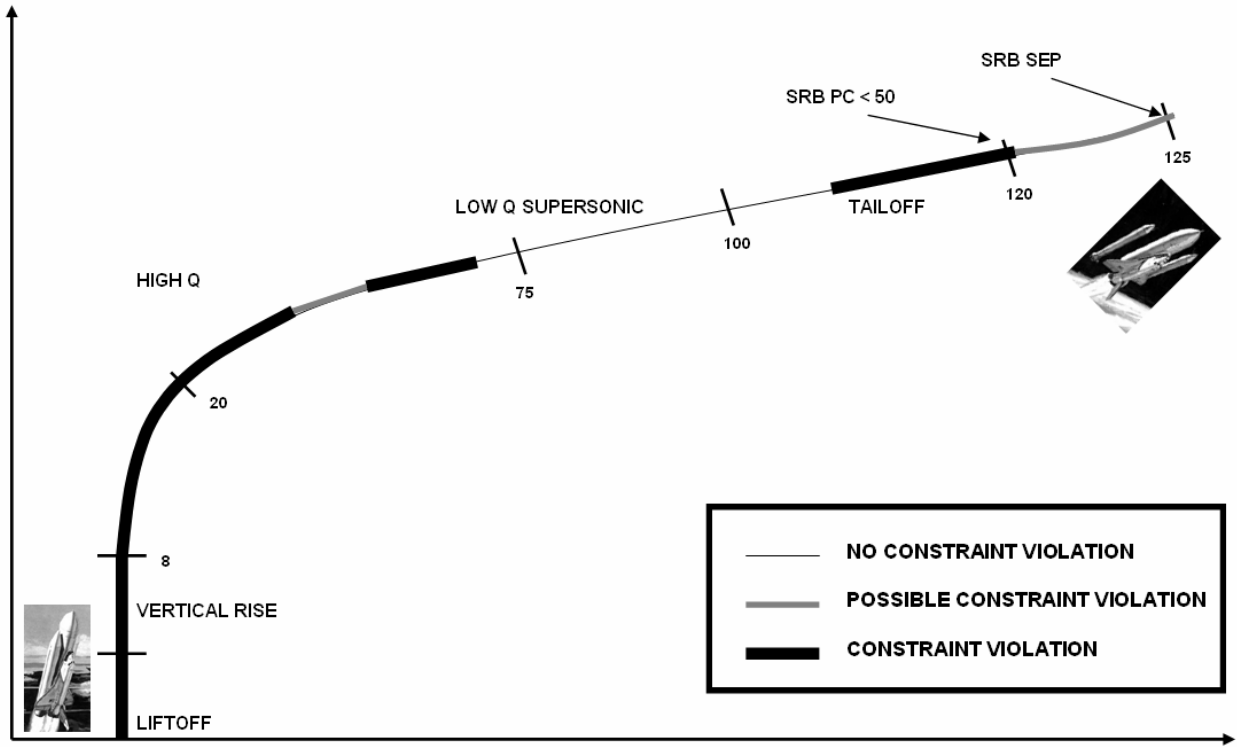


Figure 1: First Stage Black Zone Summary

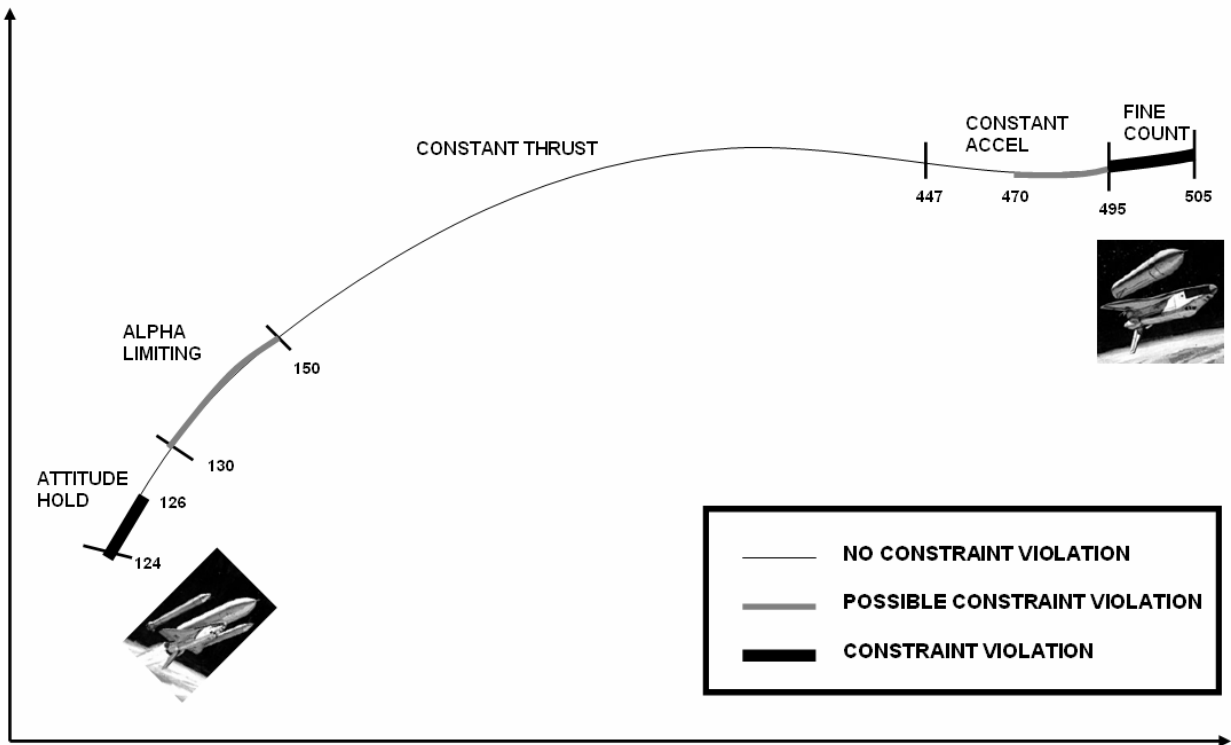


Figure 2: Second Stage Nominal Black Zone Summary

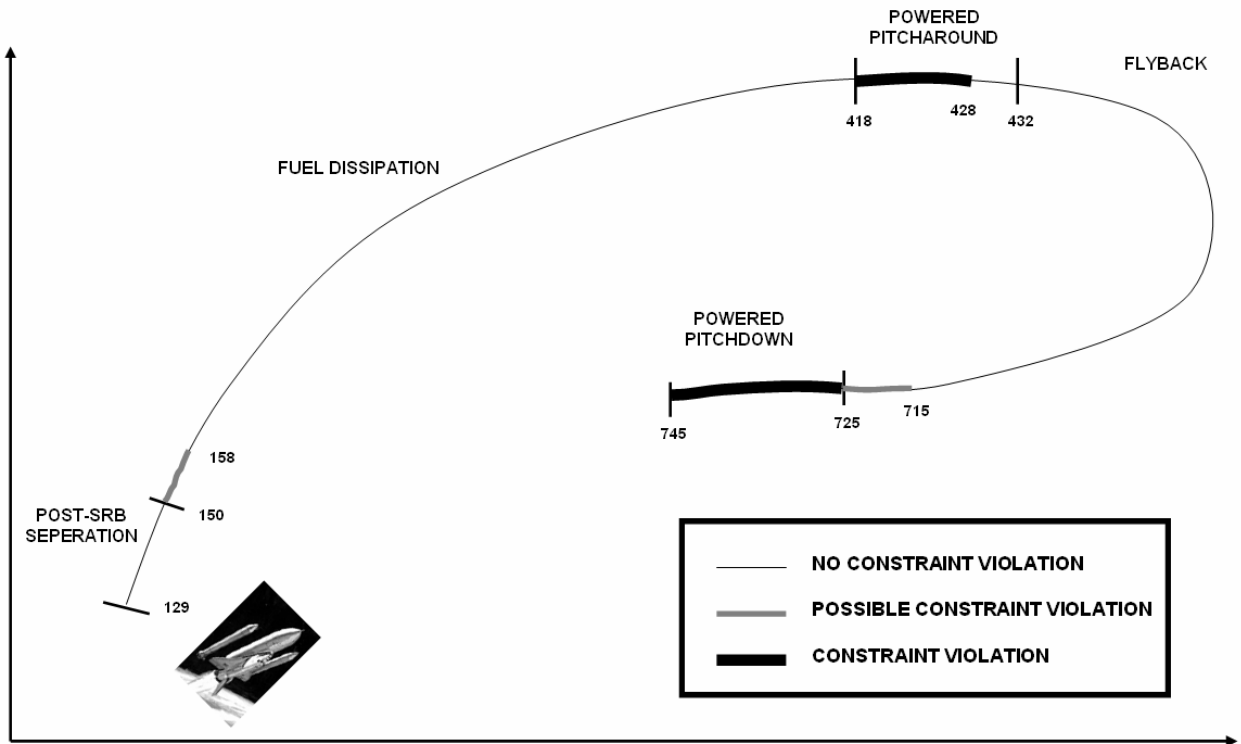


Figure 3: Powered RTLS Black Zone Summary

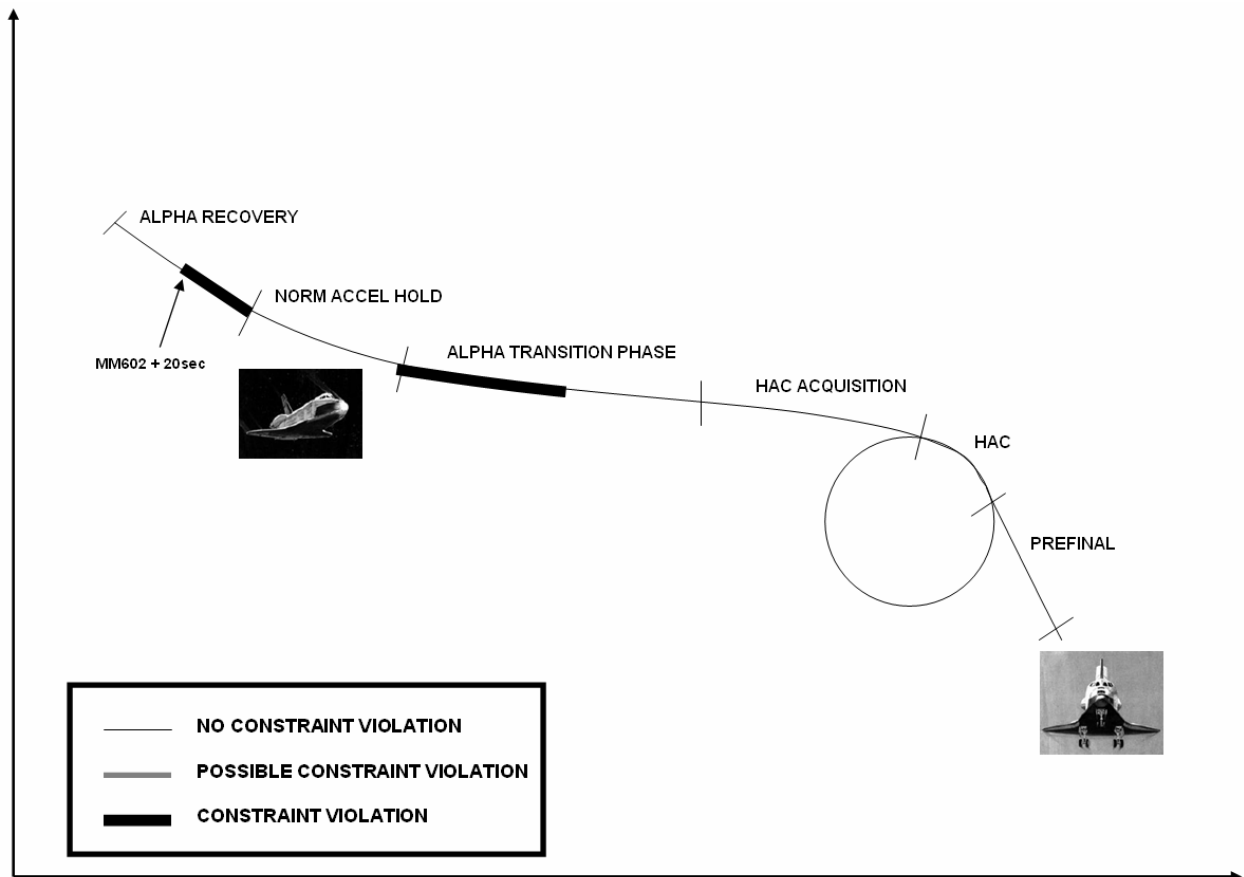


Figure 4: Glide RTLS Black Zone Summary (MM 602, 603)

REFERENCES

Backup Flight System (BFS) Stand Alone Black Zone Study Results, Rockwell International SSD91D0712, Sept. 27 1991.

TITLE

Abort Rotary Switch

PURPOSE

The purpose of this SCP is to explain how the abort rotary switch is used and its function. The abort rotary switch and abort pushbutton are used to declare aborts onboard the Orbiter. The abort rotary switch is a four position, three contact switch located on Panel F6. The abort pushbutton is located next to the switch and is depressed once the switch is positioned to the appropriate abort mode. The Flight Director illuminates the button onboard the Orbiter when an abort is declared by sending an abort command to the vehicle.

ABORT ROTARY SWITCH

DESCRIPTION

The abort rotary switch has four positions: RTLS, OFF, ATO, and TAL (Figure 1.1). Nominally, it is in the OFF position unless an abort has been declared.

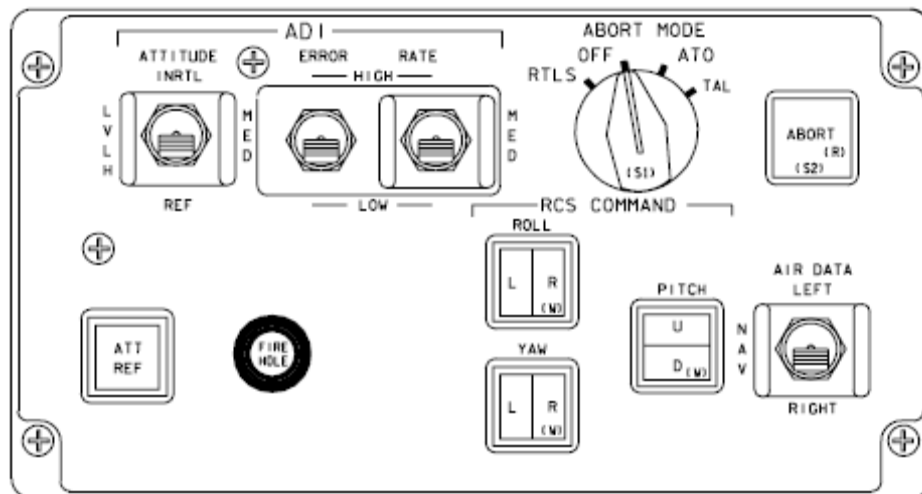


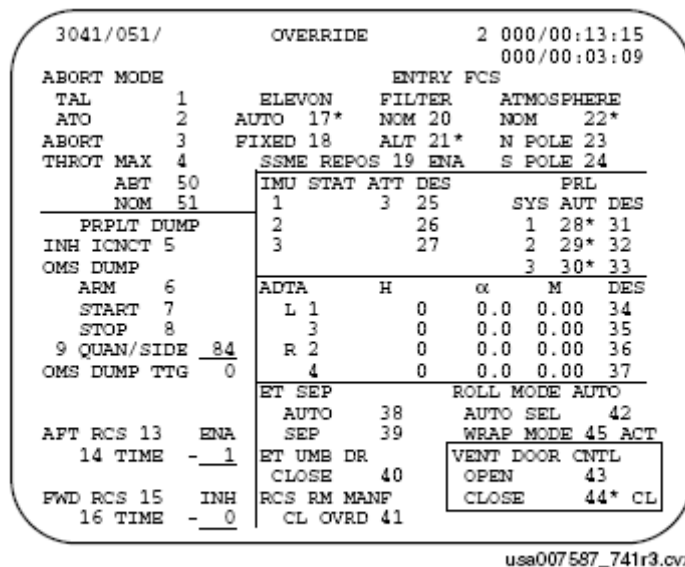
Figure 1.1: Panel F6 (Partial)

RTLS

Once the decision is made to initiate an RTLS abort, MCC will direct the crew to "Abort RTLS." The Flight Director will also illuminate the abort light on panel F6, using a switch on their console, as a backup to the voice call. Onboard, moving the Abort Mode rotary switch to RTLS and depressing the Abort pushbutton reconfigures GNC software to RTLS. If the switch malfunctions, the crew can enter OPS 601 PRO on any PASS keyboard or an ITEM 4 on the Traj display.

ATO

ATO is selected pre-MECO using the Abort Mode rotary switch and depressing the Abort pushbutton or by an item entry on SPEC 51 (Figure 1.2) if the switch fails. Upon selection of ATO, an OMS dump is provided unless a mission has OMS critical loading such that the dump is inhibited. Also, it switches to abort MECO targets and it may enable variable I-Y steering to freeze the inclination, depending on the flight.



OVERVERRIDE Display (SPEC 51)

Figure 1.2: Override Display (SPEC 51)

TAL

TAL is selected prior to MECO by placing the Abort Mode rotary switch in TAL and depressing the Abort pushbutton. An item entry on SPEC 51 (Override display) can also be used to select TAL if the switch fails. The crew should see the title of the Ascent Traj display change to TAL Traj and the MM103T (flight instruments upper right corner) as confirmation that the TAL flag has been set. Another way to confirm TAL has been selected is to check Item 41 on SPEC 50 (Horiz Sit display).

Bailout

When the Abort Mode rotary switch is moved to ATO and the Abort pushbutton is pressed in MM603/305, an attitude hold is initiated to allow the crew to stabilize the Orbiter in glided flight using the AUTO DAP functions. It is armed when Mach is less than 1.0.

ABORT PUSHBUTTON

The button can only be illuminated by the Flight Director to alert the crew of an abort. It must be depressed by the crew after declaring an abort with the Abort Mode rotary switch. The

signals from the pushbutton pass through FF1, FF2, and FF3 MDMs. The signals for the light pass through PL1 and PL2 MDMs (also called PF1 and PF2).

POWER AND SIGNAL FLOW

Below is a table that summarizes the power and signals for the Abort Rotary Switch and Pushbutton (Table 1.1).

Abort Mode	Control Bus	MDM
A	AB1	FF1
B	BC1	FF2
C	CA1	FF3

Table 3.1: Abort Rotary Switch and Pushbutton Power Supplies and Signal Flows

Power

The Abort Rotary Switch is powered by three control buses, one per contact. Control bus AB1 provides power to Abort Mode A, control bus BC1 provides power to Abort Mode B, and control bus CA1 provides power to Abort Mode C.

Signals

The signals from the Abort Rotary switch pass through Flight Forward MDMs. Abort Mode A is passed through FF1, Abort Mode B is passed through FF2, and Abort Mode C is passed through FF3.

Below is a figure (Figure 1.3) that shows the power supplies and signals flows for the Abort Rotary switch.

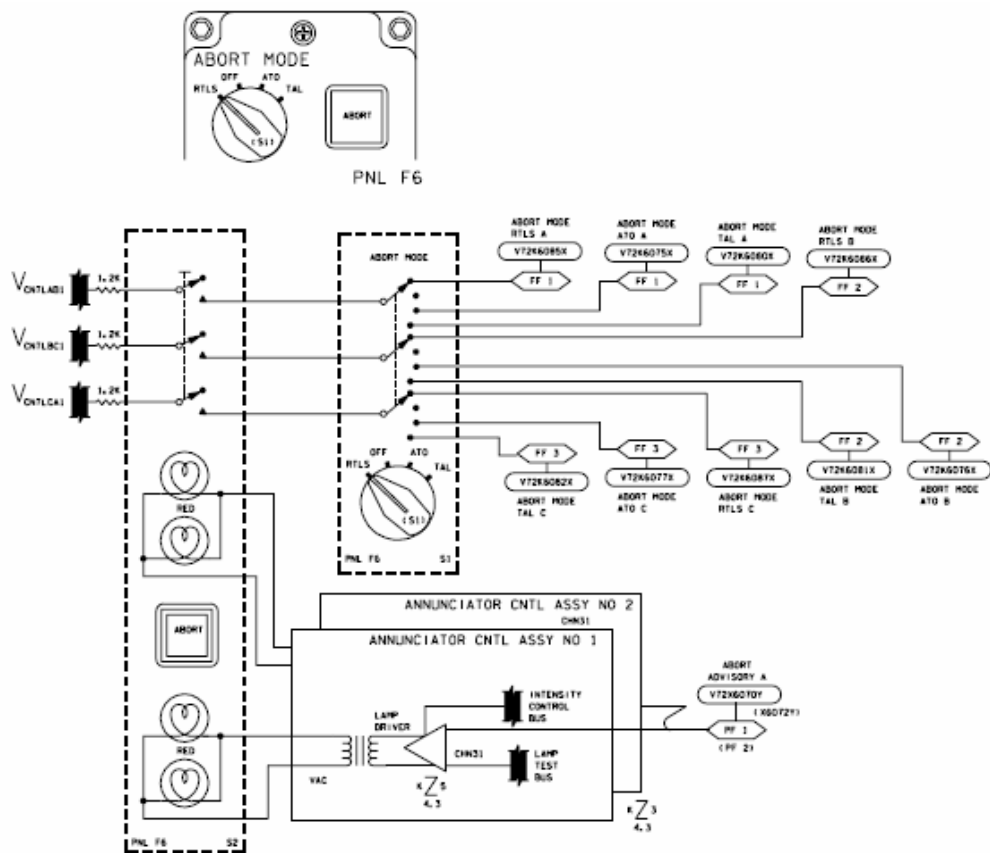


Figure 1.3: Abort Rotary Switch Power and Signal Flow

REFERENCES:

1. Space Shuttle Systems Handbook, Rev G-2, Apr 2004.
2. Shuttle Crew Operations Manual, OI-30, Oct 2004.
3. Flight Procedures Handbook, Ascent/Aborts, Rev F, Mar 2005.
4. Flight Data File, Ascent Pocket Checklist, Generic, Rev M, Dec 2004.

TITLE

POST CONTACT THRUST (PCT)

PURPOSE

The purpose of this section is to describe the purpose and procedure for ARMING/DISARMING and activating the PCT.

BACKGROUND

Post-Contact Thrusting (PCT) is an OPS 2 function which is performed during ISS docking when the Orbiter has made initial contact with its target, or is within two inches of contact with the target. Once the PCT is armed and activated, the Orbiter's down-firing jets are fired to assure a seal between the Orbiter and the docking interface before mating. The pre-programmed sequence of Orbiter jet firings is pilot initiated at contact.

The current ISS PCT I-load consists of 4 jets (2 nose - 1 from G-5, 1 from G-6, and 2 tail - 1 from G-13, 1 from G-14) firing three 80 ms pulses separated by 160 ms. Then there is a 0.96 second delay. This is followed by 2 nose jets firing four 160 ms pulses separated by 80 ms. The total duration of this sequence is 2.4 seconds. The 2.4 seconds follows a software processing delay of 120 ms + 0 to 160 ms (uniformly distributed).

The PCT Logic (Figure 6.4-1) is executed and performs the logic required to ARM/DISARM the sequence, activate/deactivate the sequence and to command the I-loaded jet firing pattern. This logic first checks to see if the sequence has been armed or disarmed via the left or right SPD BK/THROT AUTO/MAN PBI. If it has just been disarmed it performs the appropriate reset actions before returning. If the sequence is armed, the logic will check to see if the sequence is being activated or deactivated via the SPARE PBI (on either DAP panel) or the LH AUTO MAN BF PBI or deactivated via the THC, the RHC or the FREE PBI. If the sequence has been activated via the SPARE PBI (forward or aft) or the LH AUTO/MAN BF PBI, DOCKING_ACTIVE is set true to indicate the post-contact firing has been activated, the firing counters are initialized by performing the INITIATE_COUNTERS logic. If the sequence has been deactivated, DOCKING_ACTIVE is set OFF to indicate the sequence has been terminated and NEW_PANEL_SW_WORD is set to the I-loaded Post-Contact Thrusting DAP (PCT DAP). Additionally, the required DAP CONFIG parameters are set to load a new DAP load and the DAP CONFIG principal function is forced to load the new DAP loads. Finally, if the sequence is active, the DETERMINE_JET_GROUPS logic is performed to determine the jet groups to be commanded based on the I-loaded jet firing pattern and the NEW_PANEL_SW_WORD is repeatedly set to the CONTACT DAP values. The panel switch interfacing function consists of reading the panel switches, selecting DAP loads, indicating which modes and options are in effect by providing panel switch lamp drive signals and buffering of uplinked data.

PROCEDURE

To arm the PCT, the SPDBK/THROT push-buttons on panels F2 and F4 are set to AUTO. Check the light is on.

ARM PCT		
F2/F4	SPDBK/THROT pb	- AUTO
		- ✓ It is on

After the PCT has been armed, the CONTACT procedure is called out at contact indication, or when the range is within two inches. Once either of these conditions have been met, the CDR activates the PCT PBI on the DAP panel (the PCT PBI is the spare PBI). The CDR then checks the capture light on, and the initial contact light off, on the docking system. The MS will then start the event timer at 00:00:00. If NO CAPTURE (bounce off), the FAILED CAPTURE procedure is performed to put the Orbiter in position to either back away or try another capture attempt at a safe range from the docking vehicle. After the event timer has been started, the MS performs the AUTO DOCKING SEQUENCE to complete the docking. Once capture has been confirmed, the PCT will be disarmed. To disarm the PCT, the SPDBK/THROT push-buttons on panels F2 and F4 are set to AUTO. The MS will then check the light is off. Once it is disarmed, the flight controller power will be turned off.

<u>CONTACT</u>			
At first CONTACT indication OR when RNG < 2 in:			
CDR	DAP: PCT (SPARE PBI)		
	check CAPTURE It - on		
	check INITIAL CONTACT It - off		
MS	START EVENT TIMER = 00:00:00		
<table border="1"><tr><td>IF NO CAPTURE (bounce-off) Perform <u>FAILED CAPTURE</u></td></tr></table>			IF NO CAPTURE (bounce-off) Perform <u>FAILED CAPTURE</u>
IF NO CAPTURE (bounce-off) Perform <u>FAILED CAPTURE</u>			
Perform AUTO DOCKING SEQUENCE (Cue Card)			
When capture confirmed: DISARM PCT:			
F2/F4	SPDBK/THROT pb	- AUTO	
		- ✓ It is off	
A6U	FLT CNTLR PWR	- OFF	

Attitude control from free drift after docking is flight specific for ISS flights.

If a failed docking attempt were to occur, the crew may or may not deflect either hand controller to abort the sequence; therefore, the sequence will time-out 5 seconds after PCT initiation. This will allow the crew to change the DAP without deflecting the stick or pressing a deactivate PBI (Free, spare, lh_autmanbf). Five seconds was selected to allow the crew enough time to remove their hands from the spare PBI to prevent reactivation of the PCT. In the event of a successful docking, the crew will have sufficient time to manually reconfigure the DAP to damp the docking rates post-capture.

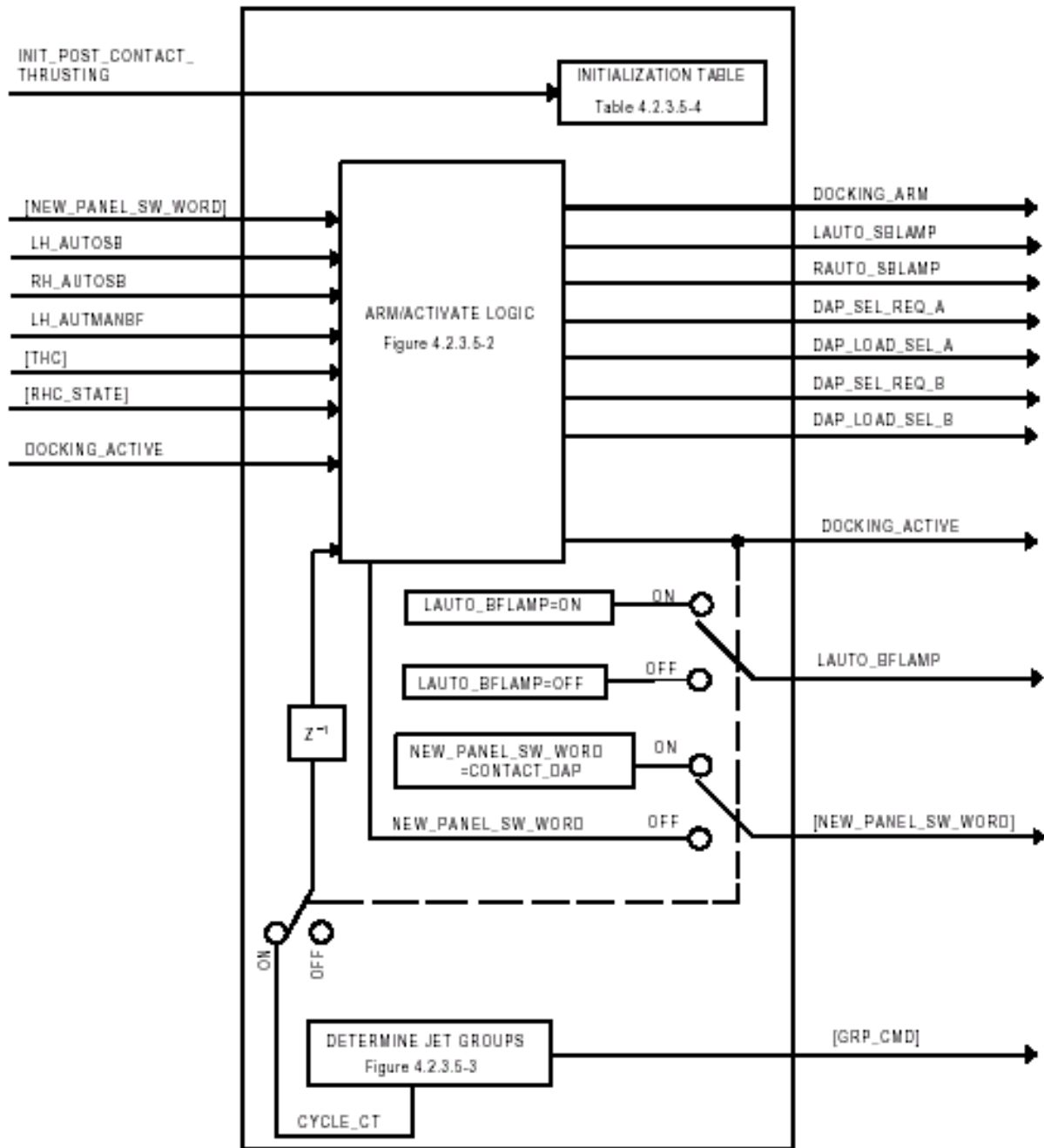
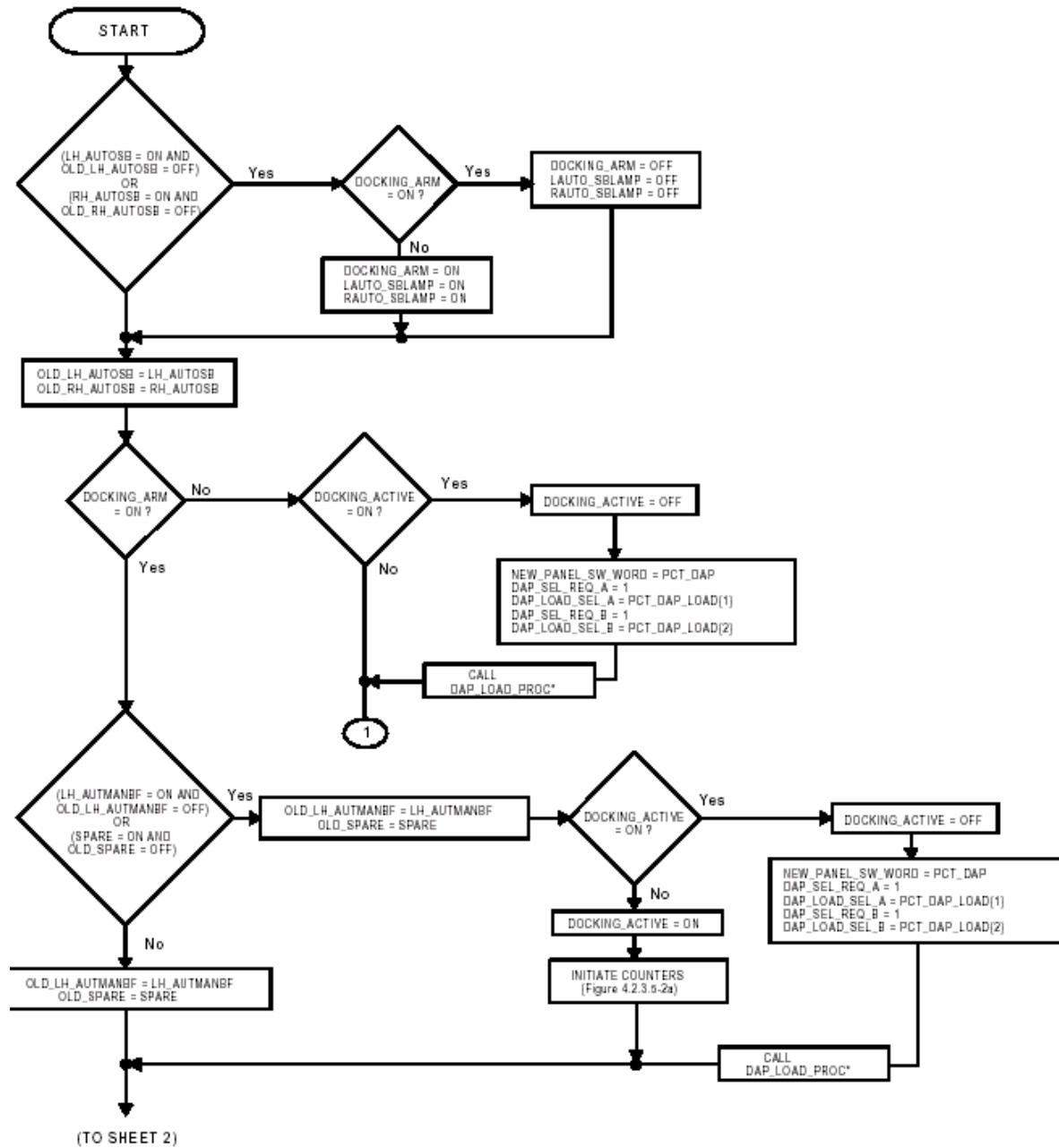
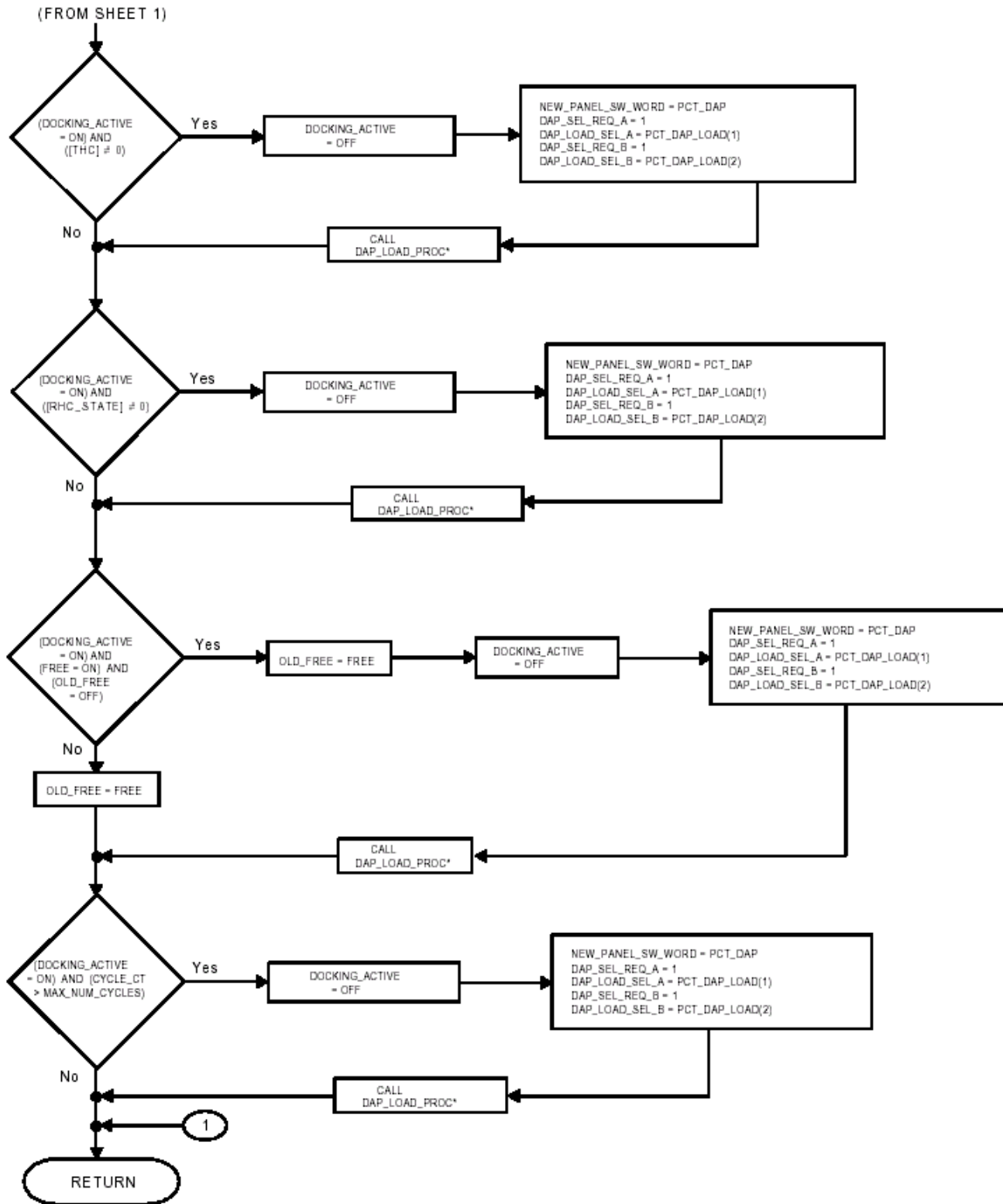


Figure 6.1-1 POST CONTACT THRUSTING LOGIC



* DAP_LOAD_PROC IS A MODULE WITHIN THE ORBIT DAP CONFIG SPEC FUNCTION (5.8)

Figure 6.1-2 ARM/ACTIVATE LOGIC (SHEET 1 of 2)



* DAP_LOAD_PROC IS A MODULE WITHIN THE ORBIT DAP CONFIG SPEC FUNCTION (5.8)

Figure 6.1-3 ARM/ACTIVATE LOGIC (SHEET 2 of 2)

Name	Description	Type	Unit	MSID
MAX_NUM_CYCLES	Maximum number of cycles allowed prior to automatically stopping the post contact thrusting sequence.	I	none	V99U5729C
PHASE1_MAX_PULSES	Number of pulses for phase one jets in one cycle of the post contact thrusting sequence.	I	none	V99U5730C
PHASE1_PULSE_ON	The duration, in number of 0.08 sec DAP cycles, of each phase one jet pulse.	I	none	V99U5731C
PHASE1_DELAY	The time delay, in number of 0.08 sec DAP cycles, after each phase one pulse, required prior to initiating the next phase one pulse.	I	none	V99U5732C
PHASE1_DELAY_PHASE2	The time delay, in number of 0.08 sec DAP cycles, after each phase one pulse delay in a cycle prior to initiating the first phase two pulse.	I	none	V99U5733C
PHASE2_MAX_PULSES	Number of pulses for phase two jets in one cycle of the post contact firing sequence.	I	none	V99U5734C
PHASE2_PULSE_ON	The duration, in number of 0.08 sec DAP cycles, of each phase two jet pulse.	I	none	V99U5735C
PHASE2_DELAY	The time delay, in number of 0.08 sec DAP cycles, after each phase two pulse, required prior to initiating the next phase two pulse.	I	none	V99U5736C
CYCLE_PAUSE	The time delay, in number of 0.08 sec DAP cycles, after each phase two pulse delay in a cycle prior to initiating the next cycle.	I	none	V99U5737C
PCT_DAP	The control panel switch signal if the contact sequence is deactivated or expires.	A(24)B	none	See Table 4.2.3.5-2a in FSSR-09
PCT_DAP_LOAD	The numbers of the DAP A and B to be used if the contact sequence is deactivated or expires.	A(2)I	none	V99U5762C V99U5763C
PHASE1_GRP_CMD	The number of jets to be fired in phase 1. [G-5, G-6, G-13, G-14]	A(4)I	none	V97U7460C V97U7461C V97U7462C V97U7463C
PHASE2_GRP_CMD	The number of jets to be fired in phase 2. [G-5, G-6, G-13, G-14]	A(4)I	none	V97U7464C V97U7465C V97U7466C V97U7467C

TABLE 6.1-1 POST CONTACT THRUST I-LOADS

REFERENCE

RNDZ Flight Data File

FSSR-09, FLT CNTL ORB DAP

TITLE

ORBIT DAP CONTROLLABILITY: PRIMARY JET REQUIREMENTS

PURPOSE

To specify the RCS jet requirements for Orbit DAP rotational and translational control in any given DAP Primary submode, and to explain the use of these requirements.

DESCRIPTION

This procedure provides the user with a quick reference tool for determining Orbit DAP Primary modes which may be acceptable for vehicle control. An analysis of the Orbit DAP Alternate control mode or the Transition DAP has not been performed, and, as such, this SCP should not be used to assess controllability in these DAPs. Also, the following specifications apply to "orbiter-alone" flight, because no analysis has been performed for configurations of significantly different mass properties, such as station-mated control.

Section 1 begins by summarizing the 18 possible Primary modes that can be selected by varying the pitch and yaw jet options, and the Low Z option. Table 6.2-I then specifies which of these modes will result in a loss of control, degraded control, or high-usage control when a single jet group is lost (see Figure 6.2-I for jet group number identification). Again, this is a quick reference table. For the loss of multiple groups, this table can be used to quickly compile a list of DAP modes which are unacceptable, but it must be used in conjunction with section 2 to determine which of the remaining submodes are acceptable (section 1 is a summary of section 2, but it only takes into account the loss of one group).

The Rotational Jet Control Tables shown in table 6.2-II of section 2 define the minimum jet groups required to maintain vehicle control in any given DAP submode. The section defines the jet groups that are required to maintain vehicle control for each of the 18 specific cases summarized in section 1. Note that only one jet is required in a group for that group to be considered available.

For a number of cases listed in section 2, there are notes associated with the requirements. These notes serve one of two purposes. The first is to inform the user of the procedure that should be used if a requirement is not met (note 1 falls into this category). The second is to provide the user with rationale for the requirements defined in table 6.2-II (Notes 2 to 4). Two things should be kept in mind which will make vehicle control easier to understand:

- A. If at least 1 jet is available in each of the 11 groups that are used for rotational control (groups 2 to 6 and 9 to 14, see figure 6.2-I), the vehicle will be controllable in any of the 18 rotational modes listed in section 1. It is only when an entire group is lost that this procedure needs to be invoked (unlike the Alternate PRCS mode, the Primary jet selection mode does not recognize the loss of an entire jet group in most cases)

- B. There is a significant difference between a jet group being unavailable and being not preferred. If all of the aft yaw jets fail or are deselected (groups 9 and 10), they are unavailable and will never fire. However, if these groups are available, but Nose-Only Yaw is selected, they are not preferred. However, this does not mean that they are never going to fire. If one of groups 2 or 3 fail, the aft yaw jets will fire even though they are not preferred. Understanding this difference will give a better understanding of why, for example, groups 9 and 10 are listed in section 2 for Nose- Only Yaw cases. The notes in Section 2 and the default logic in section 3 explain how this logic works. The user should always keep in mind that a jet should be considered available unless it has be deselected (whether manually or automatically by RM).

Section 3 contains a description of important default logic used by the DAP in performing rotational control. This logic is designed to provide a safe configuration when a normally-used jet group is lost in a particular submode, or when seemingly-conflicting modes are selected (such as tail-only control and Low Z).

While the first three sections deal with rotational control, Section 4 specifies jet requirements for translations, for both Normal Z and Low Z modes. As indicated, these requirements may be different for translations with active attitude control and translations in free drift. For translations with active attitude control, remember to also check the previous sections for rotational control requirements. Finally, Section 5 describes the default logic used by the DAP in performing translations.

PROCEDURE

Several procedures are provided here to show how sections 1, 2, and 3 can be used alone or together to determine the jet groups required for acceptable vehicle control. Note that there are also examples included in each section to explain the use of that specific section.

A. Determine if a mode is acceptable for loss of one group:

1. Using table 6.2-I in section 1, find the column associated with the failed group. Any cases which have an "L" in that column will result in a loss of control. Any cases which have an "S" in that column will be sloppy, but controllable.. An "H" indicates high RCS usage (see section 3, notes 2 and 4). All of the remaining cases can be considered controllable.

or 1. Using table 6.2-II in section 2, find the case associated with the given mode. Determine whether or not the required groups are available.

2. If all the requirements are met, the vehicle will be controllable. If any of the requirements are not met, read any notes associated with that requirement to receive further instructions or understand the rationale for the requirement. If there are no further instructions in the note, or if there is no note, assume a loss of control for that DAP mode and failure.

B. Determine if a DAP mode is acceptable for loss of multiple groups:
(steps 1 and 2 are optional)

1. In section 1, use table 6.2-I to determine if the loss of any of the failed groups alone would result in a loss of control for the given DAP mode (indicated by an "L").
2. If YES, then assume loss of control for the multiple failures (section 2 may provide rationale if desired.) If YES, then steps 3 and 4 are no longer required.
3. If NO, then find the given case in table 6.2-II of section 2. Determine whether or not the required groups are available.
4. If all the requirements are met, control will be acceptable. If any of the requirements are not met, read any notes associated with that requirement to receive further instructions or understand the rationale for the requirement. If there are no further instructions in the note, or if there is no note, assume a loss of control for that DAP mode and the given group failures.

C. Find all controllable DAP modes for loss of one group:

Using section 1, find the column associated with the failed group. Any cases which have an "L" in that column will result in a loss of control. All of the remaining cases can be considered controllable submodes (though some may be degraded).

D. Find all controllable DAP modes for loss of multiple groups:

1. Using section 1, find the column associated with one of the failed groups. Any cases which have an "L" in that column will result in a loss of control. These cases can be considered unacceptable DAP modes.
2. Repeat step 1 for each failed group. Any cases which had an "L" in a column associated with any of the failed groups is considered unacceptable.
3. Using the cases which were not identified as unacceptable, find each case in section 2. For each case, determine whether or not the required groups are available.
4. If all the requirements are met, control will be acceptable. If any of the requirements are not met, read any notes associated with that requirement to receive further instructions or understand the rationale for the requirement. If there are no further instructions in the note, or if there is no note, assume a loss of control for that submode and the given group failures.

SECTION 1: ROTATIONAL CONTROL AND LOSS OF ONE GROUP

This section provides a quick reference for determining which DAP modes CANNOT be used for the failure of an entire group of jets. It is important that table 6.2-I not be used by itself to determine which DAP modes are acceptable for the loss of more than one group. The following examples illustrate this point.

EXAMPLE 1 -

If all jets in G-4 are lost, the table shows that cases 3, 6 and 7 will result in a loss of control ("L"). If no other groups have failed, it can then be assumed that adequate control will be maintained for the remaining 15 cases.

EXAMPLE 2 -

If all jets in G-4 are lost, the table shows that cases 3, 6 and 7 will result in a loss of control. If all jets in groups G-13 and G-14 are lost, the table shows that cases 3 and 5 through 18 will also result in a loss of control. However, it cannot be assumed that the remaining cases (1, 2 and 4) will provide adequate control. This table cannot provide that information for multiple group failures. It simply narrows down the list of DAP modes which may be acceptable. Since 15 of the cases have been eliminated as acceptable modes, the user can now refer to section 2 for each of the three remaining cases, where it will be found that negative pitch control cannot be maintained for these failures.

Summary of Cases

CASE #	CASE DESCRIPTION		
	Z TRANS	PITCH CONTROL	YAW CONTROL
1*	NORM Z	Nose & Tail	Nose & Tail
2		Nose & Tail	Nose-only
3		Nose-only	Nose & Tail
4		Nose & Tail	Tail-only
5		Tail-only	Nose & Tail
6		Nose-only	Nose-only
7		Nose-only	Tail-only
8		Tail-only	Nose-only
9*		Tail-only	Tail-only
10*	LOW Z	Nose & Tail	Nose & Tail
11		Nose & Tail	Nose-only
12		Nose-only	Nose & Tail
13*		Nose & Tail	Tail-only
14		Tail-only	Nose & Tail
15		Nose-only	Nose-only
16		Nose-only	Tail-only
17		Tail-only	Nose-only
18*		Tail-only	Tail-only

*Denotes case often used in flight.

TABLE 6.2-I - VEHICLE CONTROL AFTER LOSS OF ONE GROUP

Jet group which has been lost												CAUTION	
	2	3	4	5	6	9	10	11	12	13	14		
C A S E	1							S	S	S	S	See examples A, B, and C in the PROCEDURE section for proper use of this table. Improper use can lead to incorrect conclusions.	
	2							S	S	S	S		
	3			L	H	H			L	L	L		L
	4						L	L	S	S	S		S
	5								L	L	L		L
	6			L	H	H			L	L	L		L
	7			L	H	H	L	L	L	L	L		L
N U M B E R	8							L	L	L	L	<u>LEGEND</u> L- Loss of control will occur H- Controllable, but RCS usage will be high (i.e., see note 4 in Sec. 3). S- Controllable, but vehicle may occasionally exceed att deadbands (i.e., see note 2 in Sec. 3). BLANK- control is acceptable	
	9						L	L	L	L	L		
	10				L	L					L		L
	11				L	L					L		L
	12				L	L					L		L
	13				L	L	L	L			L		L
	14				L	L					L		L
	15				L	L					L		L
	16				L	L	L	L			L		L
	17				L	L					L		L
	18				L	L	L	L			L		L

SECTION 2: ROTATIONAL CONTROL AND LOSS OF MULTIPLE GROUPS

This section lists the jet groups required to maintain adequate vehicle control for any given DAP mode (note that Boolean logic is used: • means “and”, + means “or”). The following example illustrates the use of table 6.2-II.

EXAMPLE

For the DAP configuration given in case 1, assume that all the jets in G-11 have failed. The second line of case 1 shows that one jet in either G-5 or G-6 or in both G-11 and G-12 are required for positive pitch. Since G-5 and G-6 are available (only one is required), this requirement is met. The fourth line shows that one of G-11 or G-14 and one of G-12 or G-13 are required for roll control. This requirement is met since G-12, G-13 and G-14 are available. However, there is a note associated with this requirement. In reading note 2 in section 3, the user will find that the vehicle is controllable since all of the requirements have been met, but that control will be sloppy since G-11 has been lost.

TABLE 6.2-II.- ROTATIONAL JET CONTROL TABLES

CASE 1: NORM Z, NOSE & TAIL PITCH, NOSE & TAIL YAW			
REQUIRED GROUPS	RESULTANT ROTATION	LOCATION AND DIRECTION	
5 + 6 + (11•12)	+P	FDR + FDL + (LU•RU)	
4 + (13 • 14)	-P	FU +(LD•RD)	
(11 + 14) • (12 + 13)	-R, +R	(LU+RD)•(RU+LD)	(See Note 2)
(2•3)+(9•10)	-Y, +Y	(FL•FR) + (LL•RR)	(See Note 1)

CASE 2: NORM Z, NOSE & TAIL PITCH, NOSE-ONLY YAW			
REQUIRED GROUPS	RESULTANT ROTATION	LOCATION AND DIRECTION	
5 + 6 + (11•12)	+P	FDR + FDL + (LU•RU)	
4 + (13 • 14)	-P	FU +(LD•RD)	
(11 + 14) • (12 + 13)	-R, +R	(LU+RD)•(RU+LD)	(See Note 2)
(2•3) + (9•10)	-Y, +Y	(FL•FR) + (LL•RR)	(See Note 1)

CASE 3: NORM Z, NOSE-ONLY PITCH, NOSE & TAIL YAW			
REQUIRED GROUPS	RESULTANT ROTATION	LOCATION AND DIRECTION	
5 + 6	+P	FDR + FDL + (LU•RU)	(See Note 5)
4	-P	FU +(LD•RD)	
11•12•13•14	-R, +R	LU•RD•RU•LD	(See Note 3)
(2•3) + (9•10)	-Y, +Y	(FL•FR) + (LL•RR)	(See Note 1)

CASE 4: NORM Z, NOSE & TAIL PITCH, TAIL-ONLY YAW			
REQUIRED GROUPS	RESULTANT ROTATION	LOCATION AND DIRECTION	
5 + 6 + (11•12)	+P	FDR + FDL + (LU•RU)	
4 + (13 • 14)	-P	FU + (LD•RD)	
(11 + 14) • (12 + 13)	-R, +R	(LU+RD)•(RU+LD)	(See Note 2)
(9•10)	-Y, +Y	LL•RR	

CASE 5: NORM Z, TAIL-ONLY PITCH, NOSE & TAIL YAW			
REQUIRED GROUPS	RESULTANT ROTATION	LOCATION AND DIRECTION	
11•12•13•14	+P, -P, +R, -R	LU•RU•LD•RD	(See Note 3)
(2•3) + (9•10)	-Y, +Y	(FL•FR) + (LL•RR)	(See Note 1)

CASE 6: NORM Z, NOSE-ONLY PITCH, NOSE-ONLY YAW			
REQUIRED GROUPS	RESULTANT ROTATION	LOCATION AND DIRECTION	
5 + 6	+P	FDR + FDL	(See Note 5)
4	-P	FU	
11•12•13•14	+R, -R	LU•RU•LD•RD	(See Note 3)
(2•3) + (9•10)	-Y, +Y	(FL•FR) + (LL•RR)	(See Note 1)

CASE 7: NORM Z, NOSE-ONLY PITCH, TAIL-ONLY YAW			
REQUIRED GROUPS	RESULTANT ROTATION	LOCATION AND DIRECTION	
5 + 6	+P	FDR + FDL	(See Note 5)
4	-P	FU	
11•12•13•14	+R, -R	LU•RU•LD•RD	(See Note 3)
9•10	-Y, +Y	LL•RR	

CASE 8: NORM Z, TAIL-ONLY PITCH, NOSE-ONLY YAW			
REQUIRED GROUPS	RESULTANT ROTATION	LOCATION AND DIRECTION	
11 • 12 • 13 • 14	+P, -P, +R, -R	LU • RU • LD • RD	(See Note 3)
(2 • 3) + (9 • 10)	-Y, +Y	(FL • FR) + (LL • RR)	(See Note 1)

CASE 9: NORM Z, TAIL-ONLY PITCH, TAIL-ONLY YAW			
REQUIRED GROUPS	RESULTANT ROTATION	LOCATION AND DIRECTION	
11 • 12 • 13 • 14	+P, -P, +R, -R	LU • RU • LD • RD	(See Note 3)
9 • 10	-Y, +Y	LL • RR	

CASE 10: LOW Z, NOSE & TAIL PITCH, NOSE & TAIL YAW			
REQUIRED GROUPS	RESULTANT ROTATION	LOCATION AND DIRECTION	
5 • 6	+P	FDR • FDL	(See Note 4)
13 • 14	-P, +R, -R	LD • RD	
(2 • 3) + (9 • 10)	-Y, +Y	(FL • FR) + (LL • RR)	(See Note 1)

CASE 11: LOW Z, NOSE & TAIL PITCH, NOSE-ONLY YAW			
REQUIRED GROUPS	RESULTANT ROTATION	LOCATION AND DIRECTION	
5 • 6	+P	FDR • FDL	(See Note 4)
13 • 14	-P, +R, -R	LD • RD	
(2 • 3) + (9 • 10)	-Y, +Y	(FL • FR) + (LL • RR)	(See Note 1)

CASE 12: LOW Z, NOSE-ONLY PITCH, NOSE & TAIL YAW			
When LOW Z is selected, the DAP will default to NOSE & TAIL PITCH. See CASE 10 for the required jet groups in this configuration.			

CASE 13: LOW Z, NOSE & TAIL PITCH, TAIL-ONLY YAW			
REQUIRED GROUPS	RESULTANT ROTATION	LOCATION AND DIRECTION	
5 • 6	+P	FDR • FDL	(See Note 4)
13 • 14	-P, +R, -R	LD • RD	
(9 • 10)	-Y, +Y	LL • RR	

CASE 14: LOW Z, TAIL-ONLY PITCH, NOSE & TAIL YAW			
When LOW Z is selected, the DAP will default to NOSE & TAIL PITCH. See CASE 10 for the required jet groups in this configuration.			

CASE 15: LOW Z, NOSE-ONLY PITCH, NOSE-ONLY YAW			
When LOW Z is selected, the DAP will default to NOSE & TAIL PITCH. See CASE 11 for the required jet groups in this configuration.			

CASE 16: LOW Z, NOSE-ONLY PITCH, TAIL-ONLY YAW			
When LOW Z is selected, the DAP will default to NOSE & TAIL PITCH. See CASE 13 for the required jet groups in this configuration.			

CASE 17: LOW Z, TAIL-ONLY PITCH, NOSE-ONLY YAW			
When LOW Z is selected, the DAP will default to NOSE & TAIL PITCH. See CASE 11 for the required jet groups in this configuration.			

CASE 18: LOW Z, TAIL-ONLY PITCH, TAIL-ONLY YAW			
When LOW Z is selected, the DAP will default to NOSE & TAIL PITCH. See CASE 13 for the required jet groups in this configuration.			

NOTES

- (1) From a purely dynamic standpoint, yaw control would be maintained if one jet group in each direction was available (G-2 or G-10 for positive yaw, G-3 or G-9 for negative yaw). However, whenever both jets in G-2 or G-3 are not available, Yaw Rate Default Logic forces the DAP to tail-only yaw control, which effectively makes the other group (G-2 or G-3) unavailable. This means that all yaw control must be provided by G-9 and G-10, so that both of these groups must be available if either G-2 or G-3 is not available.
- (2) If all three of the jets in any of G-11, G-12, G-13, or G-14 are failed, vehicle control will be sloppy. In other words, the vehicle will not stay within its deadbands (rate and attitude) at all times, but complete loss of control (LOC) will not occur. Control will be acceptable for activities in which the selected deadband is not critical. This situation has been seen in integrated simulations.
- (3) Tail-only Pitch or Nose-only Pitch control cannot be performed if all three of the jets in any of G-11, G-12, G-13, or G-14 are failed. This is because G-11 alone is used for -R +P commands, and G-12 alone is used for +R +P commands. Similar logic applies for G-13 and G-14 with other pitch and roll combinations. If such a command is issued and no jet is available to respond, the vehicle would continue to move out of attitude in both axes, resulting in a loss of control (LOC). SMS testing has verified LOC for this case.
- (4) Adequate control cannot be maintained if both primary jets in either G-5 or G-6 are failed while Low Z is selected (this situation is analogous to the VRCS with a forward down-firing jet failed). Having nose and tail yaw jets available would reduce the significant cross-coupling that occurs when a positive pitch command is issued, but not to the extent that this can be considered a safe configuration.
- (5) If both G-5 and G-6 are lost, positive pitch control is still available if either of G-2 or G-3 are also not available. Pitch Rate Default Logic will force the DAP into Tail-only pitch control if G-5 or G-6 AND G-2 or G-3 are not available, selecting the aft jets for pitch control. This situation would be true, for example, if two FRCS manifolds were lost (1 and 3 OR 2 and 4).

SECTION 3: ROTATIONAL DEFAULT LOGIC

To ensure the Orbit DAP is two-fault tolerant in maintaining control, special default logic is built into the DAP which causes it to change jet options as needed in response to certain jet group losses. In these failure cases, the jet option(s) selected by the crew on SPEC 20 DAP CONFIG will be automatically overridden (and will not be reflected on SPEC 20). This logic for rotational control is contained in the Pitch Rate Default Logic and the Yaw Rate Default Logic modules as specified in the Orbit DAP FSSR (STS83-0009, Figures 4.2.2.2.1-7 and -9) and the software Detailed Design Specifications. Knowledge of this logic will aid the operator in understanding the preceding jet requirements.

- (A) Loss of both primary jets in G-5 or G-6 causes the DAP to default to Nose and Tail Yaw control whenever a jet from the other group is being fired. G-2, G-3, G-9, and G-10 will be used for yaw control in this situation.
- (B) Loss of both jets in either G-2 or G-3 causes the DAP to default to Tail Only Yaw control. Only G-9 and G-10 will be used for yaw control.
- (C) Loss of both primary jets in [(G-2 or G-3) and (G-5 or G-6)] causes the DAP to default to Tail Only Pitch for positive pitch (unless LOW Z is selected, in which case the default is Nose and Tail Pitch; see paragraph D). G-11 and G-12 will be used for positive pitch control. Note that these same failures, loss of G-2 or G-3, will also cause the DAP to default to Tail Only Yaw, as noted in paragraph B.
- (D) If LOW Z is selected, the DAP will never fire upfiring jets (groups 4, 11, and 12). The DAP will default to Nose and Tail Pitch, using downfiring jets for pitch control.
- (E) During a roll command, Nose Only Pitch is replaced by Tail-Only Pitch. This is why only aft jets are fired when simultaneous roll and pitch commands are present. Since an aft jet must be used for the roll command, one is selected that will perform both commands.
- (F) During a Z translation command, the DAP defaults to Nose & Tail Pitch control.

SECTION 4: TRANSLATIONAL JET REQUIREMENTS

This section specifies the jet requirements during vehicle translations. Table 6.2-III denotes the desired translation and DAP configuration in the center column. The left and right columns then specify the jets groups that are required to maintain adequate vehicle control during nominal and Low Z translations, respectively. There are several notes below the table which provide useful information or rationale for the requirements. The user should also keep in mind that if a translation will be performed while in attitude control, all of the logic from section 2 must still be used for determining whether or not rotational control will be maintained while the translation is in progress.

TABLE 6.2-III.-TRANSLATIONAL JET CONTROL REQUIREMENTS

NORM Z		DIRECTION OF TRANSLATION (D)	LOW Z	
REQUIRED GROUPS	MINIMUM JETS	& DAP CONFIGURATION	REQUIRED GROUPS	MINIMUM JETS
7 or 8	1 1	+X--ATT HOLD	7 or 8	1 1
7 AND 8	1 1	+X--FREE DRIFT	7 AND 8	1 1
1	1 (A)	-X--ATT HOLD OR FREE DRIFT	1	1 (A)
2 AND 3 AND 5 AND 6 AND 9	1 1 1 1 (B) 1	+Y--ATT HOLD OR FREE DRIFT	2 AND 3 AND 5 AND 6 AND 9	1 1 1 1 (B) 1
2 AND 3 AND 5 AND 6 AND 10	1 1 1 1 (B) 1	-Y--ATT HOLD OR FREE DRIFT	2 AND 3 AND 5 AND 6 AND 10	1 1 1 1 (B) 1
4 AND 11 AND 12	1 1 1	+Z -- ATT HOLD OR FREE DRIFT	1 AND 7 AND 8	2 (A) 1 1
5 AND 6 AND 13 AND 14	1 (C) 1 1 1	-Z -- ATT HOLD (including docking PCT)	5 AND 6 AND 13 AND 14	1 (C) 1 1 1
5 AND 6 AND 13 AND 14	1 1 2 2	-Z --FREE DRIFT (including docking PCT)	5 AND 6 AND 13 AND 14	1 1 2 2

NOTES

- (A) Significant negative pitch rates can build up if a -X or Low +Z translation is performed in free drift. Smaller yaw and roll rates may also be present, depending on which jets fire and the Y C.G. offset.
- (B) The DAP will not allow a Y translation to be performed unless a jet is available in both forward side-firing groups (2 and 3) and both FRCS down-firing groups (5 and 6).
- (C) During a -Z translation, at least one jet from each of the FRCS down-firing of groups (5 and 6) must be available to prevent adverse yaw rates, which will result in a yaw command. Default logic cancels -Z commands during yaw commands if G-5 or G-6 are not available.
- (D) For translations with attitude hold, also consult Table 6.2-II to assess rotational control.

SECTION 5: TRANSLATIONAL DEFAULT LOGIC

Similar to the rotational default logic, special logic is built into the DAP jet selection for translations. Some of this logic is designed to ensure control is maintained for two-failure cases, while some of it ensures propellant tank constraints are not violated due to an excessive number of jets firing at one time (which may cause the RCS propellant tank acquisition screens to “break down,” or dry out and stop transferring propellant to the outlet). This logic is specified in the Orbit DAP FSSR (STS83-0009) and the software Detailed Design Specifications. Knowledge of this logic will aid the operator in understanding the jet requirements in the preceding table.

- (A) If a High +Z command is present, all X translation commands are ignored. This logic ensures the maximum number of jets firing simultaneously from any set of propellant tank is not exceeded (which would occur if the +X or -X jets were firing in addition to the three upfiring jets in that module). This logic is specified in the Single Axis Translation Logic module.
- (B) If both primary jets in either G-2, G-3, G-5, or G-6 (forward yaw or down-firing groups) are not available, all Y translation commands are ignored. This logic ensures adequate yaw control is maintained, and is specified in the Y Translation Default Logic module.
- (C) If both primary jets in either G-5 or G-6 (forward down-firing groups) are not available and a yaw command is present, -Z translation commands are ignored. This logic is also designed to ensure adequate yaw control is available, and is specified in the Z Translation Rate Default Logic module.
- (D) If more than three forward jets are firing, only one -X jet is fired in response to a -X or Low +Z translation command. This logic ensures the limit of 5 simultaneously firing jets from the forward RSC tanks is not exceeded, and is specified in the X Translation Default Logic module.

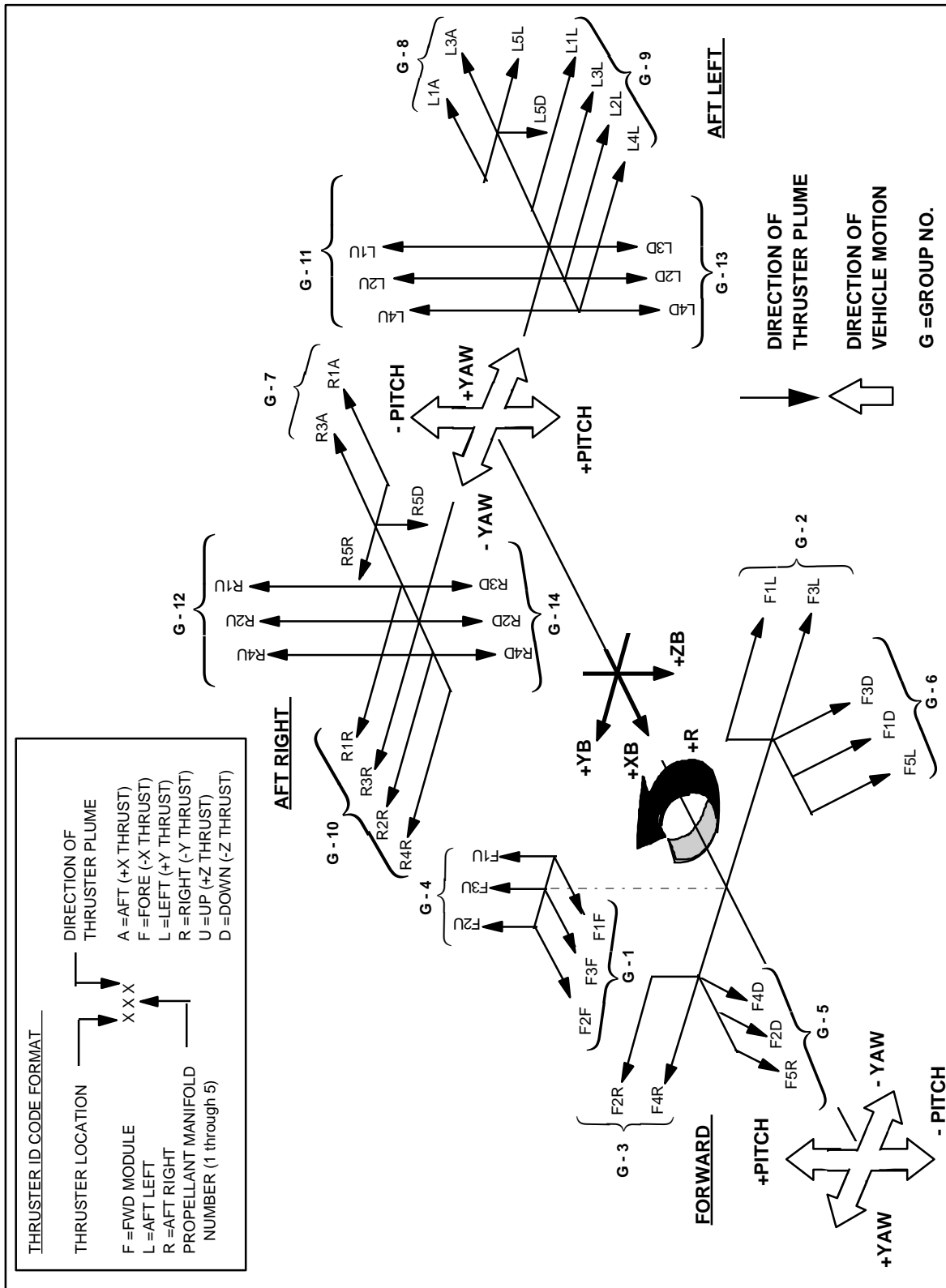


Figure 6.2-I. - RCS Jet locations and plume directions.

TITLE

ORBIT DAP UPLINK WITH GCS

GENERAL

WARNING: This procedure is governed by FCOH SOP 3.1, 3.2.1, and 3.2.1.1, and cannot be modified without prior approval of the FOIG or the Flight Director (during real-time operations). Safety critical steps are marked by a box.

Restrictions:

OI Load: OI-24 and subsequent

OPS Mode : PASS (OPS 2 only)

No BFS CMD

Major Function: GNC

Vehicles: all

Crew/MCC coordination: information only

Time Constraints: Uplink cannot be performed (will be rejected) if the targeted control accel slot is currently active. For example, if control accel 1 is currently active onboard, any uplink of mass property or notch filter data to slot 1 will be rejected.

MCC Constraints: None

Hazardous:

Require safing: no

PURPOSE

The Orbit DAP Uplink consists of orbiter mass properties (CG, moments of inertia, and products of inertia) and up to six notch filters which are used to configure the Orbit DAP for use in specific orbiter/payload configurations. The data used to build the uplink load is received from EG per the agreements in Memorandum of Understanding between Aeroscience and Flight Mechanics and Systems Divisions Defining Data, Documentation and Response Requirements for Implementation of Notch Filter and Mass Properties Uplinks, JSC-27077. The uplink can consist of mass property data only, notch filter data only, or a combination of both and is loaded into a control accel slot of 1 to 9. An uplink cannot be performed to the control accel 0 slot.

The Flight Mechanics Division (EG) analyzes payload configuration and existing DAP I-loads. If configuration requires modification, new values are developed and verified. Prior to flight, values are sent to the SASCB and MMT for approval. The method of implementation for new values, these being I-load patch or uplink, will be per direction of the Program. If a change is required during a flight, EG communicates DAP values for uplink via Chit to MOD. A "Notch Filter/Mass Properties Uplink Form" will be used to define the uplinks required. The form conforms to the uplink definition for notch filter/ mass property uplink data in the Shuttle downlist. The uplink definition identifies the flight for which uplinks are intended, the intended DAP target slot for uplinked data, and any constraints and assumptions.

As documented in the EG/MOD memorandum of understanding (MOU) SSV-95-031, dated 5/3/95, "Notch Filter/Mass Property Uplink Process", the approval process required to perform the DAP Uplink is a function of the time before launch, and is summarized as follows:

- 1) Approval process for DAP Uplinks – Four time periods used:
- 2) Prior to final I-load approval: Submitted to SASCB.
- 3) After I-Load approval, prior to FRR: Submitted to SASCB.
- 4) After FRR and prior to flight: SASCB and PRCB approval required.
- 5) During flight: SPAN/MER Chit process required with Mission Management Team approval.
- 6) Each time period's product is sent through an implementation process: development and verification, approval, testing, and ultimately execution by MOD per constraints documented in FCOH and Flight Rules.

PROCEDURES

A. *LOADING THE COMMAND INTO THE COMMAND SERVER*

1. GNC receives a copy of the approved Orbit DAP uplink data including mass properties, notch filters, and control accel slot from EG. Per the Memo of Understanding (MOU) mentioned in paragraph one of this procedure, this data may be received preflight via EG memo or during flight via CHIT.
2. A Command Manager must be running on any workstation that runs command applications. Start or Stop a Command Manager from the Master DNAV, Global Apps, Command Server menu.
3. Select the Notch Filter/Mass Properties Update Command Display from the GNC DNAV. Any previous load in the command server will be displayed. See Figure 6.3-1.
4. Clear display if required to begin a new load or retrieve a previously saved load. If retrieving a previously saved load, all data should be verified per steps 5 through 9 below.
5. Enter the desired DSM sequence number (43701 - 43750) and title. The title should be descriptive of the load since it will appear on the Command Tracking display when the load is uplinked.
6. Enter the desired control accel number into the CNTL ACC window. The Control accel is synonymous with Payload Config Slot ID, which is the FSSR name and is used by EG. The control accel can range from 1 through 9.
7. Enter the number of notch filters in the load. The number of notches can range from 0 through 6.

8. If the number of notches is 1 or more, enter the associated lower and upper Notch Filter Frequencies in the appropriate fields. The acceptable frequency inputs must range between zero and three. This is the criteria used by the onboard software to accept a notch filter uplink. If the number of notches is zero, the on-board software will assume the uplink contains mass property data only. All fields that are not used must have a zero in them.
9. If the load contains mass property data, enter the CGs (X, Y, & Z), moments of inertia (IXX, IYY, & IZZ), and products of inertia (PXY, PXZ, & PYZ) into the appropriate fields. The XCG, ZCG, IXX, IYY, and IZZ must have values greater than zero. This is the criteria used by the onboard software to accept a mass property uplink. All fields not used must have a zero in them. If all mass property data is uplinked as zero, the on-board software will assume the uplink contains notch filter data only.
10. If desired, save the load to the flight specific MEDS directory. Select STORE to send the load to the Command Server. The HEX and decimal feedback from the server is displayed on the command display.
11. Obtain a hardcopy of the new load.

File									
Notch Filter/Mass Properties Update									
DSM #		DSM Title		GMT Gen					
43702	↕	DAP A12 load		015:22:25:07					
		hex			hex				
CNTL ACC	0004	4	4	NUM Notches	0006	6	6		
	hex	hz	hz		hex	inches	inches		
1 Lower	3f3baba8	0.01456800	0.01456800	X CG	438dc800	2268.0000000	2268.50000000		
1 Upper	3f95b35b	0.03654800	0.03654800	Y CG	c1600000	-6.0000000	-6.0000000		
2 Lower	3fe8da7f	0.05684900	0.05684900	Z CG	4317ce66	380.89999390	380.89999390		
2 Upper	4010d478	0.06574200	0.06574200						
3 Lower	401b0dc7	0.10567900	0.10567900						
3 Upper	402828b3	0.15687101	0.15687101		hex	SLUG-FT2	SLUG-FT2		
4 Lower	411b0922	1.68973005	1.68973005	I XX	45e3a683	932456.187500	932456.187500		
4 Upper	411c9b91	1.78797996	1.78797996	I YY	46143a82	1325698.00000	1325698.00000		
5 Lower	4120915e	2.03549004	2.03549004	I ZZ	433a319a	931.09997559	931.09997559		
5 Upper	412773e0	2.46579003	2.46579003	P XY	43771800	1905.50000000	1905.50000000		
6 Lower	412afeef	2.68723989	2.68723989	P XZ	c510a1c5	-68124.29687	-68124.296875		
6 Upper	412e139f	2.87979007	2.87979007	P YZ	c331c000	-796.0000000	-796.00000000		
<div style="display: flex; justify-content: space-around; margin-top: 10px;"> Store Delete Clear Exit </div>									
Command Advisories									

Figure 6.3-1: Notch Filter/Mass Properties Update Command Display

B. VERIFICATION OF COMMAND SERVER LOAD

1. Verify the correct command has been loaded in the Command Server by comparing the Server feedback on the command display with the desired DAP parameters received in step A1. Some of the decimal numbers from the server may be different in the seventh or eighth place from the input due to rounding.

C. NOTIFICATION AND APPROVAL

1. Advise the GNC FCR by DSM number that the load has been built, verified, and is ready for uplink.
2. The GNC FCR will verify that the load is correct.
3. The GNC verifies that the targeted control acceleration slot is not currently active.
4. The GNC FCR will receive Flight Director approval to perform the uplink.
5. GNC coordinates with INCO on INCO Loop to uplink the command. Standard coordination shall include reading the DSM number, the MF, DSM title, and that the Flight Director has given a "Go" for uplink, as well as a read back by INCO of the information for verbal verification.
6. The GNC FCR will monitor the INCO loop until all command actions are completed. INCO will notify the GNC FCR when the actions are completed. GNC and GNC SPT will monitor the Command Tracking display and the DAP Uplink Status (U/L Status) parameter to verify a successful uplink. The DAP Uplink Status parameter retains it's last status.

U/L Status	Result
3	Mass property and notch filter data accepted.
2	Only mass property data accepted.
1	Only notch filter data accepted.
0	Rejected

E. VERIFICATION OF UPLINK ONBOARD

1. GNC/GNC SPT will log the DSM# and uplink time in the Console Logs.
2. When appropriate, have the crew select the uplinked control accel on GNC SPEC 20 while the DAP is in FREE DRIFT. On DAP_UPLINK_STATUS display, verify correct selected mass property and notch filter data on telemetry. Note that since these parameters are single precision, only the first six to seven digits will agree with the numbers uplinked.

TITLE

OMS TVC TRIM ANGLES CALCULATION (OMSTVC)

PURPOSE

The purpose of this section is to describe the procedure for calculating the orbital maneuvering system (OMS) engine gimbal trim angles for any vehicle mass configuration.

BACKGROUND

The Flight Dynamics Officer (FDO) is normally responsible for providing the preburn OMS engine gimbal trim angles. However, the Guidance, Navigation, and Control (GNC) Officer needs the capability for use in control systems evaluations for off-nominal situations and to verify premission established trim angles. The trim angles are determined as a function of the type of OMS burn; i.e., single or dual engine, vehicle center of gravity (c.g.) location, and (in the dual engine case) a desire to have the total thrust vector through the c.g. or parallel to the Orbiter X/Z plane. The uncompensated trim values obtained from the program would be loaded by the crew into the XXXXX MNVR YYYYYY display under TRIM LOAD (item's 6, 7, and 8).

The compensated trim values are those seen by the ground operators. The compensated trims output by the program are the MDM outputs which are multiplied by a scale factor term (in deg/V dc) and have a bias (in degrees) added to the results. The scale factor converts the positions into units usable by the software. The bias is a software provision to compensate for mechanical offsets of the actuator.

When a TVC is parked, the crew will probably get a GMBL FAIL message, even if the other engine is being used to perform the burn. Also expect a fail message in the transition to MM 301 from MM 201 if the TVC is OFF.

If your desired trim position is within $\pm 0.4^\circ$ of the present trim (as is likely in pitch), there will be no gimbal movement as the delta is within the actuator deadband range ($\leq 0.4^\circ$; hysteresis (0.025 inch = 0.05 V dc = 0.06° , 0.125 inch = 0.25 V dc = 0.4°)). In this case, depending on the magnitude of the mistrim, it may be beneficial to perform the park procedure twice (corrective technique). In the first step, the "interim" trim load in the axis of concern would be made large enough so that its delta with both the present, and final desired, trim positions is greater than the 0.4° deadband limit. As the limit is surpassed, the engine moves to the loaded trim position. The second step is to perform the procedure again using the final desired trim load values. The deadband is again exceeded and the engine moves to the desired trim position. (References SCP 7.3, OMS TVC Gimbal Check)

In this program there are several points at which the user is prompted to input a numerical value. During the testing of the program, it was found that if the user inputs non-numerical characters (i.e. xyz, sts, etc.) or a combination of numerical and non-numerical characters (i.e. 12y3, 143nz, etc.), the user will be kicked out of the program. If this should occur, the user will need to restart the program from the GNC DNAV menu under applications.

PROCEDURE

Use the program OMSTVC and follow the steps given below. An example program run is also given. The equations used in the program calculations are shown in figure 7.1-1.

- A. The program calculates a close approximation of the OMS engine gimbal trim angles. The only input required is the X/Y/Z components of the c.g. location in the Orbiter coordinate system (X_0 , Y_0 , Z_0). A prestored c.g. location is printed out on the computer screen.
- C. After the desired c.g. values have been entered, the program calculates the uncompensated OMS pitch and yaw trim values for the left and right engines for both parallel and c.g. burns. If the yaw trim values exceed the flight software limits of $\pm 6.44^\circ$, the new within-limit trims will be calculated and displayed. The program then determines the compensated trim values by subtracting the biases from the uncompensated trim values. These values are also displayed.
- D. A printout of the trim values can be obtained by entering "Y" when asked "Do you want a printout?" by the program.
- E. Another run of OMSTVC can be initiated by entering "y" when asked "Do you want another run? (y/n)" by the program. If you do not enter "y", the program will self terminate.

Note: The flight software limits the OMS engine gimbal travel to $\pm 5.89^\circ$ in pitch and $\pm 6.44^\circ$ in yaw. In addition, even though the total pitch limit is -5.89° , the pitch trim is limited to $\pm 4.89^\circ$. In the example below the left yaw trim parallel number of -7.53° exceeds the -6.44° software limit. When this occurs, a second printout will give a new set of yaw trim parallel numbers that are within the onboard software limits. For example, if the pitch and yaw trims for the parallel burn in the example given were to be loaded by the crew, the pitch would drive to $+4.9^\circ$ software limit and left and right yaw will drive to the input values of -6.44° for the left engine and $+4.26^\circ$ for the right engine.

EXAMPLE

- A. Execute the program by selecting OMSTVC from the GNC DNAV pull down menu under "Apps" via the mouse.
- B. Program displays:

```
OMS TVC Version xx.xx.xx GNC SCP 7.1

L/R ENG PITCH OFFSET = -15.82 DEG
L ENG YAW OFFSET = 6.50 DEG
R ENG YAW OFFSET = -6.50 DEG

CURRENT ORBITER CG (inches in veh dynamics coord system) STS-1, E-12 PRE
OMS-2 from ODB VOL 2 MASS PROP BOOK

CGX          1113.80
CGY          -0.10
CGZ          378.00

New orbiter CG? (Enter Y or N)
```

- C. Type "Y" to enter new c.g. values. Enter new c.g. locations using steps D through F.
- D. Type 1000 (X CG inches)
- E. Type -10 (Y CG inches)
- F. Type 400 (Z CG inches)
- G. The program displays the following:

```
GNC SCP 7.1, OMS TVC P/Y TRIMS

ORBITER CG (in inches)
CG X          1000.000
CG Y          -10.00
CG Z          400.00

OMS ENG TRIMS (DEG) TO BE LOADED ON THE XXXXX MNVR YYYYY DISPLAY
      L      PITCH      R      L YAW      R YAW
TRIM PAR      5.7          5.7      -7.5        5.4
TRIM CG       5.7          5.7        1.9       -4.1

YAW S/W LIMIT EXCEEDED! NEW OMS ENGINE TRIMS

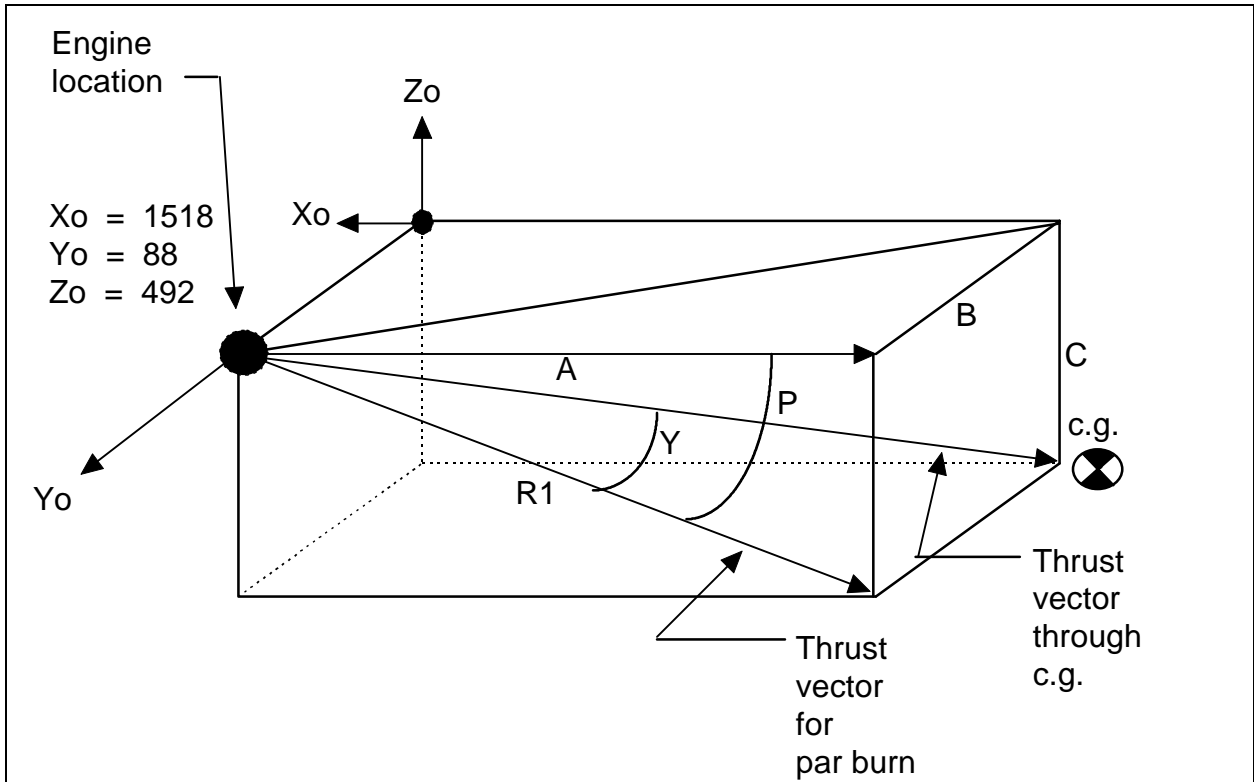
      L      PITCH      R      L YAW      R YAW
TRIM PAR      5.7          5.7      -6.4        4.3
TRIM CG       5.7          5.7        1.9       -4.1

COMPENSATED VALUES DISPLAYED ON THE GROUND (DEG)
      L      PITCH      R      L YAW      R YAW
TRIM PAR      5.68         5.68     -6.86       4.69
TRIM CG       5.68         5.68      1.51      -3.63
```

- H. Enter "y" when asked by the program if a print out is desired.

REFERENCE

- A. SODB, vol. I, pars 4.5.1.1.2.4.1 and 4.3.3.1-b, Oct. 1984.
- B. SODB, vol. II, Mission Mass Properties.
- C. GNC Offline Program OMSTVC Documentation Program.



P/Y order Euler rotation

Right OMS engine

- L pitch trim c.g. = $15.82 - \tan^{-1} (C/A)$
- R pitch trim c.g. = $15.82 - \tan^{-1} (C/A)$
- L yaw trim c.g. = $-6.50 + \tan^{-1} (D/R1)$
- R yaw trim c.g. = $6.50 + \tan^{-1} (B/R1)$
- L/R pitch trim par = $15.82 - \tan^{-1} (C/A)$
- L yaw trim par = $-6.44 + \tan^{-1} (Yc.g./R1)$
- R yaw trim par = $6.44 + \tan^{-1} (Yc.g./R1)$

where:

- A = $1518 - Xc.g.$
- B = $Yc.g. - 88$
- C = $492 - Zc.g.$
- D = $Yc.g. + 88$
- $R1 = \sqrt{A^2 + C^2}$

- Left yaw trim (compensated) = L yaw trim - (.4244)
- Right yaw trim (compensated) = R yaw trim - (-.4244)
- Left pitch trim (compensated) = L pitch trim - (.0735)
- Right pitch trim (compensated) = R pitch trim - (.0735)

Figure 7.1-1 - Equations used to calculate OMS TVC trim angles.

TITLE

OMS THRUST DEGRADATION CALCULATIONS USING TVC GIMBAL ANGLES (OMSCAL)

PURPOSE

To describe the procedure for using a computer program for calculating the thrust degradation of an orbital maneuvering subsystem (OMS) engine using thrust vector control (TVC) gimbal angles.

DESCRIPTION

The program calculates the percent thrust of an OMS engine with a suspected degraded thrust given the X and Y center of gravity (c.g.) in Orbiter body coordinates, the compensated left and right gimbal yaw angles in degrees, and the percent thrust for the good OMS engines (100 percent = 6000 lb). The Xc.g. and Yc.g. can be found in the Shuttle Operational Data Book (SODB), vol. II, Mission Mass Properties. During a two-engine burn, the compensated left and right gimbal yaw angles are read from the data plots or digital displays after the gimbals have settled to a fairly stable position.

The compensated positions required by the program are the MDM outputs which are multiplied by a scale factor term (in deg/V dc) and have a bias (in degrees) added to the results. The scale factor term converts the positions into units usable by the software. The bias term is a software provision to compensate for mechanical offsets of the actuator.

THEORY

The theoretical approach of the program is as follows.

$$\text{Thrust}_{Rt} \times r_{Rt} + \text{Thrust}_{Lt} \times r_{Lt} = \text{Torque} \quad (1)$$

where

Thrust_{Rt} = thrust of the right engine

r_{Rt} = distance from the right engine to the c.g.

Thrust_{Lt} = thrust of the left engine

r_{Lt} = distance from the left engine to the c.g.

Torque = vehicle torque

Guidance, after a settling time, will position the engines to zero the torque.

$$\text{Torque} = 0 \tag{2}$$

Combining equations (1) and (2) results in the following equation.

$$\text{Thrust}_{Rt} \times r_{Rt} + \text{Thrust}_{Lt} \times r_{Lt} = 0 \tag{3}$$

Using equation (3) and the input parameters, the thrust for the OMS engine in suspect can be found.

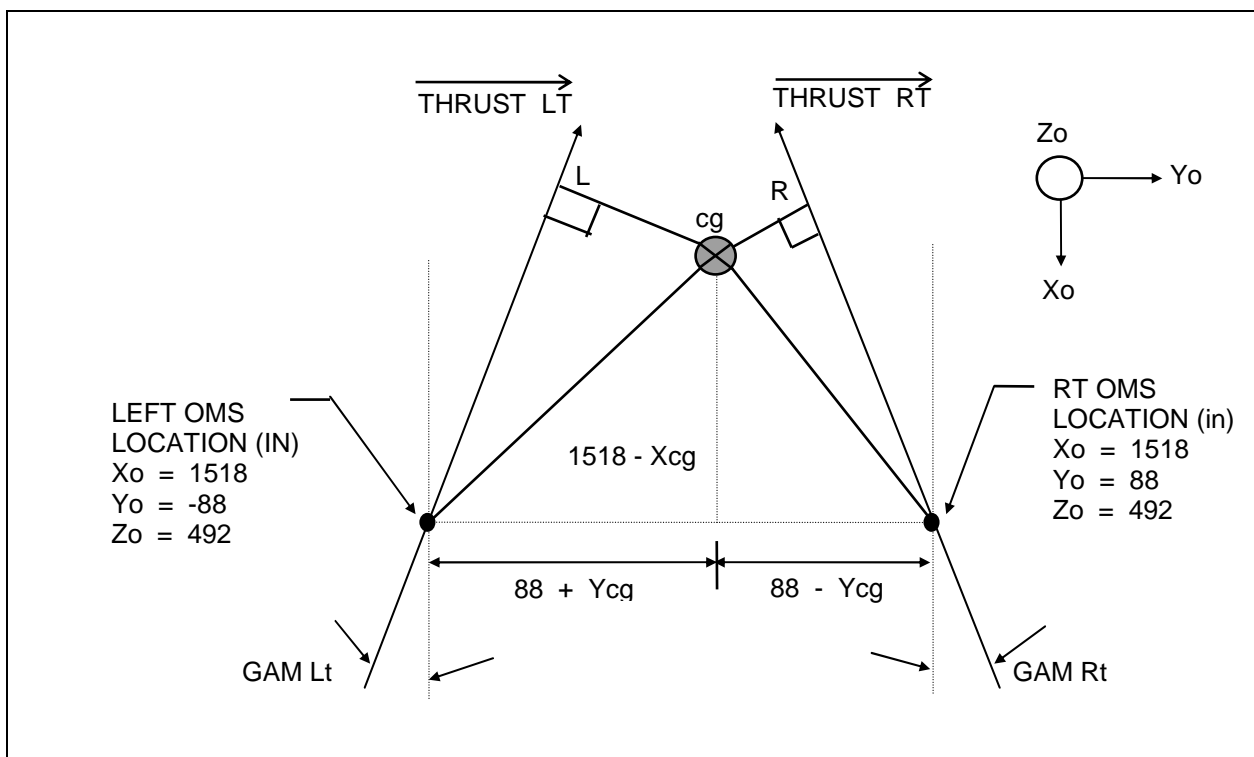


Figure 7.2-1. - Thrust vectors and vehicle c.g. in the Orbiter X-Y plane.

Figure 7.2-1 shows the thrust vectors and the vehicle c.g. in the Orbiter X-Y plane. The angles GAM_{Lt} and GAM_{Rt} are measured from the X_0 Orbiter body axis. GAM is defined as the sum of the yaw trim value plus the mechanical offset of the engine. When the left and right OMS yaw angles are equal to 0° , GAM is equal to the mechanical offsets shown in equations (4) and (5). Bias terms of $\pm 0.4244^\circ$ are added to the mechanical offsets for compensation.

$$GAM_{Lt} = 0 + 6.9244^\circ(\text{compensated}) \tag{4}$$

$$GAM_{Rt} = 0 - 6.9244^\circ(\text{compensated}) \tag{5}$$

The variables L and R are the distances from the c.g. to the left and right thrust vectors, respectively. L and R can be determined using figure 7.2-1.

$$L = (88+Yc.g.)\cos(GAML_t) - (1518-Xc.g.)\sin(GAML_t) \quad (6)$$

$$R = (88-Yc.g.)\cos(GAMR_t) + (1518-Xc.g.)\sin(GAMR_t) \quad (7)$$

When the engines are parallel with the X axis

$$\text{Left yaw trim} = -6.9^\circ \quad (8)$$

$$\text{Right yaw trim} = 6.9^\circ \quad (9)$$

$$GAML_t = 0, L = 88+Yc.g. \quad (10)$$

$$GAMR_t = 0, R = 88-Yc.g. \quad (11)$$

The percent thrust of one engine can be calculated using L, R and the percent thrust of the other engine.

$$(\text{Percent thrust left}) * L = (\text{Percent thrust right}) * R \quad (12)$$

PROCEDURE

The program accepts any numerical input for vehicle center of gravity (c.g.). The thrust input must be less than or equal to 120 percent. The gimbal yaw angles are limited to the mechanical hardstop limits plus an error term (limited to $\pm 8.4^\circ$). The error term is added to account for errors when reading data plots. Messages are annunciated when limits are violated. The answers to yes/no questions must be Y, y, N, or n, and will continue to be asked until they are answered. The program calculates the percent thrust of the remaining engine. The program then outputs the values entered and the percent thrust of both OMS engines.

Use the program and follow the steps given below. An example run is shown in the next section.

1. Enter the Xc.g., Yc.g., and Zc.g. in Orbiter body coordinates.
2. Enter the compensated left and right gimbal yaw angles in degrees.
3. Enter the OMS engine percent thrust of the good engine (100 percent = 6000 lbs.)
4. The program calculates the percent thrust of the remaining engine. The program then outputs the values entered and the percent thrust of both OMS engines. **Note:** Different crossfeed configurations and OMS failure modes (blockage, etc) may affect the relative thrust between the engines.

EXAMPLE

For example, if it is known the L OMS performance is decreased, it is easier to input the right OMS thrust percentage. This is shown in the case below:

1. Provide the following inputs when prompted:
Xc.g. = 1086.2 inches

Yc.g. = -0.4 inch
Left yaw angle = -5.90° (compensated)
Right yaw angle = 4.8° (compensated)
Right OMS engine thrust = 100 percent

The Program display looks like:

```
*****  
                                OMSCAL PROGRAM, GNC SCP 7.2  
*****  
  
USER INPUTS X C.G., Y C.G., L AND R OMS ENGINE YAW  
AND THE PERCENT THRUST FOR ONE OF THE OMS ENGINES.  
THE PROGRAM CALCULATES THE PERCENT THRUST FOR THE  
OTHER ENGINE.  
  
Do you want to enable the printer? (Y/N)  
N  
  ENTER ORBITER C.G. (X C.G., Y C.G.)  
1086.2, -0.4  
  
  ENTER LEFT GIMBAL YAW ANGLE (COMP)  
-6  
  
  ENTER RIGHT GIMBAL YAW ANGLE (COMP)  
6.5  
  
DO YOU WANT TO ENTER THE LEFT OMS ENGINE PERCENT THRUST (Y,N)  
N  
  
  ENTER RIGHT OMS ENGINE PERCENT THRUST (100%=6000LBS)  
100  
  
X C.G. = 1086.20  
Y C.G. = -0.4  
  
      GIMBAL YAW ANGLE      : PERCENT THRUST (100%=6000LBS)  
      (LEFT)  : (RIGHT)    : (LEFT)  : (RIGHT)  
-----|-----|-----|-----  
      -5.80  :    4.80    :    91.43 :   100.00
```

In this case, the left OMS has 8.57% less thrust than the right. Note that this program outputs *relative* thrust for the two OMS engines. Thus if the L OMS is known to have a problem, this data can estimate the amount of potential degradation. However, consider the following case: If the left OMS thrust was entered as 100% instead for this case, the program output would be:

```
*****
                                OMSCAL PROGRAM, GNC SCP 7.2
*****

USER INPUTS X C.G., Y C.G., L AND R OMS ENGINE YAW
AND THE PERCENT THRUST FOR ONE OF THE OMS ENGINES.
THE PROGRAM CALCULATES THE PERCENT THRUST FOR THE
OTHER ENGINE.

Do you want to enable the printer? (Y/N)
N
  ENTER ORBITER C.G. (X C.G., Y C.G.)
1086.2, -0.4

  ENTER LEFT GIMBAL YAW ANGLE (COMP)
-6

  ENTER RIGHT GIMBAL YAW ANGLE (COMP)
6.5

DO YOU WANT TO ENTER THE LEFT OMS ENGINE PERCENT THRUST (Y,N)
Y

  ENTER RIGHT OMS ENGINE PERCENT THRUST (100%=6000LBS)
100

X C.G. = 1086.20
Y C.G. = -0.4

      GIMBAL YAW ANGLE      | PERCENT THRUST (100%=6000LBS)
      (LEFT) | (RIGHT) | (LEFT) | (RIGHT)
      -----|-----|-----|-----
      -5.80  |    4.80  | 100.00 |   109.37
```

This output shows the right engine has 9% more thrust *relative* to the left OMS. If the L OMS is known to have potential degradation, this data suggests the left OMS thrust is decreased by 9%. However, since the output is *relative* data, it is possible the L OMS is healthy at 100% and the ROMS has 9% more thrust relative to it.

REFERENCES

1. Allen, William H.: Dictionary of Technical Terms (NASA-SP-7), U.S. Government Printing Office, 1965.
2. GNC Offline Program OMSCAL Documentation Folder.
3. SODB, vol. I, Shuttle System Performance Data.
4. SODB, vol. II, Mission Mass Properties.

TITLE

OMS TVC GIMBAL CHECK

PURPOSE

To define the procedures for monitoring an Orbital Maneuvering System (OMS) thrust vector controller (TVC) gimbal checkout.

The gimbal check is used to investigate/verify the health of the OMS TVC actuator drive systems. There are numerous failures that can be detected: slow rate/binding actuator, position transducer bias, instrumentation bias, command bias. All actions to be taken in the cases of these failures are described in the Flight Rules document and the FDF.

BACKGROUND

The OMS provides the propulsion to perform orbit insertion, circularization, transfer, rendezvous, and deorbit. These functions can be done via either the left, right, or both OMS engines. The OMS TVC converts automatic and manual maneuver commands to OMS engine bell deflections through actuator extend/retract voltages. The gimbal actuator assembly provides forces to gimbal the engine for thrust vector control and consists of a pitch actuator, yaw actuator, an active servo channel, and a standby servo channel (also called primary and secondary, respectively). Each servo channel contains both a pitch and yaw drive motor and mechanism, position feedback transducers, EMI filters, position command and feedback signal summing amplifiers, and motor-drive electronics.

To verify the health of these actuators, an OMS TVC gimbal check is performed on both the left and right OMS TVCs and on both the primary and secondary drive systems at various times prior to, and during, flight. The OMS Gimbal Profile Check is performed prelaunch in OPS 9 at approximately T minus 5 hours 20 minute (see values in SCP 1.4).

TABLE 7.3-1. - OMS TVC DATA SAMPLE RATES

OPS	SAMPLE RATES (samples/sec)	
	L/R PRI POSN	L/R SEC POSN
1/3	5	1
2	1	1
9	12	1

The requirements for inflight gimbal checks are defined by GNC Flight Rule A8-113C (OPS 1 and 3, perform gimbal check of both PRI and SEC drives post OMS 2 and pre deorbit burn; in OPS 2, perform postburn checks on only those systems to be used (i.e., active, whether burning or not) in subsequent single-engine burns or two-engine critical burns. Check, as required, for troubleshooting of potential failures).

PROCEDURES

A. DATA COLLECTION

When an OMS TVC gimbal check is to be run, the MPSR operator (Control or Support) has the responsibility to capture the data on the RTPlot application, using plot windows titled "L(R) PITCH", "L(R) YAW" (see SCP 11.17), as well as to monitor the check on the high-density display (GNC Orbit). Data may also be captured using ODRC.

B. OMS GIMBAL CHECK

The crew commands the OMS TVC gimbal check from the keyboard via the XXXXX MNVR YYYYY display. Selection of engine and active drive system is made [PRI L (R) - ITEM 28 (29), SEC L(R) - ITEM 30(31), OFF L(R) - ITEM 32 (33)] and then the test is initiated via the gimbal check entry (GMBL CK - ITEM 34). Once initiated by ITEM 34 EXEC, the selected gimbal actuator systems will go through a four-step gimbal drive check.

Procedurally, the secondary actuator is commanded simultaneously on both engines first, then the primary system is tested.

1. Starting from the current position, the actuators are commanded to their positive full deflection positions (approximate software limits) in both pitch and yaw.
2. After 6 seconds (75 count at 12.5 Hz), the actuators are commanded to their negative full deflection positions in pitch and yaw.
3. After 6 seconds, actuators are again commanded to their positive full deflection positions in pitch and yaw.
4. After 6 seconds, the actuators are commanded to their initial positions.

Note: Whenever both systems on both engines are tested, this is referred to as a "full up" gimbal check, as all systems are checked. This may not be performed in all cases (ref. GNC Flight Rule A8-113C) as repeated unnecessary drive checks may diminish the overall life of the actuators. Also, because only a single GMBL CHK item entry exists, both engines' selected gimbal systems will be tested in a checkout and moved during a burn, unless the OFF item entry is made.

C. **LIMIT CHECKS**

The OMS gimbal actuator software command limits for the TVCs are (spec):

Pitch	$\pm 5.89^\circ$	
Right yaw	$+6.44^\circ/-7.29^\circ$	
Left yaw	$+7.29^\circ/-6.44^\circ$	(reference 2)

Note: A positive position corresponds to an actuator extension in the left pitch and yaw and the right pitch, but an actuator retraction in right yaw.

The hardware limits are (typical):

Pitch	$+6.82^\circ/-6.54^\circ$	
Right yaw	$+7.49^\circ/-7.82^\circ$	
Left yaw	$+7.82^\circ/-7.49^\circ$	(reference 3)

The OMS TVC gimbal actuator command range for the gimbal check is (uncompensated, as seen onboard):

Pitch	± 5.9	
Yaw	$\pm 6.4^\circ$	(reference 4)

These positions are uncompensated because they are picked off before GPC processing. The commands seen on the MCC displays and plots are compensated values. The equations to convert OMS TVC trim angles can be found in SCP 7.1. Corresponding to the above (see SCP 8.2, approximate):

Pitch	$+5.80^\circ/-5.96^\circ$	
Left yaw	$+6.01^\circ/-6.88^\circ$	
Right yaw	$+6.88^\circ/-6.01^\circ$	(reference 5)

During and after the gimbal check, the rates and position values should be checked against the nominal expected values.

The OMS GMBL FAIL message is annunciated when the RM limit (CMD/POSN error $> 2^\circ$) is broken for 3.84 seconds (count of N = 24 at 6.25 Hz) (references 6 and 7).

The nominal TVC gimbal drive rate is from 4 to 5 deg/sec (failure is considered to be a rate < 2.9 deg/sec between the gimbal range of $\pm 3^\circ$) (references 8 and 9). The above command/position delta limit will be broken if the actuator rates during a gimbal check fall ≤ 2.55 deg/sec in pitch or ≤ 2.83 deg/sec in yaw (these values are slower than the spec rate for failure, but it is not desirable to fail gimbals above spec rate). A slow rate is detectable during the check but will not be apparent in a burn (due to the limited range of actuator movement).

D. FAILURES

It is advisable in most cases of an OMS TVC related failure (primary or secondary) to use the alternate good system for the remaining OMS activities. This is the preferred course of action in the following cases unless specified otherwise. The following are some of the failures that can be detected by a gimbal check.

1. Command bias

Both the primary and secondary positions differ with the commanded value by a fixed bias. This may be a condition that will still allow use of the engine depending upon the magnitude of the bias, the axis, and if it is a one- or two-engine burn. If the trim command can be biased such that the actual position reflects where the engine should be trimmed (some degree of risk in assuming the bias remains constant), it will eliminate a transient at ignition, but would cause a corresponding ADI error needle bias which may be more confusing. The system may be burned active or parked through the vehicle c.g., per Malfunction Procedure GNC SSR-8 in this case. If the command bias has driven the actuator into the hardstop, it may not be compensatable and that engine will be considered failed. A gimbal check can be run to quantify the bias and see if the engine can still be moved into a usable position, but may cause nuisance GMBL FAIL fault messages (Fig. 7.3-1).

2. Instrumentation bias

Only the position feedback to the MDM and GPC on that system is erroneous. The system can still be actively used for burns if the alternate system actuator positions are monitored for actual location/movement.

If in MM 201, the simple act of entering into MM 202 could give some insight, even without a gimbal check. Because the TVCs are unpowered during 201, when 202 is entered (upon which the selected systems are powered), if the system that has the CMD/POSN delta is selected and no actuator position movement occurs, the failure is most likely in the instrumentation, outside of the internal feedback loop, and the engine has not actually moved away from its previously trimmed position (see Fig. 7.3-1).

3. Position transducer bias

The position bias is within the internal feedback loop and the engine has actually moved to an out-of-trim position. It may be possible to bias the command such that the actual trim position of the bad engine is as required for active use for the purpose of "parking" the engine through the c.g. per Malfunction Procedure GNC SSR-8. The alternate good system transducer should be monitored for actual position. A gimbal check should be run to quantify the bias and see if the engine can still be moved into a usable position (see Fig. 7.3-1).

4. Slow/binding actuator

- a. If the actuator drive rate is slow in both directions (extend/retract), binding or motor degradation is suspected. The system may still be usable but the engine may not reach its proper trim position by the start of the burn and there will be some startup transient (it would have to be slower than 0.9 deg/sec). If after a two-engine burn (parallel burn) a single-engine burn is loaded, the engine has to move about 12 degrees in 15 seconds (engine starts to move at TIG - 15 seconds). Therefore, at 0.8 deg/sec, the actuator will just make it to burn position. It is advisable to use the alternate system, if available.
- b. If the drive rate is normal in one direction but there is no movement or a slow rate in the other (extend/retract), suspect a slipped synchro problem. (The rate would attempt to move faster than normal in one direction, but the velocity limiter will limit output to the nominal rate.) This is based on the STS-1 "slipped synchro" failure in the pitch axis. Also, OV-099 had an actuator that experienced a low rate in one direction (but above spec limit) and normal in the other direction. Since it was consistent (not intermittent or erratic), it was not considered failed. It likely had a synchro with a constant "off-set" but within spec.
- c. If the drive rate in one direction is normal but the drive rate in the other is about 25 percent of normal, this may be an 8-second timer failure. Check with the EGIL Officer to see if the full 10 amps are being pulled or if there is only 2.5 amp load reading (indicative of this failure - reference note 5 on SSSH drawing 9.13).

5. Stuck/unresponsive actuator

- a. If the actuator will not move on either system, the engine is totally locked up. No engine repositioning is possible so this engine is unusable if out of trimmed position (this depends on the axis - if yaw, it still may be good for two-engine burn cases).
- b. If the engine will move on one system and not the other, then the failed system has a motor or drive electronics failure. The good system can be used for TVC control or to park.
- c. If the actuator is unresponsive, a loss of power could be the problem. Check the RPCs. If only one of two redundant RPCs is available, then you can only move in one axis at a time (else no movement).
- d. If the engine will move in one direction but not the other (extend/retract), loss of a motor drive transistor is possible. Use the good system.

6. Abnormal excitation voltage

Feedback transducer excitation voltage problems (off-nominal voltage) are credible. They may not cause gimbal failures, but can be detected during gimbal checks (on plots). This is especially true in the pitch axis, which is nominally near zero degrees, in which case a scale factor error (caused by the bad excitation voltage) can only be detected with a gimbal check or when commanded to the stow position in MM 303.

E. ACTIONS

As noted above, it is advisable in most cases of an OMS TVC failure (primary or secondary) to use the alternate good system for the remaining OMS activities. This is the preferred course of action. Based on the failure scenario, the option to "park" or power off the TVC when trimmed through the c.g. is also available (see GNC Flight Rule A8-113A). If this park procedure is planned as a corrective action, there are some issues to consider:

1. When one engine is parked, the crew will probably get a GMBL FAIL message during subsequent OMS burns, even if the other engine is being used to perform the burn. Also expect a fail message in the transition to MM 301 from MM 201 if the TVC is OFF.
2. If the desired trim position is within $\pm 0.4^\circ$ of the present trim (as is likely in pitch), there will be no gimbal movement because the difference is within the actuator deadband range $\{\leq 0.4^\circ$; hysteresis (0.025 inch = 0.05 Vdc = 0.06°, 0.125 inch = 0.25 Vdc = 0.4°)}. In this case, depending on the magnitude of the mistrim, it may be beneficial to perform the park procedure twice (corrective technique). In the first step, the trim load in the axis of concern would be calculated so that its delta with both the present, and final desired, trim positions is greater than the 0.4° deadband limit. As the limit is surpassed the engine moves to the loaded trim position. The second step is to perform the procedure again using the final desired trim load values. The deadband is again exceeded and the engine moves to the desired trim position.

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3. Redundancy Management, FSSR STS 83-0010B (Prin. Funct. 4.92) sec. 4.10, June 30, 1987.
4. I-Loads Requirements Document, JSC-19350: II, November 1985.
5. STS Operational Flight Rules, Rule 8-113A.
6. Aerojet Technical Systems Spec. to Airesearch, ATC-42483.V, p. 40, August 17, 1987.
7. Spec MC621-0009, sec. 10.
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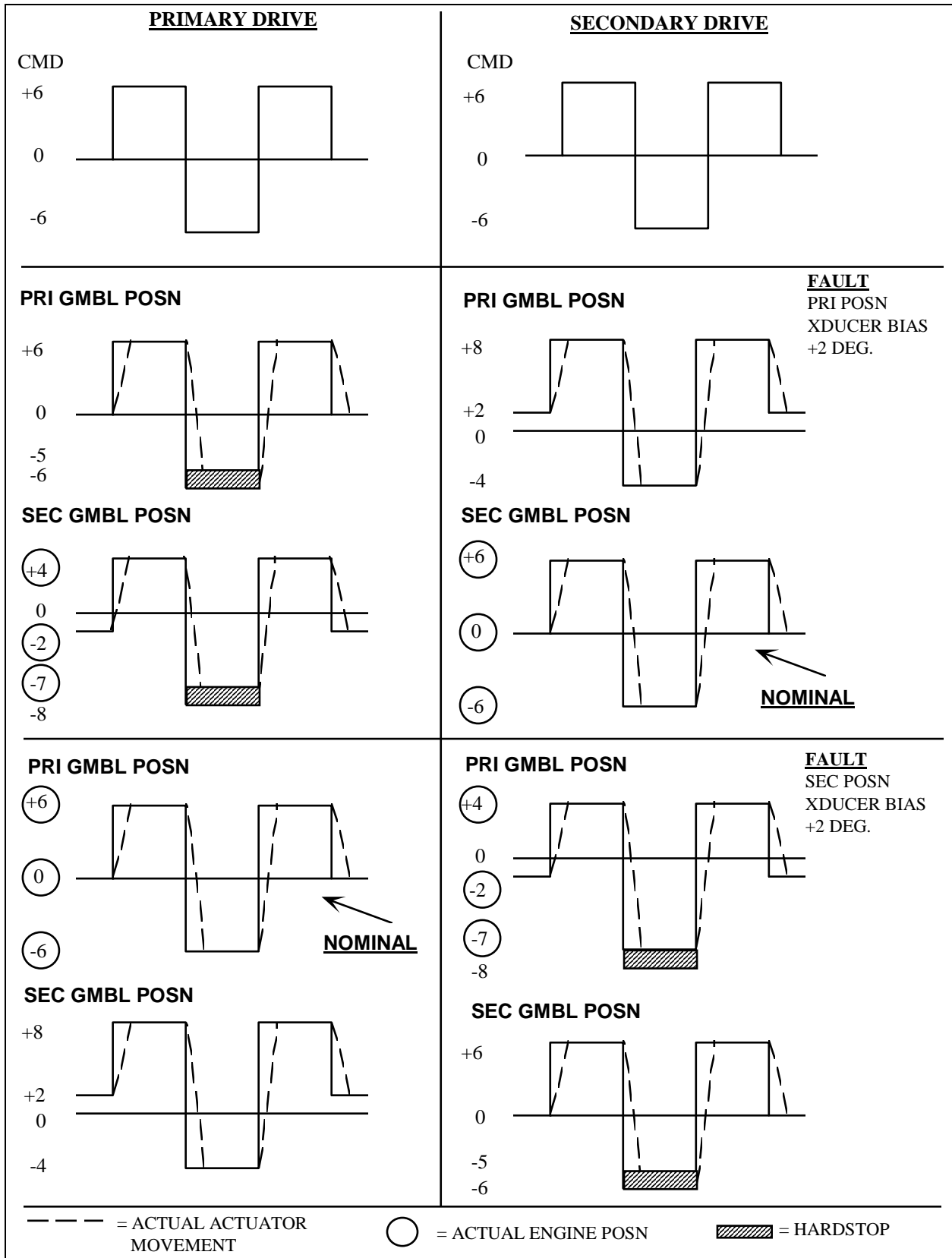


Figure 7.3-1. - OMS TVC transducer fault troubleshooting chart.

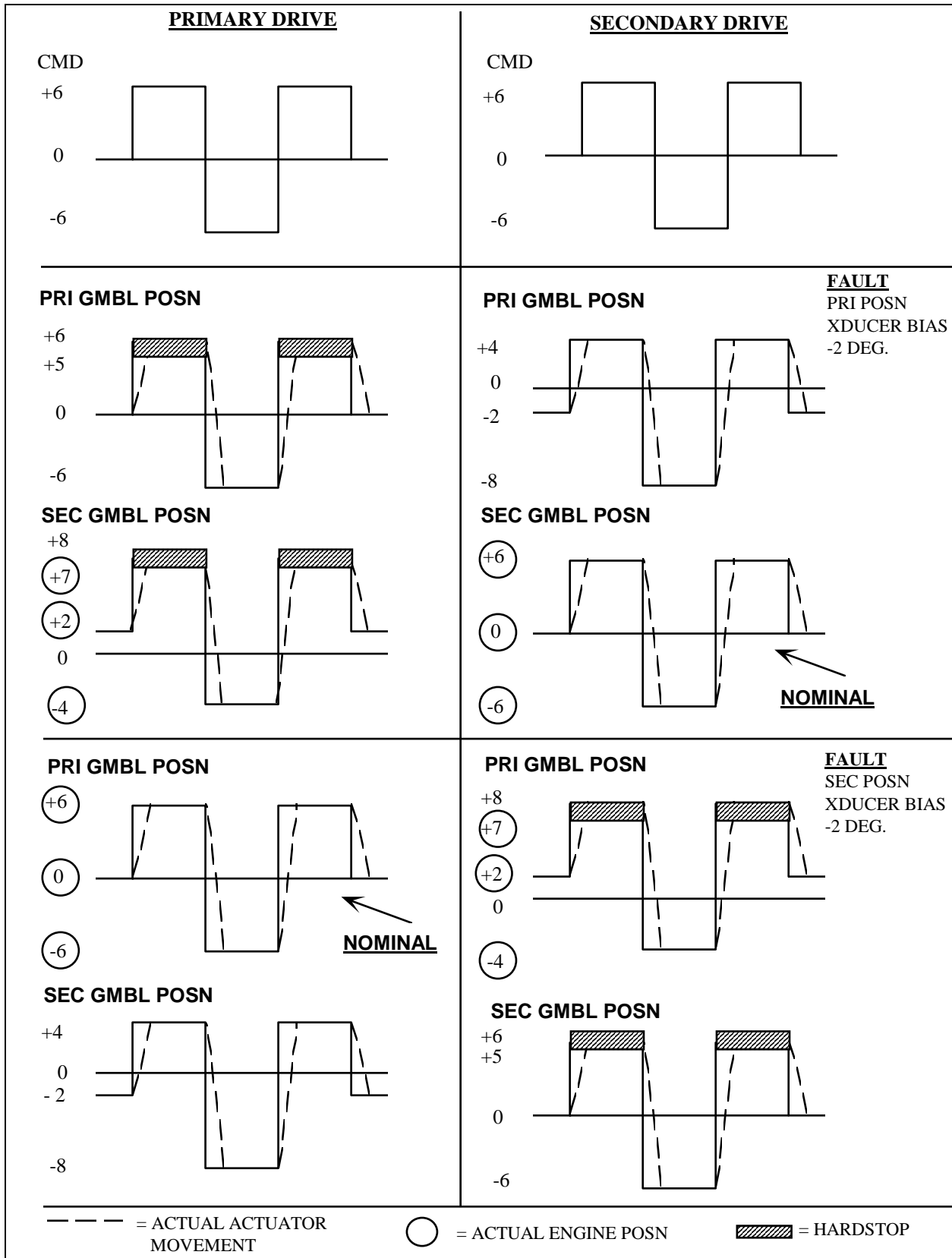


Figure 7.3-1. - Continued.

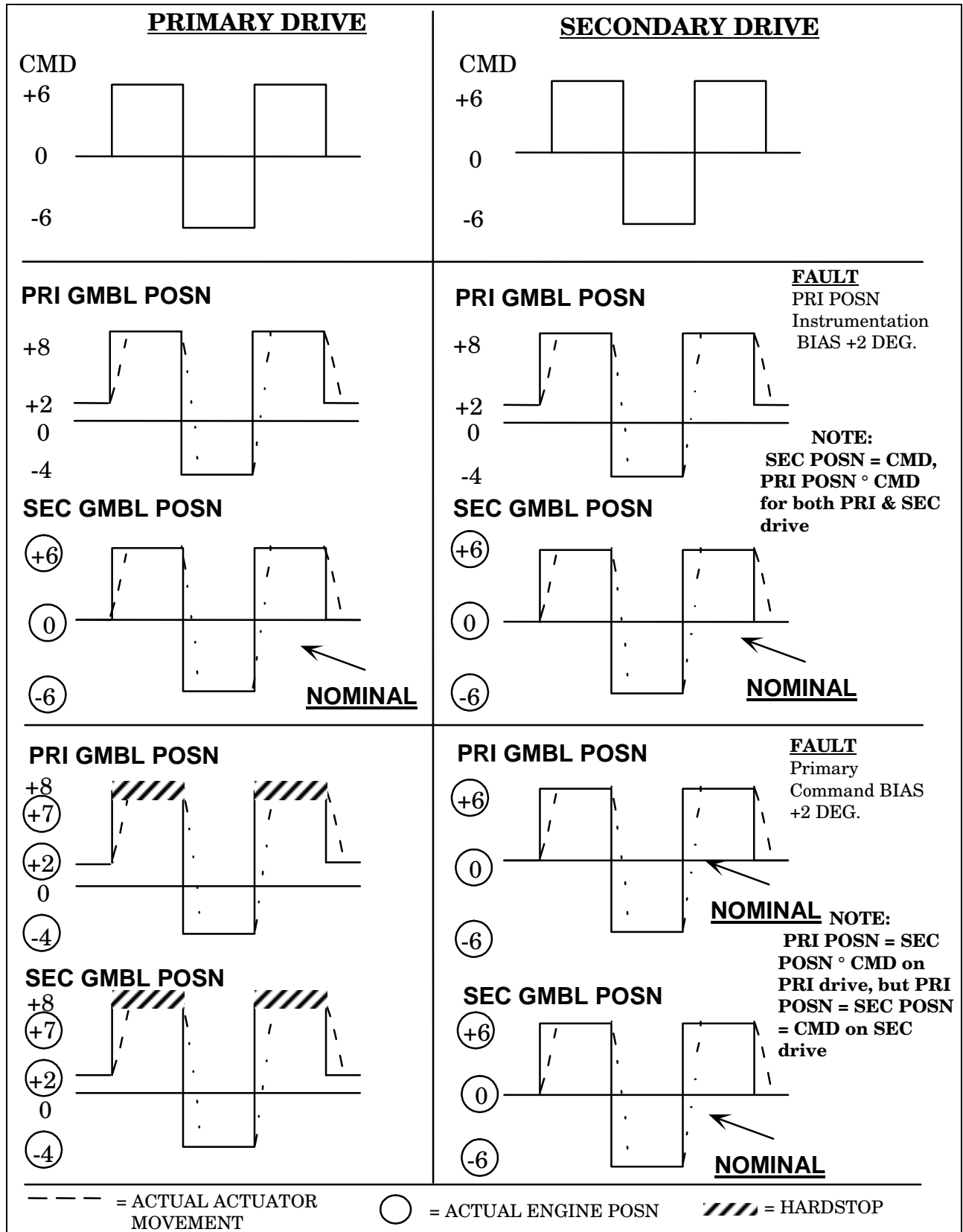


Figure 7.3-1. - Concluded.

TITLE

CALCULATION OF ORBITER ACCELERATIONS AND TORQUES (JETACCLA)

PURPOSE

To describe the procedure for using a computer program that calculates linear and angular accelerations at the center of mass and local accelerations at any point due to any combination of primary or vernier RCS jet firings and other forces. Local accelerations are derived from angular accelerations calculated from jets and forces, angular rate as an input or as calculated from average altitude, gravity gradient, and an input value for aerodrag.

BACKGROUND

The PC program JETACCLA is a combination, with enhancements, of two older programs that performed calculations of center of mass accelerations. The earlier program JETACC calculated accelerations using the following items (data from SODB):

1. A file of primary and vernier jet force and location data.
2. Internally stored force and moment corrections for jet plume impingement on the orbiter body assuming a reference CG and no deflection of aerosurfaces.
3. Optional user input of additional corrections for jet plume impingement deltas based on aerosurface deflection.

The earlier program ANGACL performed the same calculations based on user input of force and location data. The source of data for such forces as vents and engines is the SODB. However, any force data could be input to the program. Any plume impingement effects must be included in the input data.

Both programs were originally developed to run on computers with much less capability than that of computers available today. As computers evolved, the original programs were adapted to run on the new computers with limited effort expended initially to take advantage of the new computer power. Improvements (mostly to JETACC) were gradually added when convenient. These improvements included more user friendly I/O, saving of mass property inputs to a file for later retrieval, and calculation of local accelerations at points other than the CG. Largely because ANGACL was used much less frequently, it was updated only with a few of the I/O improvements. The two programs had an additional limitation in that if it were desired to know the combined effects of an RCS jet and some other force such as an OMS engine or a water dump, it was necessary to run both programs and manually add the two results.

The new program JETACCLA combines the two programs so that jet and force calculations can produce an integrated output. Since the combination allows the ANGACL part of the new program to use the same mass property inputs as the JETACC part, it is inherently updated with the mass property file save function. The combination also allows local accelerations to be

computed for any combination of jets and forces, with the option to include the effects of vehicle rates, gravity gradient, and aerodrag.

EQUATIONS

Constant Definitions

$G = 980.665$ centimeters per second per second

= $980.665/30.48$ feet per second per second

Meters per foot = 0.3048

Meters per nautical mile = 1852

Source: International Committee on Weights and Measures.

$\mu_e = 1.407644174661070960e16$ ft³/sec² (earth gravitational constant).

Earth radius (mean equatorial) = 3443.918088553 nautical miles

Source: Fundamentals of Astrodynamics and Applications by David A. Vallado of USAF Phillips Laboratory (1996).

CG Accelerations

It must be noted that the term CG (center of gravity) is routinely used to mean CM (center of mass). Center of mass is the average of incremental mass multiplied by location and is independent of the gravity field. CG is the average effect of gravity on incremental mass and is dependent on the gravity field and the vehicle attitude within that field. For most practical applications they can be considered as the same, but in microgravity environments the difference can be significant. Since the misuse of the term is so widespread no attempt will be made to correct it here. Unless stated otherwise the term CG as used in this SCP and in the program JETACCLA refers to center of mass.

The equations used by the program to calculate accelerations at the CG are:

$$F = MA$$

And the rotational equivalent

$$T = I\alpha$$

For the linear acceleration calculations the force F and the acceleration A are vectors and M is mass (a scalar) of the body. Mass is the property of matter that resists a change in velocity (acceleration) when a force is applied; it is equal to weight divided by G .

The rotational equivalent of force is torque (or moment) that is the component of force perpendicular to the moment arm multiplied by the length of the moment arm. The vector equation is $T = \text{arm} \times \text{force}$ and accounts for the force vector, in general, not being perpendicular to the arm. α is the angular acceleration (radians per second per second). The Inertia matrix is a 3 by 3 matrix representing the resistance to a change in angular rate (angular acceleration) when a torque is applied. This is the rotational equivalent of mass; it is not a scalar. In general, this resistance varies depending on the axis about which the torque is applied

and the resulting angular acceleration vector is not aligned with the torque vector. A body with a radially uniform mass distribution is an exception to the general condition. A perfectly uniform sphere, or a body composed of spherical shells each of which is uniform (that is, mass per unit volume is dependent only on radius) would react to torque the same regardless of the axis about which the torque is applied. The resulting angular acceleration vector would be aligned with the torque vector. In this very special case the inertia matrix would consist of diagonal values that are equal and off diagonal values of zero. Real vehicle structures are unlikely to fit such an ideal case. It is possible to select a coordinate frame such that the off diagonal elements become zero (the diagonals would still have different values, in general). This is impractical because as mass properties change, such as with the burning of fuel or moving of cargo, the ideal frame would change. It would be a major task just to keep up with all the transformations that would be required with each change in reference frame. The selection of coordinate frames is usually driven by other much more important criteria.

A derivation of the inertia matrix will be given later in this SCP.

The equations given are fine if we know the accelerations we want and we wish to determine the force or torque we need to apply to get that acceleration. For vehicles with CMG systems the angular rate equation is used to determine how to torque the CMG's. For the orbiter, translation jet select and PRI DAP angular rate jet selects are simple table lookups, but the ALT DAP and the VERN DAP do use the angular rate equation to select the best jets. Of course, with limited jets from which to select, it is necessary to define the criteria by which jets will be judged. Do we want to get the most rate change per unit of prop consumed or do we want to get a rate change as close as possible to the desired direction? This is, in part, the difference between dot product and min angle jet select.

However, jet select is not the purpose of this program and this SCP. What we want to know is, given the application of a known torque (force and location), what is the resulting angular acceleration? We must, therefore, solve the equations for acceleration. The linear acceleration equation can be solved by simple algebra; both sides of the equation are divided by mass. Since it is a vector/matrix equation, there is no division operator for solving the angular acceleration equation. To solve the equation we premultiply both sides by the inverse of the I matrix. Since the product of a matrix and its inverse is identity (the matrix equivalent of unity), the inertia matrix disappears from the right side of the equation. A method for determining the inverse of a matrix will be given later in this SCP.

The final equations are:

$$A = F/m$$

and

$$\omega = I^{-1} T \text{ where the superscript } -1 \text{ indicates the inverse of the I matrix.}$$

There is an additional complication in that the jet data for aft jets is given as if the plumes were free to expand without striking the body. Plume impingement effects for forward jets are generally much smaller than for aft jets and they are included in the jet data. Plume impingement correction for the aft jets is provided separately and in a slightly different format. The data could have been given as an equivalent force at some average location that produces the same torque (or moment) as the actual plume striking a large area of body surface.

However, it is given as a delta force and a delta moment with the delta moment being calculated assuming the cg is at a specific location called the Reference CG. The plume impingement correction data is supplied in two categories. The first category applies to all aft primary attitude control jets and the down firing aft vernier jets. This category reflects corrections valid with all aerosurfaces at zero deflection. These corrections are coded into the program and are made automatically. The second category applies only to aft downfiring primary jets and consists of additional corrections to be applied based on deflection of elevons and/or body flap. The data for both categories is provided in tabular form for left side (port) jets only and by jet group (aft down firing VERN jets are considered as separate groups) rather than by specific jets. Due to vehicle symmetry, the data for right side (starboard) jets can be obtained by simply changing the signs of the Y component of force and the X and Z components of moment. Aerosurface deflection correction data is provided for inboard and outboard elevons and body flap in increments of 5 degrees except for the first and last body flap entries that are more than 5 degrees from their neighboring entry. The user must obtain the data for each aerosurface that is deflected and each jet that is used and add them together to get the total aerosurface deflection plume impingement correction. Note that if firing two jets in a group the correction data is identical for each jet but it must be added into the total twice.

Since the actual vehicle cg is not at the Reference CG a final plume impingement correction must be calculated. The equation for this calculation is obtained by differentiating the vector torque equation $T = \text{arm} \times \text{force}$ yielding $\Delta T = \Delta \text{arm} \times \text{force}$ correction. Δarm is the difference between the actual cg and the Ref CG (cg – Ref CG ft in body coordinates) and force is the sum of the force correction for non aerosurface deflection and the correction for aerosurface deflection. The calculated ΔT (delta moment) is added to the provided delta moments to obtain the final moment correction to be added to the moment (T) calculated from the basic jet data. The final moment used in the matrix equation then is the sum of 4 components:

1. The moment (T) calculated from the basic jet data $T = \text{arm} \times \text{force}$ where arm is force location – cg in ft in body coordinates.
2. Moment correction for non aerosurface deflection if applicable to the jet
3. Moment correction for aerosurface deflection if applicable (and desired)
4. ΔT due to difference between Reference CG and actual cg.

The final moment sum is then used in the matrix equation to determine angular acceleration.

The force input option (derived from the older program ANGACL) has no provision for plume impingement corrections. This option allows the user to input force data in the same rectangular coordinates system as the basic jet data or in a spherical coordinate system using Rho, Gamma, Force where Rho and Gamma are angles corresponding to Universal Pointing pitch and yaw vectors, and Force is the magnitude of the force vector. The location vector is in the same rectangular coordinates (inches, structural coordinates) for either force vector input option. Conversion from rectangular to spherical coordinates may be done by the following equations where X, Y, and Z are components of the Force:

$$\text{Force} = \text{square root}(X^2 + Y^2 + Z^2)$$

$Rho = \text{Arctan2}(-Z, X)$ where arctan2 is a function which evaluates the $\text{arctan}(-Z/X)$ and resolves the quadrant ambiguity by considering the signs of the two arguments. The minus sign before the Z component means you must reverse the sign of the Z component of the force vector before calling the function with actual numbers. The Arctan2 function given is the FORTRAN version; the EXCEL version is $\text{Arctan2}(X, -Z)$. The difference between the two is the order of the call parameters within the parentheses.

$$\text{Gamma} = \text{Arcsin}(Y/F)$$

For those who may be uncomfortable with the Arctan2 function or who wish to perform the calculations with a hand calculator having no arctan2 function, RHO may be found as follows:

$$\text{Rho} = \text{Arctan}(-Z/X)$$

This equation gives a first or fourth quadrant angle. If inspection of the signs of the X and the Z components (remember to reverse the sign of the Z numerical value) of force indicate that the angle is not in either the first or fourth quadrant, add 180 degrees to find a second or third quadrant angle.

For example, if the Z component of force is -10 and the X component is -25, find $\text{arctan}(10/-25) = 338.2$ degrees (or maybe -21.8), then check the quadrant. 338.2 is a fourth quadrant angle, but the signs of the -Z and X components are +/- indicating a second quadrant angle, so add 180 degrees ($338.2 + 180 = 514.2 = 158.2$, or $-21.8 + 180 = 158.2$). Note that quadrant determination is not necessary for Gamma because Gamma is always either a first or a fourth quadrant angle.

To convert from spherical (Rho, Gamma, Force) to rectangular coordinates find the unit vector and multiply each component by the Force as follows:

1. $X = \text{Force} * \text{Cos}(Rho) * \text{Cos}(Gamma)$
2. $Y = \text{Force} * \text{Sin}(Gamma)$
3. $Z = -\text{Force} * \text{Sin}(Rho) * \text{Cos}(Gamma)$

The program displays both the linear accelerations (the net acceleration of the body) and the angular acceleration along with the forces and the torques that produce the accelerations. This result is the combined effects of all the jets and all the forces that have been input to the program. The user has the option also to display results without the inclusion of plume impingement corrections. Because results without plume impingement corrections have little practical use beyond comparison with the corrected results, no provision is made to display the uncorrected results alone. Displaying both results if uncorrected results are requested offers some protection from inadvertently using the uncorrected data to predict vehicle response.

Local Acceleration Calculations

The basic output of the program gives the linear accelerations as they would be sensed at the vehicle cg. It is sometimes desired to know the linear accelerations at some point other than the cg (angular accelerations of a rigid body are constant throughout the body). A new function, not present in either of the earlier programs JETACC or ANGACL, allows the calculation of the accelerations at any point considering any of the following factors that the user wishes to include:

1. Centripetal acceleration – due to rotation rate ω , the force associated with this acceleration is sometimes called centrifugal force.
2. Acceleration due to angular acceleration
3. Gravity gradient acceleration
4. Aerodrag acceleration

Centripetal acceleration is due to rotation rate. It can be either a user input vector or a calculated vector that is derived from a circular orbit of a specified altitude. The equation is

$Acc_{\omega} = \omega \times (\omega \times arm)$ where arm is the location of interest - cg

Acceleration is due to angular acceleration. The equation is

$Acc_{\alpha} = \alpha \times arm$ where arm is the same as for centripetal acceleration

The equation for acceleration due to gravity gradient is

$Acc_g = G_p$ (gravity vector at point where local acceleration is to be calculated (Point of Interest or POI)) – G_{cg} (gravity vector at the cg). G_p and G_{cg} are determined as follows:

The basic gravity equation is $G = \mu_e/R^2$ where μ_e is the gravitational constant of the earth (the universal gravitational constant multiplied by the mass of the earth) and R is the scalar distance from the center of the earth. The scalar value of G_{cg} is calculated using the magnitude of the vector R_{cg} from the center of the earth to the cg (0, 0, -(altitude + earth radius)). The scalar value of G_p is calculated using the magnitude of R_p . where R_p is calculated by first converting the POI location vector from body coordinates to LVLH coordinates and then adding the converted vector to R_{cg} . R_p and R_{cg} are then unitized and multiplied by the previously calculated magnitudes of G_p and G_{cg} respectively yielding the vectors G_p and G_{cg} .

Aerodrag is an input of a scalar drag in micro-g's. The program does not calculate the drag; it has no atmosphere model and it has no vehicle cross section model. The input drag is assumed to be purely along the LVLH –X axis. The program resolves the drag into body coordinate using an input vehicle LVLH attitude.

Note that the program relies on the circular orbit approximation. For orbit eccentricities that the orbiter can reach the differences are negligible, but they are listed here so that the user will be aware of them:

1. Average orb rate for an elliptical orbit is determined by replacing the radius of a circular orbit with half of the semi major axis (altitude is replaced with half the sum of apogee and perigee). Since this is an average of a continuously and cyclically varying parameter, it is correct only at two points in the orbit. The average altitude is the best to use for most purposes. However, if the user wishes to input an altitude corresponding to a particular point in an elliptical orbit, the orb rate calculation will be biased from the slightly incorrect average value toward the correct value for that point. For example, the velocity, and therefore the angular rate at apogee, is clearly less than the average velocity. Although the velocity of a circular orbit with altitude equal to apogee of the elliptical orbit is also less than the average elliptical velocity, it is higher than the true velocity at apogee. Thus using the apogee altitude as input to the program will result in a better orb rate at apogee, but it still is not exactly correct.
2. The true direction of aerodrag is the negative of the velocity vector rather than the LVLH -X direction and is therefore exactly correct only at perigee and apogee. The magnitude of aerodrag also varies with altitude and position around the earth. An average value for the full orbit or a value that is associated with a particular point in the orbit may be entered.
3. Gravity gradient is also a function of altitude so that it, too, can be accurate only at two points (only one point at apogee or perigee) in an elliptical orbit. Furthermore, the earth is treated as a uniform mass, neglecting the effects of actual mass distribution of the earth. The effects of other celestial bodies are neglected, as well.

Derivation of the inertia matrix

Derivation of the inertia matrix requires that the body be divided into small incremental volumes. Each volume is then analyzed using the angular momentum equation. Angular momentum is defined as the product of the mass, the length of the arm from the point about which the mass is rotating (normally the center of mass) to the mass, and the component of velocity due to the rotation of the vehicle. For a rigid body the velocity that is due to rotation is always perpendicular to the rotation arm. Any component of velocity that is due to the net velocity of the body is not a factor in the calculation of angular momentum. The velocity due to rotation is calculated as the product of the angular rate and the length of the arm.

The vector equation for momentum is $H = m (p \times (\omega \times p))$ where m is the mass of the incremental volume, p is the arm vector, ω is the rotation rate vector, and \times represents the vector cross product. Note that $\omega \times p$ is the velocity due to rotation and that p appears twice in the equation. The appearance of p twice is the reason that angular momentum (and moments and products of inertia) contain a distance squared. It will be helpful to think of the first p in the equation as the momentum arm and the second p as the velocity arm. It is important to understand that the two arms are the same vector, but as we consider the various combinations of vector components the arm components will not always be the same. The following derivation will show that moments of inertia develop from vector components where the momentum arm and the velocity arm are the same and products of inertia develop from components where the momentum arm and the velocity arm are different. The analysis will examine each of the possible combinations of all the components of the three vectors, ω and p twice. It would seem that there are 27 such component combinations ($3 \times 3 \times 3$). However, when the angular rate

component and the arm component are along the same axis there is no arm (arm = 0) so there are actually only 12 component combinations which produce angular momentum (3 x 2 x 2). In other words, for each component of angular rate only the arm components for the other two axes produce angular momentum. Furthermore, it will be shown that when the momentum arm component and the velocity arm component are the same the resulting momentum can be added into a single component reducing the total number of individual momentum components to nine.

The analysis assumes that the mass of the incremental volume is concentrated at the center of its volume (point mass). Although this is not strictly true for a non-infinitesimal volume, if the volume is small enough the contribution to total angular momentum of the incremental mass' angular momentum about its own center of mass can be neglected. The angular momentum calculated will be that due only to the one volume. The total angular momentum of the body is found by adding the contributions of all the incremental volumes. If we had an accurate and continuous equation giving the mass of the vehicle at any point, the incremental volume would approach zero and the sums would become integrals. In this case the assumption that there is no contribution to the total momentum by the incremental mass's momentum about its own center of mass becomes absolute truth. Of course, there can be no such perfect equation for describing a real vehicle's mass.

Derivation by Vector Equations for an incremental mass:

The equation for angular momentum is

$$H = mp \times V$$

where m is the mass, p is the position of the mass, and V is the component of linear velocity due to angular velocity. Since $V = \omega \times p$ where ω is angular velocity

$$H = mp \times (\omega \times P)$$

For convenience, divide the momentum equation by m so that it is not necessary to rewrite m with each subsequent step.

$$H/m = p \times (\omega \times p)$$

First, calculate the velocity V by performing the cross product $\omega \times p$. For convenience p_x, p_y, p_z will be written as x, y, z

ω_x	ω_y	ω_z
x	y	z

$$z \omega_y - y \omega_z$$

$$- (z \omega_x - x \omega_z)$$

$$y \omega_x - x \omega_y$$

Next, calculate the moment (per unit of mass) by performing the cross product $p \times V$

x	y	z
$z \omega_y - y \omega_z$	$-(z \omega_x - x \omega_z)$	$y \omega_x - x \omega_y$

$$y(y\omega_x - x\omega_y) + z(z\omega_x - x\omega_z) \quad -(x(y\omega_x - x\omega_y) - z(z\omega_y - y\omega_z)) \quad -x(z\omega_x - x\omega_z) - y(z\omega_y - y\omega_z)$$

Removing parentheses

$$y^2\omega_x - xy\omega_y + z^2\omega_x - xz\omega_z \quad -xy\omega_x + x^2\omega_y + z^2\omega_y - yz\omega_z \quad -xz\omega_x + x^2\omega_z - yz\omega_y + y^2\omega_z$$

Rearranging terms

$$y^2\omega_x + z^2\omega_x - xy\omega_y - xz\omega_z \quad -xy\omega_x + x^2\omega_y + z^2\omega_y - yz\omega_z \quad -xz\omega_x - yz\omega_y + x^2\omega_z + y^2\omega_z$$

Combining like ω terms within each component of the vector

$$(y^2 + z^2)\omega_x - xy\omega_y - xz\omega_z \quad -yx\omega_x + (x^2 + z^2)\omega_y - yz\omega_z \quad -zx\omega_x - zy\omega_y + x^2\omega_z + y^2\omega_z$$

Writing the equation putting the above vector in matrix form where the x component is the first row, the y component is the middle row, the z component is the bottom row and ω_x , ω_y , and ω_z define columns:

$$\begin{vmatrix} H_x/m \\ H_y/m \\ H_z/m \end{vmatrix} = \begin{vmatrix} (y^2 + z^2)\omega_x & -xy\omega_y & -xz\omega_z \\ -xy\omega_x & +(x^2 + z^2)\omega_y & -yz\omega_z \\ -xz\omega_x & -yz\omega_y & (x^2 + y^2)\omega_z \end{vmatrix}$$

Product terms are usually written in x, y, z order. After the integration over the entire body has been done the terms are scalars and the factors can be written in any convenient order. The following matrix shows the terms written in the order that puts the velocity arm adjacent to the angular rate to help with the visualization of the product of those two factors as the velocity. Subsequent matrices return to the usual form.

$$\begin{vmatrix} H_x/m \\ H_y/m \\ H_z/m \end{vmatrix} = \begin{vmatrix} (y^2 + z^2)^{1/2} (y^2 + z^2)^{1/2} \omega_x & -y x \omega_y & -z x \omega_z \\ -x y \omega_x & (x^2 + z^2)^{1/2} (x^2 + z^2)^{1/2} \omega_y & -z y \omega_z \\ -x z \omega_x & -y z \omega_y & (x^2 + y^2)^{1/2} (x^2 + y^2)^{1/2} \omega_z \end{vmatrix}$$

Multiplying by m and factoring out ω

$$\begin{vmatrix} H_x \\ H_y \\ H_z \end{vmatrix} = \begin{vmatrix} (y^2 + z^2)m & -xym & -xzm \\ -xym & (x^2 + z^2)m & -yzm \\ -xzm & -yzm & (x^2 + y^2)m \end{vmatrix} \times \begin{vmatrix} \omega_x \\ \omega_y \\ \omega_z \end{vmatrix}$$

This is the matrix form of the angular momentum cross product equation. The 3 X 3 matrix is the I (inertia) matrix. However, it applies only to the single incremental volume. To obtain the general inertia matrix we must perform the calculations for every incremental volume in the entire body and add the results element by element. While calculating a summation, mass and arm components must be evaluated for the current "ith" volume.

$$\begin{vmatrix} H_x \\ H_y \\ H_z \end{vmatrix} = \begin{vmatrix} \sum m(y^2 + z^2)\omega_x & -\sum mxy \omega_y & -\sum mxz \omega_z \\ -\sum myx \omega_x & \sum m(x^2 + z^2) \omega_y & -\sum myz \omega_z \\ -\sum mzx \omega_x & -\sum mzy \omega_y & \sum m(x^2 + y^2) \omega_z \end{vmatrix}$$

If there were a mathematical expression for mass at every point in the vehicle the summations could be replaced with integrals and the approximation that the incremental volume is small enough to ignore the distribution of mass within the volume would become truth as the volume becomes infinitesimal.

$$\begin{vmatrix} H_x \\ H_y \\ H_z \end{vmatrix} = \begin{vmatrix} \int m(y^2 + z^2) & -\int mxy & -\int mxz \\ -\int myx & \int m(x^2 + z^2) & -\int myz \\ -\int mzx & -\int mzy & \int m(x^2 + y^2) \end{vmatrix} \times \begin{vmatrix} \omega_x \\ \omega_y \\ \omega_z \end{vmatrix}$$

Note that the above equation relates angular momentum to angular velocity. What we want is the equation relating torque to angular acceleration. Noting that once calculated, the I matrix is a constant and differentiating the variables H and ω with respect to time, angular momentum H

becomes torque T , angular rate ω becomes angular acceleration α , and the momentum equation becomes the angular acceleration equation, $T = I \alpha$.

Note that while the matrix elements $-\int mxy$ and $-\int myx$ represent different components of the matrix, they are equal, the only difference being the order of the x and y values. In one case x represents the momentum arm and y represents the velocity arm; in the other case y represents the momentum arm and x represents the velocity arm. Since the matrix elements are scalars the order makes no difference in the value of the product. The same is true of the other off diagonal elements. When mass properties are specified it is customary to list only one value for each of the diagonal pairs. Note also that each of the off diagonal elements has a negative sign. The off diagonal elements are called products of inertia and when they are listed (as opposed to being provided as a final I matrix) they may be given either as $-\int(\text{product})$ or as $\int(\text{product})$. The form with the minus sign is referred to as negative products or negative integrals. The form without the minus sign is referred to as positive products or positive integrals. Do not confuse this negative sign with the algebraic sign of the number given as a product of inertia. If you are given negative products you may insert the values directly into the appropriate element of the inertia matrix preserving each product's algebraic sign. If you are given positive products you must reverse the signs of the three products (six values to be inserted into the matrix) before inserting them. The diagonal elements are called moments of inertia. Since the momentum arm and the velocity arm are the same for moments of inertia the moments are the product of two positive numbers or they are the product of two negative numbers and as such are always positive. The other factor of moments and products of inertia, mass, is always positive.

The convention adopted by the space shuttle program is to list products as positive products. This is how you will find them in the SODB and it is how the Flight Dynamics Officer (FDO) will provide them. The ISS program has officially adopted the negative products convention, but sometimes someone will do us a favor and convert them to positive products, so be sure you know what you are being given.

There is one additional consideration when building the inertia matrix from shuttle program listed mass properties. Just as with locations of various points on the orbiter, the mass properties are specified in structural coordinates; they must be converted to body coordinates before using them to evaluate the effects of applied forces. Fortunately, the unit of distance used is feet (unlike locations that are given in inches). For transformations that are not multiples of 90 degrees, the inertia matrix elements will change in value. For transformations which are multiples of 90 degrees but where axes change name (e.g. X becomes Y) the inertia matrix values will remain the same but signs and location of products and location of moments will change. Fortunately, the structural to body transformation is 180 degrees about Y so X becomes $-X$, Y remains Y , and Z becomes $-Z$. For this transformation all elements retain their absolute value and their location in the matrix, but the signs of the XY and the YZ products change. Since correcting for positive products requires reversing the sign of all three products and correcting for coordinate transformation requires reversing two of the products (XY and YZ) both corrections can be made simultaneously by simply reversing the sign of one product (XZ). The program takes positive products as input and makes the single product (two matrix elements) sign reversal described above.

Visualization of the Inertia Matrix

The following is offered as a means of visualizing what the components of the inertia matrix represent.

Refer to the definition of angular momentum (for an incremental mass) and separate the vectors into components. The components of the position vector p become distances from an axis. The angular momentum about the X axis then consists of the following 4 components:

1. The mass times the moment arm component from the X axis along the Y axis times the velocity component due to rotation about the X axis displaced from the X axis along the Y axis times the angular velocity about the X axis. For this component of angular momentum both the velocity arm and the moment arm are Y resulting in $mY^2\omega_x$.
2. The mass times the moment arm component from the X axis along the Z axis times the velocity component due to rotation about the X axis displaced from the X axis along the Z axis times the angular velocity about the X axis. For this component of angular momentum both the moment arm and the velocity arm are Z resulting in $mZ^2\omega_x$.
3. The mass times the moment arm component from the X axis along the Y axis times the velocity component due to rotation about the Y axis displaced from the Y axis along the X axis. For this component of angular momentum the velocity arm is X and the moment arm is Y resulting in $-mYX\omega_y$. Note that when the X and Y values are both positive the direction of rotation about the X axis is negative by the right hand rule. The direction of rotation is always opposite to the sign of the product of the X and Y factors. This is the source of the negative associated with each of the products of inertia.
4. The mass times the moment arm component from the X axis along the Z axis times the velocity component due to rotation about the Z axis displaced from the Z axis along the X resulting in $-mZX\omega_z$. Note that, similar to 3 above, when the X and Z values are both positive the direction of rotation about the X axis is negative by the right hand rule.

Note that components 1 and 2 have the same angular velocity component and can therefore be combined into a single term $(Y^2 + Z^2)\omega_x$. The combined components 1 and 2 and components 3 and 4 comprise the top row of the inertia matrix. Components 1 and 2 could have been visualized by considering the total perpendicular distance from the X axis times the angular velocity about the X axis. The distance from the X axis is the square root of $(Y^2 + Z^2)$ and, since the distance appears twice in the calculation of angular momentum, the term becomes $(Y^2 + Z^2)\omega_x$ yielding the same result as when treating the Y and Z displacement from the X axis as separate components.

The four components of angular momentum about the Y axis and the four components about the Z axis, derived as above, comprise the middle and the bottom rows, respectively, of the inertia matrix.

Matrix Inversion

Matrix inversion can be done only on a square matrix where the number of rows equals the number of columns. The process described is valid for any order of square matrix, but it becomes very cumbersome for large order matrices. There are mathematical techniques, beyond the scope of this SCP, which reduce the complexity of inverting high order matrices and, in fact the subroutine used by the program (borrowed from the literature) uses a technique called "partial pivot". The subroutine is capable of inverting up to a 10 X 10 matrix, but, of course, this program asks it only to invert a 3 X 3 matrix. The "brute force" or pure method described here will work for any order and it is actually easier to use for a manual 3 X 3 inversion. The reader must understand three matrix math terms:

1. The minor matrix of a matrix element – the matrix remaining after the row and the column of the original matrix containing the element are eliminated.
2. The transpose of a matrix – rows and columns of the matrix are exchanged (i.e., row 1 becomes column 1, row 2 becomes column 2, etc.)
3. The determinate of a matrix – a single scalar value obtained by adding the results of multiplying each element of one row (or one column) by $(-1)^{(R+C)}$ and the determinate of its minor matrix. R and C are row number and column number respectively. If the minor matrices described above are of order 3 or greater, their determinates must be calculated as above with this process continuing until the minor matrices are of order 2. Obviously, finding the determinate of higher order matrices by this method becomes very tedious. When the minor matrices have been reduced to order 2, a scalar value can be calculated from the four elements as the product of the upper left and the lower right minus the product of the lower left and upper right. The final determinate of the original matrix is the sum of all the terms.

A square matrix is inverted by replacing each element with the determinate of its minor matrix, dividing each of the new elements by the determinate of the full matrix, and then transposing the matrix. Since the off diagonal pairs of the inertia matrix are equal, the final transpose does not change the value of any element and therefore is not required

PROGRAM EXECUTION PROCEDURE

This section describes how to run the program assuming the user is familiar with the detail I/O description given later in this SCP.

1. On the MCC PC, execute the program by selecting JETACC from the START under Applications/Restricted Apps/GNC.
2. Change mass properties, store them to a file, or retrieve them from a file as desired. Enter item C to go to jets and forces menu.
3. Enter a RUN ID, if desired. Enable aerosurface deflection plume impingement corrections as desired. Enter all the jets and forces to be included in the case. Clear the jet (and force) list if a mistaken jet or force has been entered. If clearing the list to run a new case,

it will also be necessary to change the RUN ID. Enter item C to display results. Enter a blank line to go to the output control menu.

4. If desired, select results without plume impingement correction to displayed/printed along with the corrected results. If desired, select RCS data option. If desired, select maximum precision output for all subsequent printed outputs. If desired, redirect the printed output to a DOS file. Display (again) or print the results. If another case is to be run, either return to the jets and forces menu with item J or return to the mass properties menu with item M. It is desired to calculate local accelerations at a point other than the cg or if it is desired to add aerodrag to the results, execute item L.
5. If item L (local accelerations) has been selected on the previous menu, enter the location for which local accelerations are desired in either the body frame (feet from CG) or the structural frame (inches). (NOTE: If it is desired only to add aerodrag to the CG accelerations, no location entry should be made.) If desired, enter a body rate. If GG acceleration, calculated orb rate, or aerodrag is desired, enter GG parameters. Display or print the results. As many cases of local acceleration as desired may be run while on this menu; all cases will have the same accelerations due to jets and forces. Enter item J to return to main program to alter output form, to change jets and forces, or to quit the program.

DETAILED PROGRAM I/O DESCRIPTION

The program operates from four main menus. The first menu deals with mass properties, the second menu provides for input jets or forces, the third menu controls output of the CG angular and linear accelerations, and the fourth menu provides for calculation and output of forces at points other than the CG. Most inputs to the program are not case sensitive; exceptions will be noted.

MASS PROPERTIES MENU

Refer to the onscreen menu or Figure 7.4-1 for the following input description.

Mass properties used by the program can be either the default values already in the program, values stored in a file, or values input by keyboard.

The default mass properties from STS-96 Day 3.

MASS PROPERTY INPUTS

Individual mass property elements may be input by typing the bracketed character(s) associated with the element. All elements of mass properties may be entered as a group by typing A (the bracketed character for ALL INERTIAS, CG, and WEIGHT). This data can be obtained from the Flight Dynamics Officer (FDO) or the Shuttle Operational Data Book (SODB), Volume II, "Mass

Properties Book". The products of inertia will be positive products (see derivation of inertia matrix for details). If a source other than FDO or the SODB is used to obtain the inertia matrix care must be taken to note the form of the products of inertia and the coordinate system. If the form is negative products, the signs of all three products of inertia must be reversed to convert the to positive products form before they can be input to the program. If the matrix is given in body coordinates it must be converted to structural coordinates by reversing the signs of the I_{xy} and the I_{yz} products. Note that both of these corrections can be accomplished by simply reversing the sign of the I_{xz} product rather than reversing the signs of all products and then reversing two of them back to their original sign.. Conversion from other coordinate frames requires transforming the inertia matrix through the coordinate transformation matrix representing the relative orientation of the two coordinate frames. Because the inertia matrix has more mathematical properties than simple a collection of three vectors in matrix form, the transformation is more than complex than a simple multiplication by the coordinate transformation matrix. The process requires premultiplying the inertia matrix by the transformation matrix (direction cosine matrix) from the coordinate frame of the inertia matrix to the structural frame and post multiplying the result by the transformation matrix from structural coordinates to the inertia matrix coordinate frame.

ITEM D

Item D reloads default mass properties.

ITEMS F AND T

Items F and T prompt the user for a DOS pathname for the file to be read from (F) or written to (T). A valid DOS pathname must be used. When reading a mass property file, the user must know the DOS pathname. If only the filename, for either read or write, is specified the program will assume the current working directory.

ITEM C

Item C calls the next menu.

ITEM Q

Item Q terminates the program.

JETS AND FORCES MENU

Refer to the onscreen menu or Figure 7.4-2 for the following input description.

ITEM I

Item I prompts for a 127 character case sensitive string in which the user may place an identification of a run. The string will be printed with all program outputs. The string does not clear when clearing the jets and forces list; the user must input a new string or a blank string when performing a new (different) run.

ITEM C

Item C displays the program results on the screen. Subsequently striking ENTER calls the output control menu.

ITEM J

Item J initiates a looping prompt to enter one or more jet names to add to the jet list shown below the jets and forces item. An illegal name will cause an error message and return to the

jets and forces menu where the current list may be reviewed before resuming jet inputs. Jet name inputs are NOT case sensitive (f1F, f1f, and F1F all result in adding F1F to the jet list). If aerosurface deflection corrections are enabled and an appropriate jet is entered (AFT downfiring PRI jets), the user is prompted to enter force and moment correction data.

This data is found in tables that appear later in this SCP along with instruction for using the tables.

To terminate the jet input loop and return to the jets and forces menu, enter a blank line.

ITEM F

Item F calls a subroutine which is basically the previous ANGACL program with modifications to make it work with JETACCLA. While in the subroutine any number of forces may be input. Each input force will be added to the jet list of the main program.

The input structure is essentially the same as that of the previous ANGACL program. The user is first prompted to enable the printer if he wishes a printout of the force inputs and the calculation results. All forces entered and the results (for this execution of item F) will be printed if the printer is enabled. If maximum precision printout is desired that option must be selected, before entering item F, by going to the output control menu, executing item S, and returning to this menu to enter the force. The printer is disabled when the user terminates input and returns to the jets and forces menu.

Following the printer prompt, there is a prompt for a three character name for the force; characters entered beyond three are truncated. These three characters are an addition to the older ANGACL program; they correspond to the three character jet name of item J inputs and they will appear in the jet list of the main program. This input IS case sensitive; the name will appear exactly as it is entered. The program will not accept a name that is exactly the same as a jet name (with both of the letters in the name capitalized). This feature prevents confusion between jet name inputs under item J, which are always capitalized by the program, and a force input that may, deliberately or inadvertently, be give the same name. If it is desired to use a jet name, at least one of the letters in the name must be lower case. If the force name contains one or two blanks, the blanks will be treated as valid characters; that is, the blanks will appear in the jet list exactly as they were entered. If no characters are input (or all blanks) the program will insert three dashes as an indicator in the jet list that a force was entered with no name. The dashes are used to indicate that a non-named force has been entered. A name entry of three dashes cannot be distinguished in the program output from a blank name entry.

The next prompt is to enter either a V or an A. Entering a V calls a prompt for a force input in rectangular coordinates: X, Y, and Z vector components in the body frame. Entering an A calls a prompt for a force input in polar coordinates: Rho, Gamma, and Force in the body frame, where Force is the force magnitude, and Rho and Gamma are two angle giving the direction of the force. Rho and Gamma correspond, respectively, to pitch and yaw as defined by Universal Pointing.

The next prompt is to enter the location of the force in the structural frame in units of inches. The input data is then displayed for verification with a Y or N (Yes or No) prompt for correct data. N returns to the V or A input to reenter the data; Y calls a Y or N prompt for another force. Y returns to the V or A prompt: N displays (and prints, if the printer was enabled) the results of all the forces that have been entered for this execution of item F.

Striking ENTER returns to the jets and forces menu where more jets and forces may be entered by the J or the F items.

ITEM A

Item A toggles the program between aerosurface deflection correction inputs enabled and disabled. While enabled, entry of an appropriate jet under item J is followed by sequential prompts for input of force and moment corrections for aerosurface deflections. The force and moment corrections are found in tables that appear later in this SCP along with instructions for using the tables. If, after entering a jet name, the user discovers that aerosurface deflection corrections has been inadvertently enabled, zeros may be entered for all deflection data parameters. While aerosurface deflection corrections is disabled, there will be no prompt to enter correction data. Because the aerosurface correction capability is seldom used, the program defaults to disabled. The item A line indicates whether aerosurface deflection correction is enabled or disabled.

ITEM L

Item L clears the jet (and force) list. No provision has been made to delete only one jet or force from the list. If a mistake is made, the entire list must be cleared. Item L does not clear RUN ID. If a new case (different jets and forces) is desired the RUN ID must be changed by Item R or it will indicate the previous case..

ITEM Q

Item Q terminates the program.

JET LIST LIMIT

The string that stores the jet list is limited to 57 jets/forces. This is enough for all 44 jets plus 13 forces. Although there is little reason to enter any single jet more than once, there is nothing in the program to prevent it, and there is no limit to how many forces may be input. 57 is considerably more than needed for most practical cases, however, any number of jets and forces may be input. Jets and forces in excess of 57 will not appear in the jet list but the program output data will reflect all inputs. When the 57th jet/force is input, a message is displayed indicating that any further jets/forces will not be listed. The message suggests manually tracking any further jets/forces or breaking the case into two or more runs, each consisting of 57 or fewer jets/forces, and then manually adding the results of the separate runs. If more than 57 jets/forces are entered the jet list will end with a comma; there is no other indication in the program output that there are jets/forces that do not appear in the list.

OUTPUT CONTROL MENU

Refer to the onscreen menu or Figure 7.4-3 for the following input description. This menu controls the output of the program. It also provides for calling the local acceleration calculations, for returning to the jets and forces menu to add jets/forces or to run a new case, and for returning to the mass properties menu to change mass properties. Returning to the mass properties menu clears the jet list, but it does not clear the RUN ID. It is mandatory to clear the jet list when changing mass properties because the accumulated accelerations are calculated as the jets (and forces) are added to the list. Simply changing mass properties cannot update this accumulation; failure to clear the jet list could result in a program output showing accelerations and mass properties that do not match.

ITEM D

Item D displays the program results on the screen.

ITEM P

Item P prints the program results and displays them on the screen.

ITEM J

Item J returns to the jets and forces menu where more jets/forces may be added to the list.

ITEM M

Item M returns to the mass properties menu. The jet list is cleared when the mass properties menu is called; run id is not cleared.

ITEM W

In addition to the accumulation of corrected accelerations and forces/torques, the program maintains an accumulation of accelerations and forces/torques without correction for plume impingement effects. Item W toggles between output of both uncorrected and corrected outputs and corrected output only. Because the uncorrected data is of little practical use, the program initializes to corrected output only. The item line indicate whether the uncorrected output is enabled with YES or NO.

ITEM R

Item are toggles between RCS data output enabled and disabled. If enabled a prompt follows the display of results to enter a number of jets for which data is to be displayed. A looping prompt for this number jet names follows. Although the jet data is displayed and printed at the bottom of the normal program output, the jets requested do not have to match the jets used for the calculations. The item line indicates if RCS data output is enabled with a YES or NO.

ITEM S

Item S prompts for a DOS path/file name to which to send the printed output rather than actually printing it. This is useful if it is desired to work electronically with the output or if the machine being used cannot print DOS to hardware. In the latter case the saved file can then be read by a windows application (as text) and then it may be printed. The file may have format problems such as unintended line wraps and extraneous characters from FORTRAN carriage control characters, but the data will be there. Any valid DOS path/file name may be used except that PRN (non-case sensitive) is reserved by FORTRAN to select printer hardware. After invoking print to file, the hardware printer may be reinstated by executing item S and entering PRN or prn. The path/file name is given below the item line; remember that PRN is the hardware printer.

ITEM F

The program output formats are defined to show the data to a precision that is appropriate for most practical situations. If the user wishes to see more precision in the outputs he may request full precision by item F. The printed program outputs will then be given in exponential form with 17 places of accuracy. Since the internal calculations are performed only to 16 places, the 17th place is always zero, indicating that there is no more precision available. Since the exponential format does not allow the four parameters to fit on one line, this option wraps the line around to show the third and fourth parameters below the first and second parameters (the ANGACL printout format does not need the wraparound). The full precision option affects only the printed output; the screen output is the same under either option. Item F toggles between the full

precision and the normal precision options. The item line indicates if full precision output is selected with YES or NO.

ITEM L

Item L calls the local acceleration menu.

ITEM Q

Item Q terminates the program

LOCAL ACCELERATIONS MENU

Refer to the onscreen menu or Figure 7.4-4 for the following input description.

ITEM D

Item D displays the results of the local acceleration calculations on the screen. Requesting an output without specifying a location will result in cg accelerations.

ITEM P

Item P prints the results of the local acceleration calculations and displays them on the screen. Requesting an output without specifying a location will result in cg accelerations.

ITEM S

Item S prompts for a location in the structural frame in units of inches. The program calculates the coordinates of this point in the body frame in units of feet from the cg. This item overwrites any previous input under item B.

ITEM B

Item B prompts for a location in the body frame in units of feet from the cg. The program calculates the coordinates of this point in the structural frame in units of inches. This item overwrites any previous input under item S.

ITEM R

Item R prompts for an inertial rate vector input. This item overwrites any rate which may have been calculated by a previous execution of item G.

ITEM G

Item G provides for the calculation gravity gradient force, orb rate, and transformation of an input drag value from the LVLH frame into the body frame. The required inputs are grouped under item G because the calculation of gravity gradient and orb rate require attitude and altitude and transforming aero drag into the body frame requires attitude. The item displays a description of the input parameters with the prompt.

Item G prompts for the following 6 input values: LVLH pitch, yaw, and roll attitude, altitude in nautical miles, a numerical flag indicating whether orb rate is to be calculated based on altitude, and a scalar value for drag in microgs.

An input value of zero for the orb rate flag prevents the calculation of orb rate; a previously entered rate (item R) or an orb rate calculated from a previously entered altitude will be retained. An input of any non-zero value will cause orb rate calculated from the altitude. The orb rate calculated is for a circular orbit. For elliptical orbits that the orbiter can reach, the error is insignificant, at least for our purposes. The best altitude to use for elliptical orbits is the average (half the sum of perigee altitude and apogee altitude). This results in an average orb rate where the vehicle completes one full (inertial) revolution in one orbit (inertial) revolution. A slightly improved, but still not completely correct, orb rate can be calculated at or near perigee or apogee by entering that altitude instead of the average altitude. It is still not correct because the velocity of a vehicle (and consequently its orb rate) at a given perigee is higher than the velocity of a vehicle in a circular orbit at that altitude and the velocity of a vehicle at apogee is lower the velocity of a vehicle at that altitude. For most applications, the average orb ate is close enough and in many cases it really is the desired value.

GG calculations are based on the approximation of a radially uniform earth mass distribution in empty space. Earth oblateness, gravity anomalies due to "lumps" in the earth, and the gravitaional influence of other celestial bodies is ignored. The error due to this approximation is insignificant for our application. Just as for calculating orb rate, the average altitude is good enough for most practical applications. However, if the very best GG calculation is desired, the actual altitude of the orbital point of interest can be used, keeping in mind the effect that this choice of altitude will have on the calculation of orb rate. GG is dependent only on altitude; orbit ellipticity is not a factor. A negative value for altitude cancels GG and orb rate calculations; this option allows for attitude to be used for aero drag calculations without getting a GG or orb rate calculation. The inertial rate retains its previous value regardless of the value of the orb rate flag when altitude is negative. Note that if an orb rate calculated by one item G entry is retained when another item G is executed by setting the orb rate flag to 0 or by entering a negative altitude, the orb rate resolution into body coordinates is valid only if the attitudes of the two item G entries is the same.

The aero drag input is a scalar (magnitude) in microgs. The program treats it as a vector in the -X LVLH direction. This is not exactly correct for elliptical orbits; the true direction is the negative of the velocity vector, but the error for elliptical orbits that the orbiter can reach is insignificant for our purposes. The program transforms the LVLH vector into the body frame. It is emphasized that the program does not compute aero drag. There is no atmospheric model and there is no vehicle cross section model. It is the user's responsibility to determine what the drag value is from some external source such as FDO.

Table 7.4-IV gives the locations of the three IMUs which are of particular interest for local accelerations.

PROGRAM OUTPUT DESCRIPTION

The printed outputs will be described. The screen output is essentially the same except that in some cases there will be screen overflow and in other cases items are left out of the screen output to prevent overflow; these cases will be identified.

Main JETACCLA Results

Figure 7.4-5 is a typical printed output of the main JETACCLA results with all data content options active. Figure 7.4-6 is the same printed output in maximum precision format. The data is from a sample case. At the top of the page is the program title and the mass properties used for the calculations; these items do not appear on the screen display because they would frequently cause screen overflow and their inclusion is not important for the purpose of the screen display. RUN ID is printed below mass properties if an ID has been entered; if the ID is blank this line is not printed.

The JETS, FORCES of the case are listed below RUN ID. Aerosurface plume impingement corrections are listed next. This line is neither printed nor displayed on the screen if no corrections are entered. The uncompensated (for plume impingement effects) linear accelerations and forces and the angular accelerations and torques are printed next. If the user has not enabled the "uncompensated outputs" via the output control menu, this data is not printed. The compensated results are then printed.

Requested RCS data is printed next. Finally, if either an input for aerosurface deflection plume impingement correction has been made or if a request has been made for RCS data of any jet which has nominal plume impingement corrections, the reference CG is printed. Depending on how many of the data options, how many aerosurface deflection plume impingement corrections have been entered, and how many jets for RCS data have been made, the screen may overflow. The printed page has more lines than the screen, but it is still possible to overflow the page. This is not a real problem because the data simply continues on the next page.

Note that line wrap is used for the maximum precision printout because the format does not fit on a single line.

Local Acceleration Results

Figure 7.4-7 is a typical printed output of local accelerations using an extension of the above sample case. Figure 7.4-8 is the same printed output in maximum precision format. The program title is printed at the top of the page followed by RUN ID, unless RUN ID is blank. Jets and forces are printed next. If no jets or forces are entered via the Jets and Forces menu this line will not be printed. Attitude and altitude are printed next. If no GG (Item G) has been entered or if GG calculation has been canceled by a negative altitude and there is a zero entry for aerodrag this line will not be printed.

The next data line contains the inertial rate; it is not printed if the rate is zero. The next line is angular acceleration as calculated by the main program; it is not printed if it is zero. The next data output is the location of interest printed in both body frame and structural frame; it is always printed even if it is at the CG because no location of interest has been entered. The next data output is the linear acceleration at the point of interest in both ft/sec² and micros. This is the primary result of the local acceleration calculation. The individual components of the local acceleration are listed below the primary results.

The components are the CG linear acceleration (from the main JETACCLA computations), the linear acceleration at the point of interest due to the angular acceleration, the linear acceleration

at the point of interest due to angular rate, the linear acceleration at the point of interest due to gravity gradient, and the linear acceleration due to aerodrag. Any component which is zero is not printed. If all components are present the screen will overflow down to the attitude line.

Note that line wrap is used for the maximum precision printout because the format does not fit on a single line.

Printout of Force Inputs

Figure 7.4-9 is a typical printed output of the forces input. Figure 7.4-10 is the same printed output in maximum precision format. The program title is printed at the top of the page. RUN ID is printed next, unless it is blank.

Next, each input force and location is printed along with its user supplied three character name (to be used in the jets and forces list). The force vector is printed in both rectangular and spherical coordinates. The word "Input" appears at the beginning of the line displaying the vector as it was entered.

The mass properties used for the calculations are printed below the input forces.

The linear accelerations and forces and the angular accelerations and torques resulting from the combined input forces are printed next along with the spherical coordinates equivalent of the combined force (Rho, Gamma, Force (Magnitude)). To prevent overflow input forces are not displayed on the screen. The printed page has more lines available than the screen, but multiple forces can still cause page overflow. This is not a real problem because the data simply continues on the next page.

Note that line wrap is used for input forces on the maximum precision printout because there is not enough space on a single line. No line wrap is necessary for the results portion of the printout because the original layout provided ample space.

Plume Impingement corrections

Within the program, force and moment corrections are made to compensate for plume impingement using the data in table 7.4-I (assumes zero surface deflection). This feature requires no user input. Table 7.4-I is provided only for the user reference to the source data. Additional plume impingement corrections may be made based on non-zero aerosurface deflections (see table 7.4-II). The total increment of force and moment due to aerosurface deflections must be entered into the program. The increment d is obtained by adding the individual components from each aerosurface. For example, the total change in F_x due to a particular configuration of the aerosurfaces is obtained as follows from table 7.4-II.

$$DF_x (\text{tot}) = DF_x (\text{INBD ELV}) + DF_x (\text{OTBD ELV}) + DF_x (\text{BF})$$

The procedure is similar for the other components. Note that table 7.4-II gives the aerosurface impingement increments for a primary left-hand down-firing jet. To obtain aerosurface impingement increments for a primary right-hand down-firing jet, the sign must be changed for the values in the columns DFy, DMx, DMz. If the user chooses not to input plume impingement increments due to aerosurface deflections, the program will assume all aerosurfaces are at zero degrees. All plume impingement correction data is based on a reference CG. The program corrects for the difference between the reference CG and the actual CG.

The program also provides the option of printing out the uncorrected RCS data and the correction data, if any, for zero aerosurface deflection for any particular jet. This data is from tables 7.4-I and 7.4-III. The RCS data is printed at the bottom of a normal JETACCLA output, but it is not related to the jet list unless the user makes it so by asking for the list jets only.

Force Input Data Source

Engines

Tables 7.4-V, 7.4-VI, 7.4-VII, and 7.4-VIII contain data for OMS, SSME, and SRB engines.

ON-ORBIT Venting

The forces and moments produced by the on-orbit venting of effluents can reduce navigation and pointing accuracies and affect the rate of RCS propellant consumption required to maintain attitude. There are three categories of on-orbit venting. They are scheduled, contingency, and failure. See figure 7.4-13 for an overview of venting locations.

A. SCHEDULED VENTING

See Table 7.4-IX for scheduled venting data.

1. Thrust due to airlock depressurization
2. Flash evaporator in the full-up mode of operation
 - a. High-load nozzle
 - b. Impingement forces and moments
 - c. Topping nozzle
3. Flash evaporator in the topping mode of operation
4. FCP purge thrust
5. Hydraulics water-boiler thrust
 - a. WSB nozzle thrust vs. water flow rate (single WSB)
 - b. Steady-state WSB nozzle thrust force (one nozzle) vs. percent of full APU power
 - c. APU/hydraulic water boiler steam flowrate vs. percent APU shaft horsepower
 - d. WSB thrust force vs. time (single nozzle)
6. APU thrust
7. MPS liquid hydrogen propellant dumping thrust, forces and moments due to impingement

B. CONTINGENCY VENTING

See Table 7.4-X for contingency venting data.

1. APU/WSB, AOA on-orbit thrust

C. FAILURE VENTING

See Table 7.4-XI for failure venting data.

1. RCS thrust
2. FCP reactant regulator relief thrust

```
UNCERTIFIED JETACCLA PROGRAM, GNC SCP 7.4, VERSION 6.0, 4/21/00
CURRENT ORB MASS PROP (DEFAULT IS STS-96, DAY 3)

CURRENT INERTIAS(SLUG-FTSQ), CG(INCHES), AND WEIGHT(LBS):
I[XX]o = 947269.30          [X]o CG = 1091.60
I[YY]o = 7712236.30       [Y]o CG = -.50
I[ZZ]o = 8017282.40       [Z]o CG = 373.60
I[XY]o = 100.10
I[XZ]o = 262441.80       [W]EIGHT = 236747.00
I[YZ]o = -3165.70

MISCELLANEOUS COMMANDS:
[D]EFAULT MASS PROPERTIES
[A]LL INERTIAS, CGs, & WEIGHT
WRITE MASS PROPERTIES [T]O A FILE
READ MASS PROPERTIES [F]ROM A FILE
INPUT [C]OMplete
[Q]UIT JETACCLA

ENTER BRACKETED CHARACTER(S) TO MAKE A SELECTION:
```

Figure 7.4-1 Mass Properties Menu

```
RUN [I].D.:
(127 characters available for user specified label to be printed out
with data for run identification.)

INPUT [C]OMplete

ENTER [J]ETS or [F]ORCES to add to the list shown below:

JETS, FORCES:

MISCELLANEOUS COMMANDS:
[A]EROSURFACE DEFLECTION CORRECTION DISABLED (TOGGLE)
C[L]EAR JET LIST
[Q]UIT JETACCLA

ENTER BRACKETED CHARACTER TO MAKE A SELECTION:
```

Figure 7.4-2 Jets and Forces Menu

```
      DISPLAY RESULTS:
[D]ISPLAY ONLY
DISPLAY AND [P]RINT

      MODIFY INPUTS:
RETURN TO [J]ETS AND FORCES MENU
RETURN TO [M]ASS PROPERTIES MENU

      OUTPUT PARAMETERS:
OUTPUT [W]ITHOUT PLUME IMPINGEMENT CORRECTIONS: NO
[R]CS DATA PRINTED OUT: NO
OUTPUT IN [F]LOATING POINT FULL PRECISION: NO
[S]END PRINTOUT TO AN ASCII FILE (NOTE: PRN = PRINTER)
  FILENAME IS PRN

      MISCELLANEOUS COMMANDS:
COMPUTE [L]OCAL ACCELERATIONS
[Q]UIT JETACCLA

ENTER BRACKETTED CHARACTER TO MAKE A SELECTION:
```

Figure 7.4-3 Output Control Menu

```
      OUTPUTS:
COMPUTE LOCAL ACCELERATIONS - [D]ISPLAY ONLY.
COMPUTE LOCAL ACCELERATIONS - DISPLAY AND [P]RINT.

      INPUTS:
NEW LOCATION - [S]TRUCTURAL COORDINATES.
NEW LOCATION - [B]ODY COORDINATES FROM CG.
INERTIAL [R]ATE VECTOR - BODY COORDINATES.
[G]G AND AERODRAG.

      MISC:
RETURN TO [J]ETACC.

ENTER BRACKETTED CHARACTER TO MAKE A SELECTION:
```

Figure 7.4-4 Local Acceleration Menu

JETACCLA PROGRAM, GNC SCP 7.4, VERSION 1.0, 8/9/00

INERTIAS(SLUG-FTSQ), CG (INCHES), AND WEIGHT (LBS)

IXXo =	947269.30	Xo CG =	1091.60
IYYo =	7712236.30	Yo CG =	-.50
IZZo =	8017282.40	Zo CG =	373.60
IXYo =	100.10		
IXZo =	262441.80	WEIGHT =	236747.00
IYZo =	-3165.70		

RUN I.D.: JETACCLAS Major Test Case
JETS, FORCES: F1F, R2D, F1, F2

JET(ASDEF)	FXb	FYb	FZb	MXb	MYb	MZb
R2D	37.30	.50	-13.60	-106.80	-308.30	-489.10

WITHOUT PLUME IMPINGEMENT CORRECTIONS

	Xb	Yb	Zb	MAGNITUDE
LIN ACC (ft/sec sq)	-.096734	-.031017	-.097941	.141110
FORCES (lbs)	-711.80	-228.24	-720.68	1038.33

	ROLL(Xb)	PITCH(Yb)	YAW(Zb)	MAGNITUDE
ANG ACC (deg/sec sq)	-.502876	-.254298	.059113	.566609
TORQUES (ft-lbs)	-8585.24	-34233.59	10589.04	36847.97

WITH PLUME IMPINGEMENT CORRECTIONS

	Xb	Yb	Zb	MAGNITUDE
LIN ACC (ft/sec sq)	-.088200	-.032757	-.070843	.117775
FORCES (lbs)	-649.00	-241.04	-521.28	866.62

	ROLL(Xb)	PITCH(Yb)	YAW(Zb)	MAGNITUDE
ANG ACC (deg/sec sq)	-.401467	-.199049	.060787	.452207
TORQUES (ft-lbs)	-6916.22	-26796.80	10355.73	29549.01

JET	FXb	FYb	FZb	Xo/MXb	Yo/MYb	Zo/MZb
F1F	-875.10	26.20	148.00	306.72	-14.65	392.96
R2D	170.40	-291.80	-801.70	1529.00	111.00	440.00
IMPG	25.50	-13.30	213.00	1769.00	8000.00	274.30

REFERENCE CG Xo = 1076.70 Yo = .00 Zo = 375.00

Figure 7.4-5 Main JETACCLA Printout (Normal Precision)

JETACCLA PROGRAM, GNC SCP 7.4, VERSION 1.0, 8/9/00

INERTIAS(SLUG-FTSQ), CG (INCHES), AND WEIGHT (LBS)

IXXo = .947269300000000000D+06 Xo CG = .109160000000000000D+04
IYYo = .771223630000000000D+07 Yo CG = -.500000000000000000D+00
IZZo = .801728240000000000D+07 Zo CG = .373600000000000000D+03
IXYo = .100100000000000000D+03
IXZo = .262441800000000000D+06 WEIGHT = .236747000000000000D+06
IYZo = -.316570000000000000D+04

RUN I.D.: JETACCLAS Major Test Case
JETS, FORCES: F1F, R2D, F1, F2

JET(ASDEF) FXb/MXb FYb/MXb FZb/MZb
R2D .373000000000000000D+02 .500000000000000000D+00 -.136000000000000000D+02
 -.106800000000000000D+03 -.308300000000000000D+03 -.489100000000000000D+03

WITHOUT PLUME IMPINGEMENT CORRECTIONS

	Xb/Zb	Yb/MAGNITUDE
LIN ACC (ft/sec sq)	-.96734151508082870D-01	-.31017287802845100D-01
	-.97941440917652390D-01	.14111021954365760D+00
FORCES (lbs)	-.71180100716628350D+03	-.22823518223330700D+03
	-.72068463103929550D+03	.10383343920087840D+04

	ROLL(Xb)/PITCH(Yb)	YAW(Zb)/MAGNITUDE
ANG ACC (deg/sec sq)	-.50287555865863180D+00	-.25429753883068830D+00
	.59113110557359700D-01	.56660870589088460D+00
TORQUES (ft-lbs)	-.85852359273210640D+04	-.34233589260101650D+05
	.10589036444670380D+05	.36847966054908230D+05

WITH PLUME IMPINGEMENT CORRECTIONS

	Xb/Zb	Yb/MAGNITUDE
LIN ACC (ft/sec sq)	-.88199596690730050D-01	-.32756814899375620D-01
	-.70842870367012980D-01	.11777474288062280D+00
FORCES (lbs)	-.64900100716628360D+03	-.24103518223330700D+03
	-.52128463103929550D+03	.86662444745972200D+03

	ROLL(Xb)/PITCH(Yb)	YAW(Zb)/MAGNITUDE
ANG ACC (deg/sec sq)	-.40146689057617680D+00	-.19904877238850690D+00
	.60787131181716260D-01	.45220698063561420D+00
TORQUES (ft-lbs)	-.69162209273210650D+04	-.26796804260101640D+05
	.10355726444670380D+05	.29549008454879850D+05

JET	FXb	FYb	FZb	Xo/MXb	Yo/MYb	Zo/MZb
F1F	-875.10	26.20	148.00	306.72	-14.65	392.96
R2D	170.40	-291.80	-801.70	1529.00	111.00	440.00
IMPG	25.50	-13.30	213.00	1769.00	8000.00	274.30

REFERENCE CG Xo = 1076.70 Yo = .00 Zo = 375.00

Figure 7.4-6 Main JETACCLA Printout (Maximum Precision)

JETACCLA PROGRAM, GNC SCP 7.4, VERSION 1.0, 8/9/00

RUN I.D.: JETACCLAS Major Test Case
 JETS, FORCES: F1F, R2D, F1, F2
 Attitude and altitude for GG and/or drag computations:
 PITCH = 33.00 YAW = 315.00 Roll = 156.00 ALTITUDE = 160.00000 NMI

	X	Y	Z	MAGNITUDE	
INRTL RATE	.046909	.042853	.019079	.066339	DEG/SEC
ANG ACC	-.401467	-.199049	.060787	.452207	DEG/SEC2
Location	491.60	-120.50	313.60		INCHES, STR
	50.00	-10.00	5.00	51.23	FT, BODY FROM CG
LOC ACC	-.0994418	.0578433	.1784311	.2123021	FT/SEC2
	-3090.75	1797.82	5545.81	6598.55	MICROGs
COMPONENTS OF LOCAL ACCELERATION DUE TO:					
CG ACC-JETS	-.0881996	-.0327568	-.0708429	.1177747	FT/SEC2
	-2741.33	-1018.11	-2201.86	3660.55	MICROGs
ANG ACC	-.0067609	.0880814	.2437720	.2592852	FT/SEC2
	-210.14	2737.65	7576.67	8058.83	MICROGs
INRTL RATE	-.0000383	.0000397	.0000050	.0000554	FT/SEC2
	-1.19	1.23	.16	1.72	MICROGs
GG	.0000218	.0000681	-.0000650	.0000966	FT/SEC2
	.68	2.12	-2.02	3.00	MICROGs
AERODRAG	-.0044648	.0024110	.0055619	.0075287	FT/SEC2
	-138.77	74.93	172.87	234.00	MICROGs

Figure 7.4-7 Local Acceleration Printout (Normal Precision)

```

JETS, FORCES:  F1F, R2D,  t1,  t2
Attitude and altitude for GG and/or drag computations:
PITCH = .3300000000000000D+02      YAW = .3150000000000000D+03
Roll = .1560000000000000D+03  ALTITUDE = .1600000000000000D+03 NMI

                X/Z                Y/MAGNITUDE
INRTL RATE .46908622669669250D-01 .42853159164147060D-01
          .19079455715970650D-01 .66338810371688260D-01 DEG/SEC

ANG ACC    -.40146689057617680D+00-.19904877238850690D+00
          .60787131181716250D-01 .45220698063561410D+00 DEG/SEC2

Location   .4915999999999999D+03-.1205000000000000D+03
          .3136000000000000D+03                INCHES, STR

          .5000000000000000D+02-.1000000000000000D+02
          .5000000000000000D+01 .51234753829798000D+02 FT, BODY FROM CG

LOC ACC    -.99441804734402980D-01 .57843255455884960D-01
          .17843109710394220D+00 .21230207522369240D+00 FT/SEC2

          -.30907457779207000D+04 .17978233405855960D+04
          .55458080381457050D+04 .65985502213479060D+04 MICROGs

COMPONENTS OF LOCAL ACCELERATION DUE TO:
CG ACC-JETS-.88199596690730050D-01-.32756814899375620D-01
          -.70842870367012980D-01 .11777474288062280D+00 FT/SEC2

          -.27413272698969090D+04-.10181129316667450D+04
          -.22018637238879290D+04 .36605509149417810D+04 MICROGs

ANG ACC    -.67609264315345100D-02 .88081374489623420D-01
          .24377201329459190D+00 .25928523506727610D+00 FT/SEC2

          -.21013601753215610D+03 .27376528115551400D+04
          .75766657984318420D+04 .80588314713491110D+04 MICROGs

INRTL RATE-.38274513459360070D-04 .39673876452044330D-04
          .49924782389050900D-05 .55352323277788020D-04 FT/SEC2

          -.11896082456713500D+01 .12331017771189050D+01
          .15517096737604290D+00 .17204028016774120D+01 MICROGs

GG         .21751422071652410D-04 .68060837945606590D-04
          -.64956439803252990D-04 .96564699015276370D-04 FT/SEC2

          .67605486556975690D+00 .21153955128225120D+01
          -.20189078688473140D+01 .30013225984261940D+01 MICROGs

AERODRAG  -.44647585207507070D-02 .24109611512395170D-02
          .55619181379275870D-02 .75287273622047230D-02 FT/SEC2

          -.13876893711153310D+03 .74934963407259840D+02
          .17286970050326350D+03 .2340000000000000D+03 MICROGs
    
```

Figure 7.4-8 Local Acceleration Printout (Maximum Precision)

JETACCLA PROGRAM, GNC SCP 7.4, VERSION 1.0, 8/9/00
RUN I.D.: JETACCLA Major Test Case

*** Force Number 1 FORCE NAME (for JETACCLA): F1
Input Force Vector FXb = 10.00 FYb = 20.00 FZb = 30.00
Force Vector RHO = -71.57 GAMMA = 32.31 Force = 37.42
Location Xo = 1000.00 Yo = 100.00 Zo = 500.00

*** Force Number 2 FORCE NAME (for JETACCLA): F2
Force Vector FXb = -17.10 FYb = 17.36 FZb = -96.98
Input Force Vector RHO = 100.00 GAMMA = 10.00 Force = 100.00
Location Xo = 500.00 Yo = -50.00 Zo = 200.00

Current Inertias (slug-ft2): Current C.G.s (inches):
IXXo = 947269.30 Xo = 1091.60
IYYo = 7712236.30 Yo = -0.50
IZZo = 8017282.40 Zo = 373.60

IXYo = 100.10 WGT = 236747.00
IXZo = 262441.80
IYZo = -3165.70

For a Force Vector (lbf): with RHO, GAMMA(deg) and force (lbf):
FXb = -7.10 RHO = 96.051
FYb = 37.36 GAMMA = 29.017
FZb = -66.98 FORCE = 77.029

The ang accls (deg/sec2) are: The translational accls (ft/sec2) are:
AXb = .038988 Xb = -0.00965
AYb = .031202 Yb = .005078
AZb = .007395 Zb = -0.009103

The vehicle torques (ft-lbs) are:
TXb = 610.77
TYb = 4199.61
TZb = 854.46

Figure 7.4- 9 Input Force Printout (Normal Precision)

JETACCLA PROGRAM, GNC SCP 7.4, VERSION 1.0, 8/9/00

RUN I.D.: JETACCLA Major Test Case

```
*** Force Number 1      FORCE NAME (for JETACCLA):  F1
Input Force Vector FXb = .1000000000000000D+02  FYb = .2000000000000000D+02
                      FZb = .3000000000000000D+02
Force Vector RHO = -.71565051177077990D+02  GAMMA = .32311533237423850D+02
Force = .37416573867739420D+02
Location Xo = .1000000000000000D+04  Yo = .1000000000000000D+03
      Zo = .5000000000000000D+03

*** Force Number 2      FORCE NAME (for JETACCLA):  F2
Force Vector FXb = -.17101007166283430D+02  FYb = .17364817766693030D+02
                      FZb = -.96984631039295420D+02
Input Force Vector RHO = .1000000000000000D+03  GAMMA = .1000000000000000D+02
Force = .1000000000000000D+03
Location Xo = .5000000000000000D+03  Yo = -.5000000000000000D+02
      Zo = .2000000000000000D+03
```

```
Current Inertias (slug-ft2):          Current C.G.s (inches):
IXXo = .9472693000000000D+06          Xo = .1091600000000000D+04
IYYo = .7712236300000000D+07          Yo = -.5000000000000000D+00
IZZo = .8017282400000000D+07          Zo = .3736000000000000D+03
IXYo = .1001000000000000D+03          WGT = .2367470000000000D+06
IXZo = .2624418000000000D+06
IYZo = -.3165700000000000D+04
```

```
For a Force Vector (lbf):          with RHO, GAMMA(deg) and force (lbf):
FXb = -.71010071662834310D+01          RHO = .96051296223202740D+02
FYb = .37364817766693040D+02          GAMMA = .29017290933819900D+02
FZb = -.66984631039295420D+02          FORCE = .77029180866632150D+02
```

```
The ang accls (deg/sec2) are:      The translational accls (ft/sec2) are:
AXb = .38987877032144110D-01          Xb = -.96503081081307720D-03
AYb = .31202323085626310D-01          Yb = .50778994501630700D-02
AZb = .73950005597681590D-02          Zb = -.91032484956213540D-02
```

```
The vehicle torques (ft-lbs) are:
TXb = .61076723934560100D+03
TYb = .41996144065650310D+04
TZb = .85446052800371380D+03
```

Figure 7.4-10 Input Force Printout (Maximum Precision)

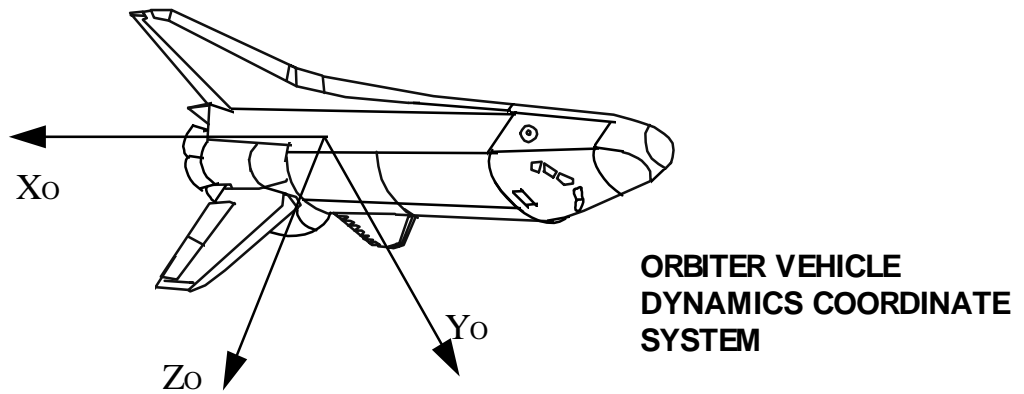
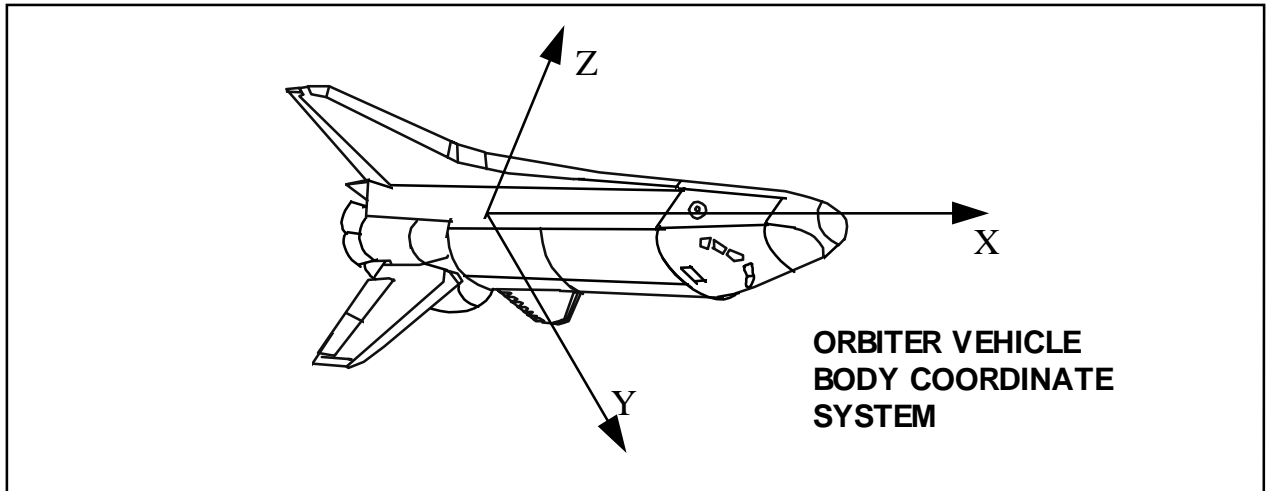


Figure 7.4-11 - Orbiter Coordinate Systems

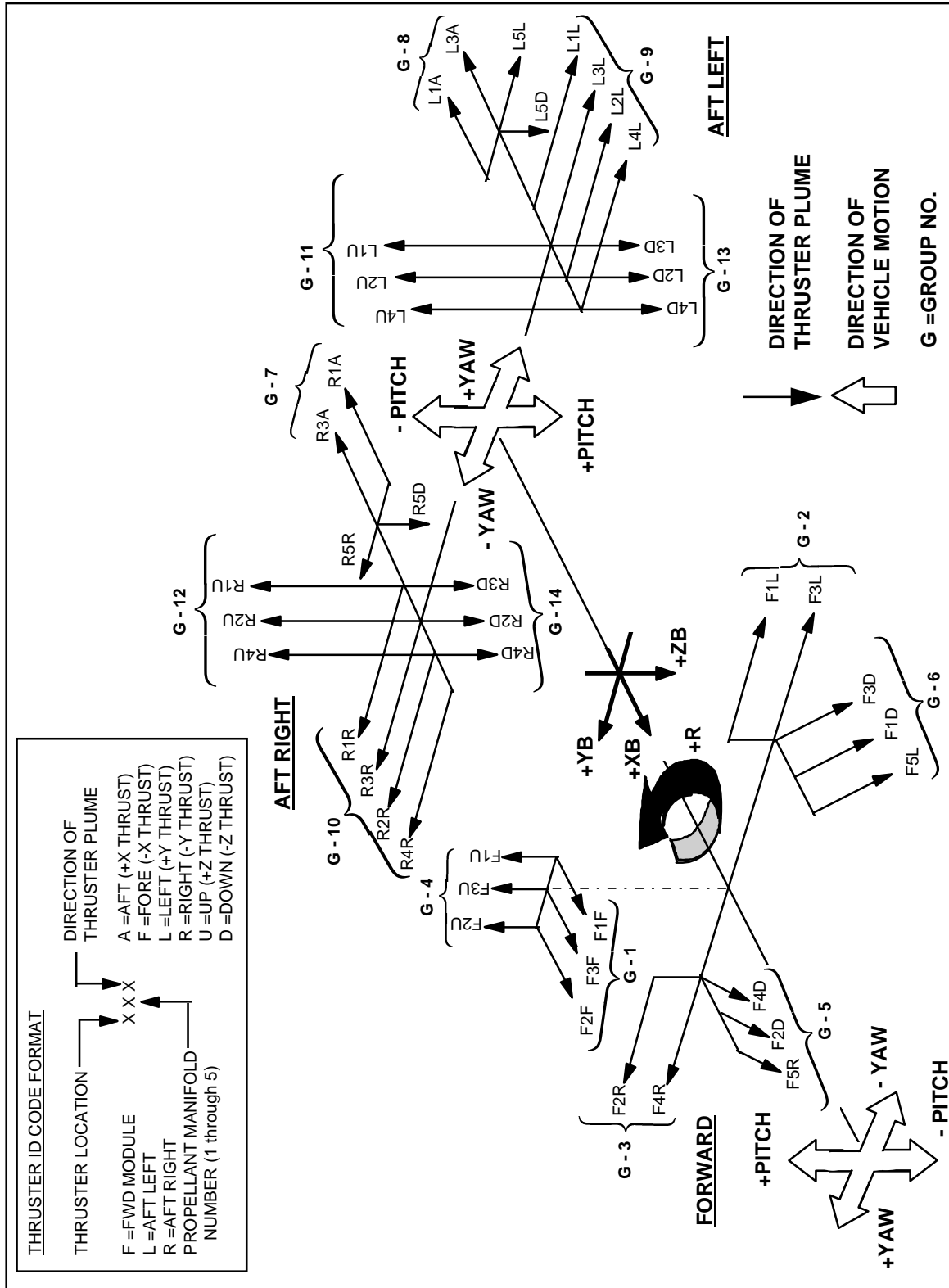


Figure 7.4-12. - RCS Jet locations and plume directions.

TABLE 7.4-I. - ON-ORBIT PLUME IMPINGEMENT FORCES AND MOMENTS

(a) Primary jets *

	FORCES (LB)			MOMENTS (FT-LB)		
	F_x	F_y (a)	F_z	M_x (a)	M_y	M_z (a)
Down jet	25.5	13.3	213.0	-1769.0	8000.0	-274.3
Up jet	0.0	39.3	1.1	983.0	57.4	-1537.0
Side jet	1.3	-0.7	10.7	-319.2	295.0	57.3

^a These forces and moments are for left-hand jets; for right-hand jets, change the sign of F_y , M_x and M_z .

(b) Vernier jets **

	FORCES (LB)			MOMENTS (FT-LB)		
	F_x	F_y (a)	F_z	M_x (b)	M_y	M_z (b)
L5D	3.91	4.35	10.93	-92.64	435.29	-170.40

^b These forces and moments are for L5D only; for R5D, change the sign of F_y , M_x and M_z .

Note: The reference cg for the Moments is $X_0 = 1076.7$, $Y_0 = 0.0$, $Z_0 = 375.0$. The program corrects for actual cg.

*Source: JSC-22078, "Addendum to Flight Assessment Package Orbiter Aerodynamics FAD26," April, 1986.

**Source: Engineering Analysis Division Memorandum EX32/8202-24, "Vernier RCS On-Orbit Plume Impingement Values," 2/10/82.

TABLE 7.4-II. -PLUME IMPINGEMENT INCREMENTS

(PRIMARY DOWN-FIRING JETS)

(a) Inboard Elevon

Elev defl (deg)	Forces (lb)			Moments (ft-lb)		
	DF _x	DF _y (c)	DF _z	DM _x (c)	DM _y	DM _z (c)
-35	-11.4	4.5	-74.6	1091.8	-2480.2	-316.6
-30	-14.0	4.1	-67.3	990.4	-2255.8	-338.8
-25	-16.3	3.4	-56.9	844.7	-1928.9	-350.8
-20	-17.3	2.7	-44.4	665.5	-1527.6	-340.5
-15	-16.0	1.9	-31.6	479.6	-1108.7	-299.5
-10	-12.6	1.2	-19.4	297.6	-697.0	-227.0
-5	-7.1	0.5	-8.1	127.4	-302.2	-124.0
0	0.0	0.0	0.0	0.0	0.0	0.0
5	7.8	-0.3	3.4	-64.4	150.8	128.4
10	16.2	-0.5	5.9	-108.8	286.9	267.4
15	23.7	-0.6	3.6	-86.4	263.6	386.8
20	29.7	-0.4	-1.9	-13.5	128.5	479.8

^c These values are for a left-hand down-firing jet; for a right-hand down-firing jet, change the sign of DF_y, DM_x, and DM_z.

(b) Outboard elevon

Elev defl (deg)	Forces (lb)			Moments (ft-lb)		
	DF _x	DF _y (d)	DF _z	DM _x (d)	DM _y	DM _z (d)
-35	-0.3	0.1	-2.2	63.3	-65.4	-13.7
-30	-0.4	0.1	-2.0	58.8	-61.1	-15.0
-25	-0.4	0.1	-1.8	52.5	-55.0	-15.8
-20	-0.4	0.1	-1.5	44.6	-47.2	-15.9
-15	-0.4	0.1	-1.2	35.0	-37.5	-14.7
-10	-0.3	0.1	-0.8	24.0	-26.3	-11.8
-5	-0.2	0.0	-0.4	12.2	-13.5	-7.0
0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.3	0.0	0.4	-11.5	13.1	9.2
10	0.6	-0.1	0.7	-21.3	25.1	20.2
15	1.0	-0.1	1.0	-29.6	36.0	33.0
20	1.5	-0.1	1.2	-34.7	43.4	46.4

^d These values are for a left-hand down-firing jet; for a right-hand down-firing jet, change the sign of DF_y, DM_x, and DM_z. The D of DF_x, etc., refers to the fact that the forces and moments are due to aerosurface Deflections

TABLE 7.4-II. -PLUME IMPINGEMENT INCREMENTS CONTINUED

(c) Body flap

Deflection percent (deg)		Forces (lb)			Moments (ft-lb)		
		DF _x	DF _y (e)	DF _z	DM _x (e)	DM _y	DM _z (e)
0.08	-11.7	-21.5	0.0	8.3	-78.4	188.6	-183.3
19.6	-5.0	-11.9	0.0	6.2	-57.0	171.2	-101.2
34.2	0	0	0.0	0.0	0.0	0.0	0.0
48.9	5	7.7	0.0	-6.7	60.8	-214.7	64.7
63.5	10	14.0	0.0	-15.2	134.4	-510.8	117.3
78.2	15	19.0	0.0	-24.0	211.7	-823.3	157.8
100.3	22.55	26.4	0.0	-38.6	337.4	-1373.9	192.8

- ^e These values are for a left-hand down-firing jet; for a right-hand down-firing jet, change the sign of DF_y, DM_x, and DM_z. Note that since DF_y happens to be zero, in this case, changing signs is trivial.

TABLE 7.4-III. - RCSDAT

Xo, Yo, Zo, and FXb, FYb, FZb, = JET LOC (inch) and JET FORCE X, Y, Z, (lb) can be found in SODB VOL 1 PROP SECTION

JET	X ₀	Y ₀	Z ₀	FX	FY	FZ
F2F	306.72	14.65	392.96	-875.1	-26.2	148.0
F3F	306.72	0.0	394.45	-875.1	0.0	150.9
F1F	306.72	-14.65	392.96	-875.1	26.2	148.0
F1L	362.67	-69.50	373.73	-26.3	873.6	18.2
F3L	364.71	-71.65	359.25	-21.0	870.3	0.5
F2R	362.67	69.50	373.73	-26.3	-873.6	18.2
F4R	364.71	71.65	359.25	-21.0	-870.3	0.5
F2U	350.93	14.39	413.46	-32.3	-11.7	874.4
F3U	350.92	0.0	414.53	-31.9	0.0	873.5
F1U	350.93	-14.39	413.46	-32.3	11.7	874.4
F2D	333.84	61.42	356.95	-28.0	-616.4	-639.5
F1D	333.84	-61.42	356.95	-28.0	616.4	-639.5
F4D	348.44	66.23	358.44	-24.8	-612.6	-639.4
F3D	348.44	-66.23	358.44	-24.8	612.6	-639.4
F5R	324.35	59.70	350.12	-0.8	-17.0	-17.6
F5L	324.35	-59.70	350.12	-0.8	17.0	-17.6
R3A	1555.29	137.00	473.06	356.8	0.0	151.1
R1A	1555.29	124.00	473.06	856.8	0.0	151.1
L3A	1555.29	-137.00	473.06	856.8	0.0	151.1
L1A	1555.29	-124.00	473.06	856.8	0.0	151.1
L4L	1516.00	-149.87	459.00	0.0	870.5	-22.4
L2L	1529.00	-149.87	459.00	0.0	870.5	-22.4
L3L	1542.00	-149.87	459.00	0.0	870.5	-22.4
L1L	1555.00	-149.87	459.00	0.0	870.5	-22.4
R4R	1516.00	149.87	459.00	0.0	-870.5	-22.4
R2R	1529.00	149.87	459.00	0.0	-870.5	-22.4
R3R	1542.00	149.87	459.00	0.0	-870.5	-22.4
R1R	1555.00	149.87	459.00	0.0	-870.5	-22.4
L4U	1516.00	-132.00	480.50	0.0	0.0	870.0
L2U	1529.00	-132.00	480.50	0.0	0.0	870.0
L1U	1542.00	-132.00	480.50	0.0	0.0	870.0
R4U	1516.00	132.00	480.50	0.0	0.0	870.0
R2U	1529.00	132.00	480.50	0.0	0.0	870.0
R1U	1542.00	132.00	480.50	0.0	0.0	870.0
L4D	1516.00	-111.95	437.40	170.4	291.8	-801.7
L2D	1529.00	-111.00	440.00	170.4	291.8	-801.7
L3D	1542.00	-110.06	442.60	170.4	291.8	-801.7
R4D	1516.00	111.95	437.40	170.4	-291.8	-801.7
R2D	1529.00	111.00	440.00	170.4	-291.8	-801.7
R3D	1542.00	110.06	442.60	170.4	-291.8	-801.7
L5D	1565.00	-118.00	455.44	0.0	0.0	-24.0
R5D	1565.00	118.00	455.44	0.0	0.0	-24.0
L5R	1565.00	-149.87	459.00	0.0	24.0	-0.6

TABLE 7.4-IV.- IMU LOCATIONS-INCHES (FT)
[SODB, VOL I, PARAGRAPH 4.5.1.2.3.B]

IMU	X ₀	Y ₀	Z ₀
1	419.2 (34.9)	-13.75 (-1.2)	422 (35.2)
2	419.2 (34.9)	0.0	422 (35.2)
3	419.2 (34.9)	13.75 (1.2)	422 (35.2)

TABLE 7.4-V.-ORBITAL MANEUVERING SUBSYSTEM (OMS) DATA
[SODB, VOL I, PAR. 4.3.3.4.6, AND SODB, VOL II, FIGURE 4.1-2 TO 8]

	Thrust point location (inch)			Null position (deg)		Null offset (deg)	
	X ₀	Y ₀	Z ₀	Pitch/RHO	Yaw/GAM	Pitch	Yaw
L OMS	1518	-88	492	0/-15.824	0/+6.5	-15.824	+6.5
R OMS	1518	+88	492	0/-15.824	0/-6.5	-15.824	-6.5

- RHO = pitch trim + pitch offset
- GAM = yaw trim + yaw offset
- Approximate thrust force is 6000 lbf/engine
- OMS engine null offset positions are:
 L/R pitch = -15° 49' 28" (-15.824444 deg)
 L yaw = +6° 30' (+6.5 deg)
 R yaw = -6° 30' (-6.5 deg)

TABLE 7.4-VI. - SPACE SHUTTLE MAIN ENGINE (SSME)DATA
[SODB, VOL I, PARAGRAPHS 4.3.1.1.T.1 AND 2]

	Thrust point location (inch)			Null position (deg)		Null offset (deg)	
	X ₀	Y ₀	Z ₀	Pitch/RHO	Yaw/GAM	Pitch	Yaw
SSME 1	1445.00	0	443.0	0/-16	0/0	-16.0	0.0
SSME 2	1468.17	-53	342.64	0/-10	0/+3.5	-10.0	+3.5
SSME 3	1468.17	+53	342.64	0/-10	0/-3.5	-10.0	-3.5

TABLE 7.4-VII. - SPACE SHUTTLE MAIN ENGINE (SSME) DATA

	MPS dump position (deg) (I-load)*		MPS stow position (deg) (I-load)	
	Pitch/RHO	Yaw/GAM	Pitch	Yaw
SSME 1	10.0/-6	0/0	0/-16.0	0/0
SSME 2	10.5/.5	0/+3.5	-10/-20	-3.5/0
SSME 3	10.5/.5	0/-3.5	-10/-20	+3.5/0

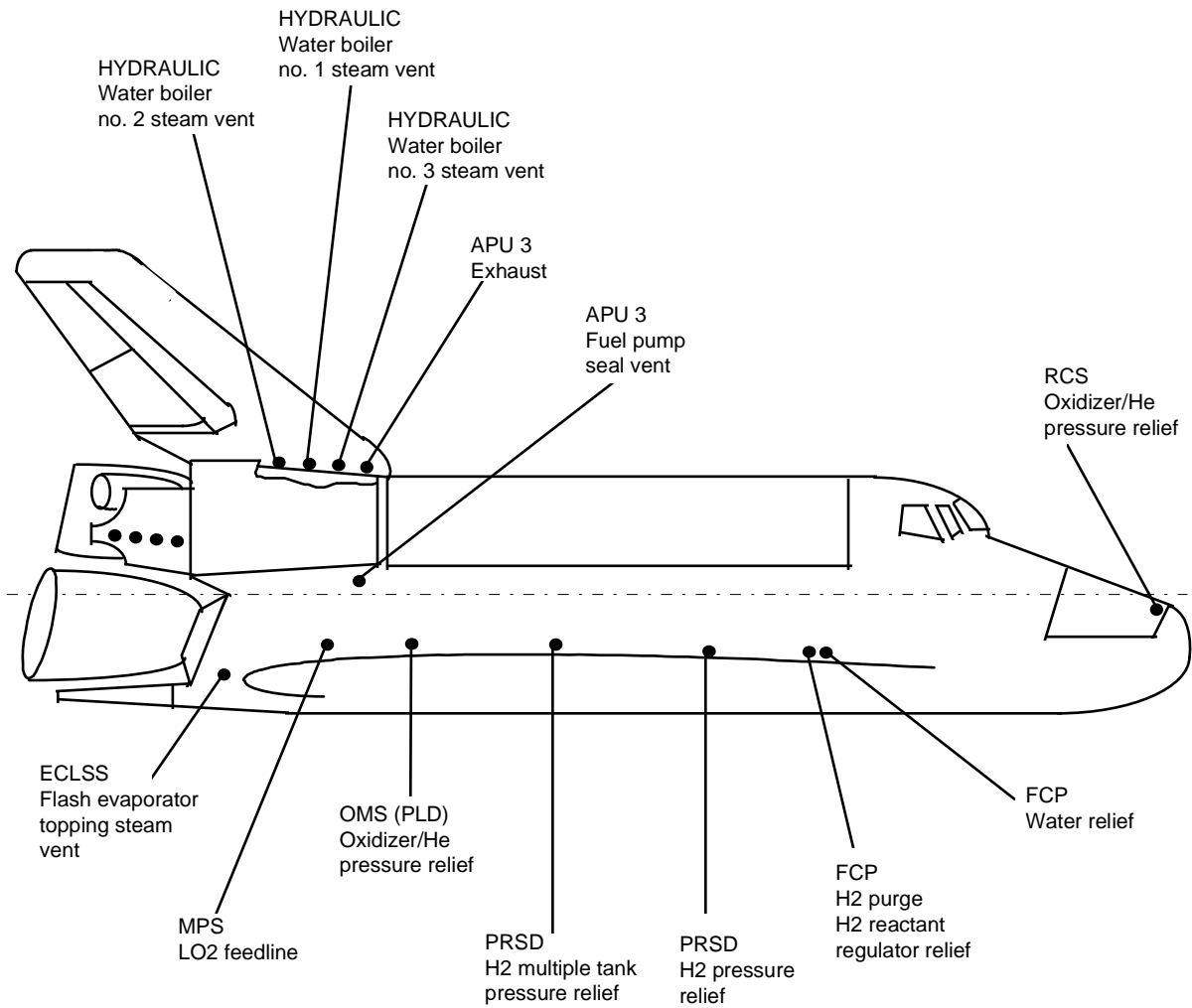
- o RHO = pitch + pitch offset
- GAM = yaw + yaw offset
- Approximate thrust force (LO2) during MPS dump is approximately 700 lbf/engine *
- LH2 dump location for norm mission is:
 - $X_0 = 1453.06$
 - $Y_0 = -116.83$
 - $Z_0 = 392.30$
- Approximate thrust force (100 percent)
During engine burn is
 - (a) Sea level $375,000 \pm 6,000$ lbf
 - (b) Vacuum $470,000 \pm 6,000$ lbf

*For detailed information on MPS dumps, refer to SODB Vol. 1.

TABLE 7.4-VIII.- SOLID ROCKET BOOSTER ENGINE (SRB) DATA
[SODB, VOL I, FIGURE 2-1]

	Thrust point location (inch)		
	X_0	Y_0	Z_0
L SRB	1671.0	-250.5	63.5
R SRB	1671.0	+250.5	63.5

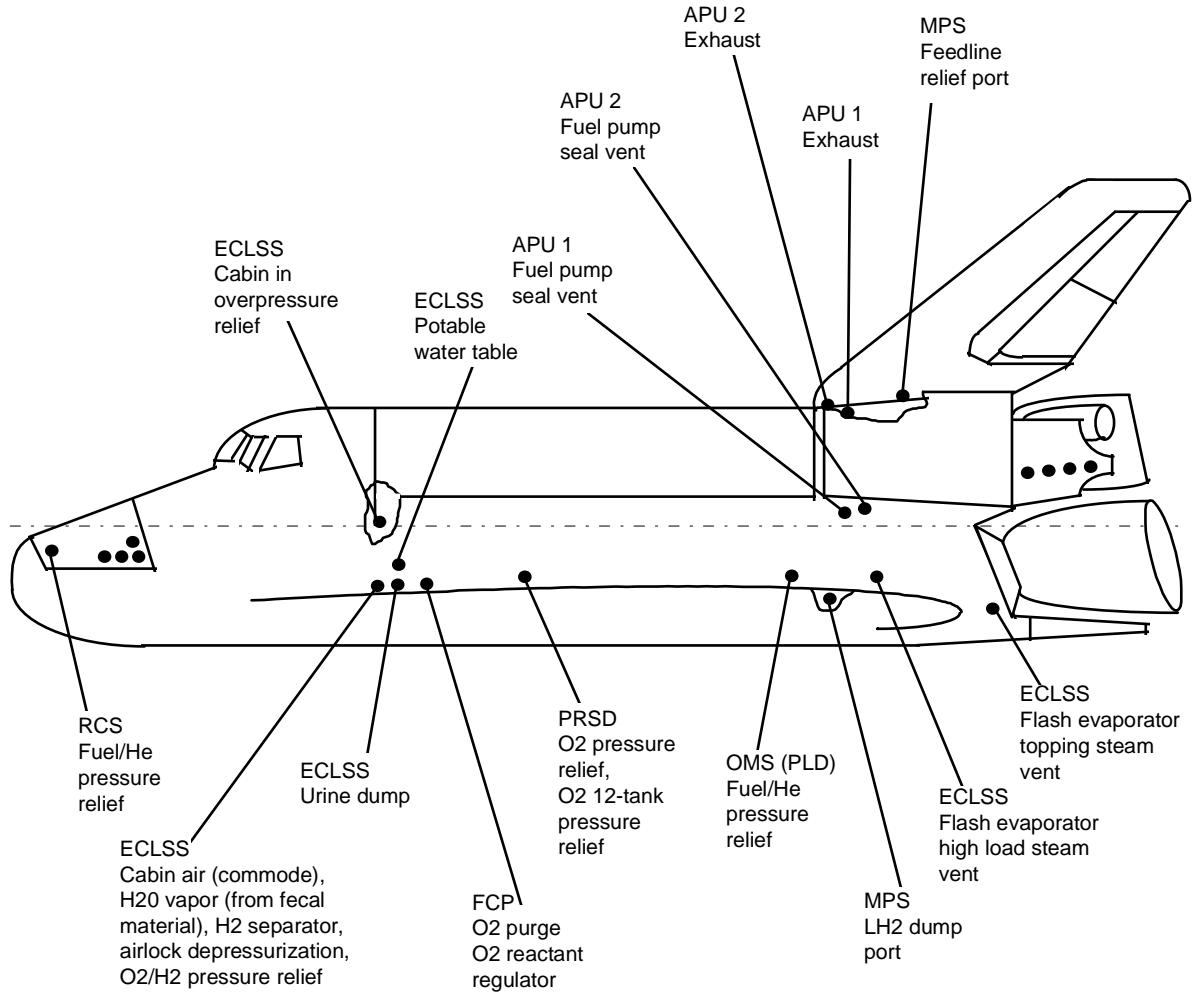
SRB Thrust Per Engine:
Sea level = 2,650,000 lbf
Vacuum = 3,000,000 lbf



(a) Right side

Note: See SODB, vol, I, paragraph 4.1.4.6, On-orbit Venting, for detail vent force, and location data.

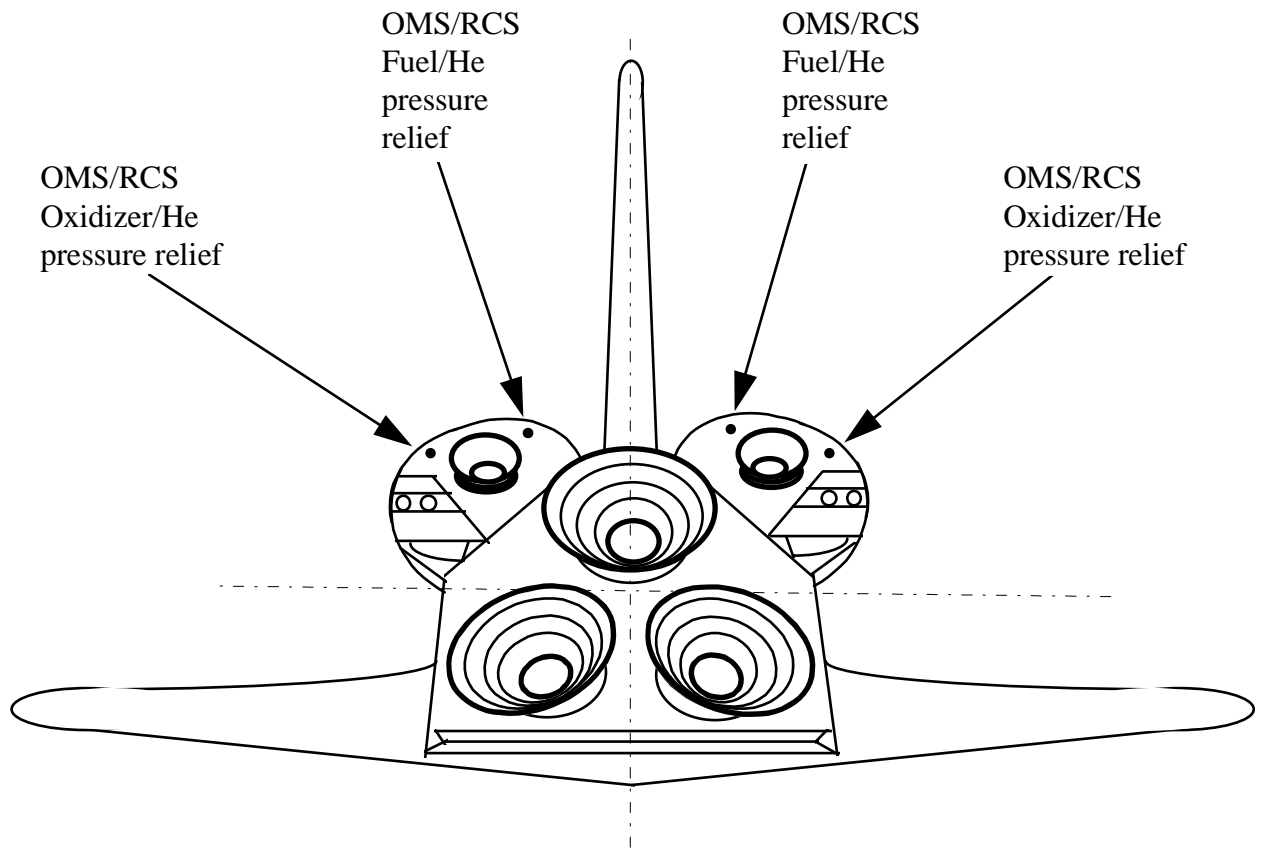
Figure 7.4-13.- Overview of on-orbit venting locations.



(b) Left side

Note: See SODB, vol, I, paragraph 4.1.4.6, On-orbit Venting, for detail vent force, and location data.

Figure 7.4-13.-Continued.



(c) Rear view

Note: See SODB, vol, I, paragraph 4.1.4.6, On-orbit Venting, for detail vent force, and location data.

Figure 7.4-13.-Concluded

Table 5.1-1-VII - SCHEDULED VENTING

Source	Location			Effluent	Thrust, lb	Vector			Duration	Remarks
	X0	Y0	Z0			FXB	FYB	FZB		
ECLSS Cabin air (commode)	602.0	-105.5	335.965	Air	Negligible	0	1	0	2 sec. 4 to 14 times per 24 hr	Depends on number of people
Water vapor from fecal material	602.0	-105.5	335.965	H ₂ O	Negligible	0	1	0	Continuous	
H ₂ O separator (FCP water)	602.0	-105.5	335.965	H ₂	Negligible	0	1	0	Continuous	Flow rate 2 x 10 ⁻⁷ lb/sec
Airlock depressurization ^a	602.0	-105.5	335.965	Air	1.0 to 4.75	0	1	0	8 minutes, three times per mission	
Waste water dump	620.0	-105.5	335.965	Urine Humidity condensation	0.093	0	1	0	4.5 hr per week- mission < 7 days	
Potable water dump	620.0	-105.5	342.4	Water	0.093	0	1	0	3 hr per day	Dependent on fuel cell H ₂ O production rate.
Flash evaporator topping 1 and 2 ^a	1505.7	±128.4	304.8 ^b	H ₂ O (steam)	0.21 max Full-up mode Topping mode	-0.1102	0.9916	0.0677	10 hr/day average	Dependent on fuel cell H ₂ O production rate. Supplements radiators during orbital operations.
High load ^a	1390.3	-113.8	326.8	H ₂ O (steam)	2.08 max Full-up mode	-0.1031	0.9943	0.0284	Operational during ascent above 140,000 ft and after payload bay door closure down to 100,000 ft.	Supplements radiators during orbital operations.
Fuel cell H ₂ purge ^a	640.9	105.4	339.2	H ₂ (g)		0	-1	0	Normal mode: 2 minutes per FCP every 8 hr	
O ₂ purge ^a	640.9	-105.4	339.2	O ₂ (g)		0	1	0	Concurrent with H ₂ purge	

^a See SODB vol. 1 paragraph 4.1.4.6 for additional data.
^b OV-102

Table 7.4-IX Scheduled Venting

Table 5.1-VII - CONCLUDED

Source	Location			Effluent	Thrust, lb	Vector			Duration	Remarks
	X0	Y0	Z0			FxB	FyB	FzB		
Hydraulics water boiler Number 1 ^a Number 2 ^a Number 3 ^a	1375.7	16.3	508.1	H ₂ O (g)	3.0 max	0	0	1	15 minutes ascent, 5 minutes checkout, & 65 minutes entry	Ascent, On-orbit APU checkout, Deorbit burn and entry
	1395.7	16.3	510.5	H ₂ O (g)	3.0 max	0	0	1		
	1355.7	16.4	505.8	H ₂ O (g)	3.0 max	0	0	1		
APU exhaust APU 1 ^a APU 2 ^a APU 3 ^a	1327.9	-15.9	502.5	N ₂ (g)	23.0 max	0	0	1	15 minutes ascent, 5 minutes checkout, & 65 minutes entry	Ascent, On-orbit APU checkout, Deorbit burn and entry
	1318.7	-15.7	501.3	H ₂ (g)	23.0 max	0	0	1		
	1327.9	15.9	502.5	NH ₃ (g)	23.0 max	0	0	1		
MPS LH ₂ LO ₂ LH ₂	1453.1	-116.8	372.3	LH ₂		0	0.999	-0.017	c	Normal and TAL abort
	Through engines			LO ₂	c				c	Typical RTLs
	1334	-108	315.4	LH ₂	c				c	

^a See SODB vol. 1 paragraph 4.1.4.6 for additional data.
^c See SODB vol. 1 paragraph 4.3.1.10 for additional data.

Table 7.4-IX Scheduled Venting (Continued)

Table 5.1-VIII - CONTINGENCY VENTING

Source	Location			Effluent	Thrust, lb	Vector			Duration	Remarks
	X0	Y0	Z0			FXB	FYB	FZB		
Fuel cell water relief	631.1	105.4	339.2	Water (l)	<0.01	0	-1	0	Can be continuous	Occurs only if ECLSS cannot accept FCP water.
Hydraulics water boiler Number 1 ^a Number 2 ^a Number 3 ^a	1375.7	16.3	508.1	H ₂ O (g)		0	0	1	AOA from MECO to EI	
	1395.7	16.3	510.5	H ₂ O (g)		0	0	1		
	1395.7	16.4	505.8	H ₂ O (g)		0	0	1		
APU exhaust APU 1 ^a APU 2 ^a APU 3 ^a	1327.9	-15.9	502.5	N ₂ (g)		0	0	1	AOA from MECO to EI	
	1318.7	-15.7	501.3	H ₂ (g)		0	0	1		
	1327.9	15.9	502.5	NH ₃ (g)		0	0	1		

^a See SODDB vol.1 paragraph 4.1.4.6 for additional data

Table 7.4-X Contingency Venting

Table 5.1-IX - FAILURE VENTING

Source	Location			Effluent	Thrust, lb	Vector			Duration	Remarks	
	X0	Y0	Z0			FXB	FYB	FZB			
RCS pressure relief ^a											
Fwd oxidizer	285.5	40.6	361.4	He+	19.8 max	-0.4520	-0.8103	0.3729	30 sec max	Occurs only if open failure of both primary and secondary regulators.	
Fwd fuel	285.5	-40.6	361.4	N ₂ O ₄	19.8 max	-0.4520	0.8103	0.3729			
Aft oxidizer (RHS)	1507.7	128.1	510.1	MMH	19.8 max	0.9986	-0.0379	0.0366			
Aft fuel (RHS)	1509.4	65.7	529.9	N ₂ O ₄	19.8 max	0.9986	-0.0379	0.0366			
Aft oxidizer (LHS)	1507.2	-128.1	510.1	MMH	19.8 max	0.9986	0.0379	0.0366			
Aft fuel (LHS)	1509.4	-65.7	529.9	N ₂ O ₄	19.8 max	0.9986	-0.0379	0.0366			
OMS pressure relief				He+					3 minutes max		Occurs if open failure of both primary and secondary regulator stages, excessive regulator/isolation valve leakage or prop tank over-temperature.
Oxidizer (RHS)	1507.7	128.1	510.1	N ₂ O ₄	12.35	0.9986	-0.0379	0.0366			
Fuel (RHS)	1509.4	65.7	529.9	MMH	12.35	0.9986	-0.0379	0.0366			
Oxidizer (LHS)	1507.2	-128.1	510.1	N ₂ O ₄	12.35	0.9986	-0.0379	0.0366			
Fuel (LHS)	1509.4	-65.7	529.9	MMH	12.35	0.9986	-0.0379	0.0366			
APU fuel pump seal									9 minute max	3 kits Failure of fuel pump seal ring only	
APU 1	1343.3	-107.8	413.3	N ₂ H ₄	3.5	0	1	0	Leakage stops at crew initiated shutdown		
APU 2	1349.9	-108.3	413.6	N ₂ H ₄	3.5	0	1	0			
APU 3	1343.3	107.8	413.3	N ₂ H ₄	3.5	0	-1	0			
ECLS											
O ₂	602.0	-105.5	335.965	O ₂ (g)	4.6	0	1	0	10 minutes maximum (deplete one tank)	Single failure of pressure regulators	
N ₂	602.0	-105.5	335.965	N ₂ (g)	4.9	0	1	0	16 minutes (deplete two of four tanks)		
Cabin overpressure relief valves ^b	576.0	-67.7	394.4	Air	53	-1	0	0	Flow stops at crew-initiated shutdown	Opens at 15.5 psi cabin pressure	
	576.0	-74.2	394.4		53 (nozzle thrust) ^c	-1	0	0			

^a See SODB vol. 1 paragraph 4.1.4.6 for additional data.

^b Plume impingement within PLB will change magnitude and direction of thrust vector.

^c Regulator or line failure resulting in flow through both valves.

Table 7.4-XI Failure Venting

Table 5.1-IX - CONCLUDED

Source	Location			Effluent	Thrust, lb	Vector			Duration	Remarks
	X0	Y0	Z0			FXB	FYB	FZB		
PRSD H ₂ relief (fwd) ^a H ₂ relief (aft) ^a O ₂ relief ^a	822.2	105.4	342.5	H ₂ (g)	0.10/tank	0	-1	0	Total venting time (each tank) in 17 hr: ~20min in cycles < 10 sec Total venting time (each tank) in 16 hr: ~2.4hr in cycles ≤100 sec	Occurs due to tank overheat; heaters failed ON most likely cause.
	990.0	105.4	342.5	H ₂ (g)	0.07/tank	0	-1	0		
	760.0	-105.4	355.5	O ₂ (g)	0.57/tank	0	1	0		
Fuel Cell ^a H ₂ reactant regulator O ₂ reactant regulator	640.9	105.4	339.2	H ₂ (g)		0	-1	0	Flow stops at crew-initiated isolation.	Failure of FCP reactant regulator.
	640.9	-105.4	339.2	O ₂ (g)		0	1	0		
Hydraulic water boiler ^a Number 1 Number 2 Number 3	1375.7	16.3	508.1	H ₂ O (g)	3.0 max	0	0	1	No venting if hydraulic system fails.	
	1395.7	16.3	510.5	H ₂ O (g)	3.0 max	0	0	1		
	1355.7	16.4	505.8	H ₂ O (g)	3.0 max	0	0	1		

^a See SODB vol. 1 paragraph 4.1.4.6 for additional data.

Table 7.4-XI Failure Venting

TITLE

RCS Jet Pulse (Hot-Fire)

PURPOSE

To describe the procedure for determining expected jet firing duration (using the Pulse program) as commanded by the Orbit DAP and resultant vehicle attitude rate changes.

BACKGROUND

The duration of a jet firing (or "jet on-time") to be expected for a given DAP command may be required prior to the actual firing to learn the expected vehicle attitude rates. This information is useful when evaluating a jet suspected of being failed or degraded in thrust, or when predicting orbiter attitude rates or propellant consumption for payload or consumables management.

For evaluating a suspect jet, the crew will perform Malfunction Procedure RCS SSR-2: Hot Fire RCS. The central idea behind this procedure is to fire only the suspect jet in response to a manual command, by deselecting all the other jets that may be fired for the given command. Comparing the actual resultant attitude rate changes from the firing with those predicted for a nominal jet firing will yield insight into the jet's health. Recall that the indicated ADI rates immediately following the firing will be driven by the state estimator, and are a DAP estimate only; the actual steady-state rate changes (seen a few seconds later) must be used for analysis. Thus, for a failed jet, the indicated ADI rate will be nominal initially, but will then fall back to the pre-firing value (or some intermediate value for a degraded jet). For a healthy jet, the indicated rate will be a sustained nominal value, at the level determined with this SCP.

Calculation of the firing length is done using the Pulse computer program. A manual calculation procedure is presented at the end of this SCP as a backup to the Pulse program.

PROCEDURE

OVERVIEW

A brief summary of the steps (described below) to be performed is as follows:

1. Gather required information (mass properties, suspect jet, DAP state at jet firing, etc.)
2. Determine the expected jet firing duration using the Pulse program.
3. Determine the expected resultant vehicle accelerations using the JETACC program.
4. Calculate the resultant orbiter attitude rate changes using the results from steps 2 & 3.
5. Prepare the console for monitoring of the jet firing.
6. Compare the actual resultant rate changes with those from 4 above to determine the jet's health.

1. GATHER REQUIRED DATA

The following data is needed, obtained from the indicated sources:

- a. the jet to (hot) fire (from the Propulsion Officer, PROP)
- b. the command type to be input, translation or rotation (from SSR-2)
- c. the vehicle's *actual* mass properties (from the Flight Dynamics Officer, FDO, or as *predicted* in SODB Volume II), including: orbiter mass, center-of-gravity (C.G.) location, and moments and products of inertia)

If the jet firing will be performed in the current orbiter state (mass properties and DAP configuration), the following information does not need to be acquired (the Pulse program will access them from the downlist automatically).

- d. the DAP configuration at the time of the firing, including:
 - ◆ for rotational commands:
 - the rotational jet selection option (Primary, Alternate, or Vernier)
 - the rotational pulse size (input on SPEC 20: DAP CONFIG)
 - ◆ for translational commands:
 - the Z translation option (Normal or Low Z translation)
 - the translational pulse size (input on SPEC 20: DAP CONFIG)
- e. the DAP's *selected* mass properties *at the time of the firing*. These are based on the Control Accel value of the selected DAP load. Below are the downlisted selected MSIDs and the appropriate I-Load range:

Selected center of gravity:	X (V93U5430C) Y (V93U5431C) Z (V93U5432C)	I-Loads (V97U2508C through V97U2537C)
Selected products of inertia:	X (V93U5433C) Y (V93U5434C) Z (V93U5435C)	I-Loads (V97U2568C through V97U2597C)
Selected moments of inertia:	X (V93U5436C) Y (V93U5437C) Z (V93U5438C)	I-Loads (V97U2538C through V97U2567C)
- f. the Jet Select algorithm, (Minimum Angle or Maximum Dot Product)
- g. the Pitch and Yaw Jet Options (All jets or Tail Jets only).

2. DETERMINE EXPECTED FIRING DURATION

- A. Start the Pulse program by selecting it under the MCC workstation GNC/Apps menu.
- B. The program will automatically select the current *selected* DAP configuration and mass properties from the downlist (as long as the Realtime option is selected in the Data Source section). If the firing will be performed in a different configuration, override the program by selecting the User option under Data Source and manually entering the desired parameters.

NOTE: An error resides in the current version of the Pulse program in that the Vehicle Mass parameter (under Mass Properties) is tied to a downlisted Variable Parameter that no longer provides the vehicle mass. Therefore, for an accurate calculation of jet firing duration, the user will need to manually enter the correct Vehicle Mass after selecting the User option under Data Source.

- C. Select the desired command type.
- D. Record the calculated jet firing duration for use below.

3. DETERMINE EXPECTED ACCELERATIONS

- A. Start the JETACC program by selecting it under the MCC workstation GNC/Apps menu.
- B. Input the actual orbiter mass properties obtained in step 1 (see SCP 7.4 for further information).
- C. Record the calculated angular accelerations with plume impingement corrections for use below.

4. CALCULATE EXPECTED ORBITER ATTITUDE RATES

Using the results from steps 2 and 3 above, the orbiter attitude rates for a nominal jet firing are calculated as follows:

$$\text{Roll Rate} = (\text{Ang Accel (X)}) \times (\text{Firing Duration}),$$

$$\text{Pitch Rate} = (\text{Ang Accel (Y)}) \times (\text{Firing Duration}),$$

$$\text{Yaw Rate} = (\text{Ang Accel (Z)}) \times (\text{Firing Duration})$$

5. PREPARE THE CONSOLE FOR THE FIRING

The RTPLOT tool may be used for monitoring of the jet firing. Start the RTPLOT "IMU Derived Body Rates". Ensure the scale is appropriate for the expected rate level. A plot of the *indicated* RCS jet chamber pressure may also be used.

6. COMPARE THE ACTUAL AND PREDICTED RATES

Monitor the jet firing with the above tools, and observe the resultant *steady-state* attitude rate *changes*. Recall that the initial indicated rate changes will be those from the DAP State Estimator, and must not be used for evaluation; only the subsequent values are true orbiter rates, see Figure 7.5-1. Report the result to the GNC Officer.

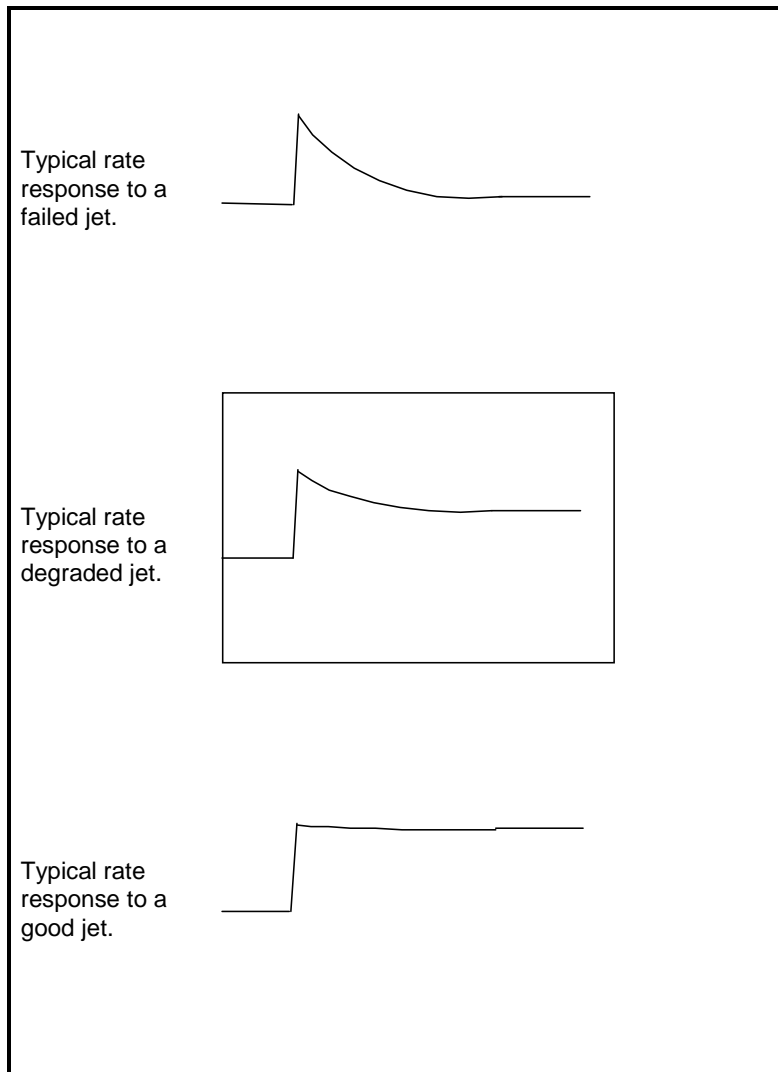


Figure 7.5-1 - Typical Vehicle Rate Responses to RCS Hot Fire

MANUALLY CALCULATING THE FIRING DURATION

If the Pulse program is unavailable, the firing duration may be calculated manually using the following DAP equations in the tables below. The rotation pulse equation requires the MAG_CONT_ACCL which is downlisted for the current DAP configuration, i.e. VERN, PRI, or ALT and DAP CNTL ACCL. An equation for calculating the MAG_CONT_ACCL for the PRI DAP mode is also included. The calculations for the VERN or ALT DAP mode MAG_CONT_ACCL are too complex to be included here.

TABLE 7.5-1 ORBIT DAP ROTATION EQUATIONS AND I-LOADS

ROTATION PULSE EQUATION (Software module GFFORB)
$\text{JET ON TIME} = (\text{TDAP}) \left[\text{Truncate} \left[1 + \frac{\text{ROT_PULSE}}{(\text{TDAP}) (\text{MAG_CONT_ACCL})} \right] \right]$
<p>Where:</p> <p>TDAP = Duration of one software cycle (0.08 sec)</p> <p>ROT_PULSE = Desired angular vehicle rate (SPEC 20: DAP CONFIG)</p> <p>MAG_CONT_ACCL = Average angular acceleration by axis, obtained from the downlist as these MSIDs: V90U2798C (roll) V90U2828C (pitch) V90U2829C (yaw)</p> <p>If MAG_CONT_ACCL needs to be calculated (Valid for PRI DAP mode);</p>
$\text{MAG_CONT_ACCL} = \frac{(\text{MAG_CONTROL_ACCEL_REF_PRIM})(\text{PRINCIPAL_INERTIA_REF})}{\text{SEL_MOMENTS_I}}$
<p>Where:</p> <p>MAG_CONTROL_ACCEL_REF_PRIM are I-loaded usually as: Roll (V98U9941C) = 0.8 deg/sec² Pitch (V98U9942C) = 0.9 deg/sec² Note: Verify I-loads against the S/W Yaw (V98U9943C) = 0.6 deg/sec²</p> <p>PRINCIPAL_INERTIA_REF are I-loaded usually as: Roll (V98U9938C) = 938131 slug ft² Pitch (V98U9939C) = 7129268 slug ft² Note: Verify I-loads against the S/W Yaw (V98U9940C) = 7462045 slug ft²</p> <p>SEL_MOMENTS_I is dependent on the Control Accel value of the selected DAP load. The most likely case is Control Accel = 0 which are usually I-loaded as: MOMENTS_OF_INERTIA_NOM Roll (V97U2538C) = 938131 slug ft² Pitch (V97U2539C) = 7129268 slug ft² Note: Verify I-loads against the S/W Yaw (V97U2540C) = 7462045 slug ft²</p> <p>If the Control Accel is equal to 1 through 9, use the appropriate I-load value from the array MOMENTS_OF_INERTIA_ARRAY (V97U2541C through V97U2567C).</p>

TABLE 7.5-2 ORBIT DAP TRANSLATION EQUATIONS AND I-LOADS

TRANSLATION PULSE EQUATION (Software module GFFORB)

$$\text{JET ON TIME} = (\text{TDAP}) \left[\text{Truncate} \left[1 + \frac{(\text{TRANS_PULSE}) (\text{ORB_MASS}) (E)}{(\text{TDAP}) (\text{MAG_CONT_FORCE})} \right] \right]$$

Where:

- TDAP = Duration of one software cycle (0.08 sec)
- TRANS_PULSE = Desired translation velocity gain (ft/sec)
- ORB_MASS = Onboard vehicle mass, (slugs)
- E = 11 for Low +Z translations only; otherwise E=1
- MAG_CONT_FORCE = Translation acceleration I-load (lb)

MAG_CONT_FORCE I-load Values:

+/-X (V97U2957C) = 1760 lbs	
+/-Y (V97U2958C) = 1760 lbs	Note: Verify I-loads against the S/W
+/-Z (V97U2959C) = 3055 lbs	

MANUAL EXAMPLE: JET F3F HOT FIRE

Calculate the rates you would expect on the vehicle when F3F is hot fired.

Step 1. Use the following mass properties, and use SSR-2 to obtain the translation pulse size of 0.1 feet/second, and the required -X THC command.

lxx = 1007736.10	X CG = 1091.70
lyy = 7643120.00	Y CG = -.30
lzz = 7974127.30	Z CG = 372.70
lxy = 553.40	
lxz = 278553.80	WEIGHT = 238078.20
lyz = 791.90	

Step 2. Calculate the jet on-time using the translation pulse equations:

a) First, calculate the vehicle's mass (ORB_MASS). Remember to get the onboard weight value from FDO (or use V90U1961C).

$$\begin{aligned} \text{ORB_MASS} &= \text{Onboard Weight} \div 32.17 \text{ ft/sec}^2 \\ &= 238078.2 \text{ lbs} \div 32.17 \text{ ft/sec}^2 \\ &= 7400.6 \text{ slugs} \end{aligned}$$

b) Use the translation pulse equation:

$$\text{JET_ON_TIME} = \text{TDAP} * \left(\text{Truncate} \left[1 + \frac{(\text{TRANS_PULSE}) (\text{ORB_MASS}) (E)}{(\text{TDAP}) (\text{MAG_CONTROL_FORCE})} \right] \right)$$

$$\text{TDAP} = 0.08 \text{ sec/cycle}$$

$$\text{TRANS_PULSE} = 0.10 \text{ ft/sec (RCS SSR-2)}$$

$$\text{MAG_CONTROL_FORCE} = 1760 \text{ lbs (-X translation I-load)}$$

$$\text{JET_ON_TIME} = (0.08) \left(\text{Truncate} \left[1 + \frac{(0.10)(7400.6)(1)}{(0.08)(1760)} \right] \right) = 0.48 \text{ sec}$$

Step 3. Determine vehicle accelerations from JETACC using the mass properties in Step 1.

From JETACC the angular accelerations when F3F fires are:

$$\begin{aligned} \text{Roll} &= +0.00025 \text{ deg/sec}^2 \\ \text{Pitch} &= -0.04819 \text{ deg/sec}^2 \\ \text{Yaw} &= +0.00017 \text{ deg/sec}^2 \end{aligned}$$

Step 4. Calculate the rate changes using the jet on-time you calculated in Step 2 and the accelerations you obtained in Step 3:

$$\text{Rate} = \text{Accel} \times \text{Time}$$

$$\begin{aligned} \text{Roll rate} &= +0.00025 \text{ deg/sec}^2 \times 0.48 \text{ sec} = 0.00 \text{ deg/sec} \\ \text{Pitch rate} &= -0.04819 \text{ deg/sec}^2 \times 0.48 \text{ sec} = -0.02 \text{ deg/sec} \\ \text{Yaw rate} &= +0.00017 \text{ deg/sec}^2 \times 0.48 \text{ sec} = 0.00 \text{ deg/sec} \end{aligned}$$

Step 5. Pitch rate is the largest, -0.02 deg/sec. Roll and yaw rates are negligible.

MANUALLY CALCULATING THE TRANSLATIONAL PULSE SIZE

The crew may need a specific TRANSLATIONAL PULSE SIZE to be entered in the DAP CONFIG (SPEC 20) to allow the jets to fire continuously for a desired amount of time (JET ON TIME). The procedure below outlines what needs to be done for the manual calculation of the TRANSLATIONAL PULSE SIZE.

Step 1. Solve for the current ORB_MASS being used by the DAP software for specifically calculating JET ON TIME.

$$\text{ORB_MASS} = \text{CGCV_K_T(AXIS)} * \text{MAG_CONT_FORCE} * \text{TDAP}$$

MAG_CONT_FORCE and TDAP values are in TABLE 7.5-2 CGCV_K_T(AXIS) is requested as a Variable Parameter following the procedure in FCOH Section 4.8 -VARIABLE PARAMETER DOWNLIST USAGE.

Step 2. Request the Variable Parameter for CGCV_ORB_DAP_MASS_HFE by following the procedure in FCOH Section 4.8. This value is the updated orbiter mass being used by the DAP software.

Step 3. Compare ORB_MASS with CGCV_ORB_DAP_MASS_HFE.

If the values are not equal, a TRANSLATIONAL PULSE INITIALIZATION must occur in order for the value of ORB_MASS to be updated and thus be equal with CGCV_ORB_DAP_MASS_HFE. For TRANSLATIONAL PULSE INITIALIZATION to be triggered one of the following triggers must be executed:

NORM to PLS on the translation submode pbi's while PRI is selected
THC HOT STICK upmode to PRI
Post Contact Thrusting is Armed
GPS OPS Transitions: G2 to G8, G8 to G2, OPS MODE recall in MM201,
MM801

Step 4. Solve for the TRANSLATION PULSE SIZE (TRANS_PULSE) using the JET ON TIME equation in TABLE 7.5-2.

$$\text{JET ON TIME} = (\text{TDAP}) \left[\text{Truncate} \left[1 + \frac{(\text{TRANS_PULSE}) (\text{ORB_MASS}) (\text{E})}{(\text{TDAP}) (\text{MAG_CONT_FORCE})} \right] \right]$$

REFERENCES

1. GNC Systems Briefs, Section 16 - Orbit DAP, JSC-18863.
2. SCP 7.4, Calculation of Orbiter Acceleration and Torques for Reaction Control System Jet Firings (JETACC).
3. Shuttle Operational Data Book, Volume II - Mission Mass Properties, NSTS-08934.
4. Primary Avionics Software Module GFFORB (GFF.3 and GFF.4), Orbit DAP.
5. Shuttle Flight Data File, Malfunction Procedures, Revision D, RCS SSR-2, Hot Fire RCS,, JSC-48027.
6. Shuttle Flight Data File, Orbit Operations Checklist, Revision F, RCS Hot Fire Test, JSC-48035.

TITLE

ASCENT OMS TVC FAILURE ANALYSIS

PURPOSE

To describe the techniques used to determine the failure mode of an OMS thrust vector control system anomaly during powered flight (Major Modes 102-103, 601), for purposes of implementing Flight Rules A8-53: OMS TVC LOSS (part C), and A6-101: OMS ENGINE BELL MOVEMENT DURING ASCENT.

BACKGROUND

During powered ascent, the OMS engines are commanded to the stow position, down and outboard, to protect them from the high aerodynamic loads experienced during maximum dynamic pressure (from 40 seconds to 1 minute, 10 seconds MET). The position values corresponding to stow are as follows (compensated, as seen in MCC):

Pitch = + 5.8 deg
Left Yaw = + 6.01
Right Yaw = - 6.01.

Special software (the OMS TVC command SOP) is active during this time to ensure the engines do not move from these positions to prevent structural damage of the OMS engine nozzles. This software is designed to handle two types of failure scenarios:

- 1) Both OMS TVC systems are available, or
- 2) Only one OMS TVC system is available (i.e., the other TVC system is commfaulted)

In the case where both TVC systems are available (primary and secondary), if movement of more than 0.7 degrees is detected by both the primary and secondary transducers, then the primary TVC motor is automatically powered to drive the engine back into the stow position. If the engine remains out of the stow position by more than 0.7 degrees after 2 software cycles (approximately 0.16 seconds), the primary motor is turned off and the secondary motor turned on, again to drive the engine back into stow position. Once the OMS actuator is returned to the stow position, the transducer system that was selected at the time the actuator was within 0.7 degrees (of the stow position) will remain active.

EXAMPLE (Failure Scenario #1):

L OMS moves 3 degrees inboard (yaws inward to +3.01 degrees) at MET 1:00 minute, as sensed by both the LY Primary and LY Secondary transducers (due to a no-back failure). The LY Primary system is enabled for 0.16 seconds, but due to the large amount of yaw in the LY actuator, the LY PRI transducer drive rate (between 3 and 5 deg/sec) is unable to return the LY actuator to within 0.7 degrees of the command before the 2 cycle timer expires. At the expiration of the 2 cycle timer, the L PRI TVC is turned off, and the L SEC TVC is enabled to drive the actuator back to the LY stow position. Once in the stow position, the L OMS SEC will remain enabled.

EXAMPLE (Failure Scenario #2):

R OMS PRI is lost behind a GPC 4 failure at MET 1:00 minute. After an RTLS abort is declared (MM 601) for low performance on the C SSME in first stage, the RP SEC TVC detects upward motion of 4.4 degrees (pitch up towards the airstream). Since the R PRI system is not available (due to the GPC 4 commfault), the R SEC system would automatically enable and would drive the RP back towards the stow position. Once in the RP stow position, the R OMS SEC will remain enabled.

Per flight rules, if both sensors (primary and secondary) indicate a movement from stow position into the airstream of more than 1.5 degrees during maximum dynamic pressure, the affected OMS engine cannot be used due to possible OMS engine nozzle damage. If only one sensor is available, and it indicates movement (the movement is suspected but not confirmed), the engine cannot be used for OMS assist, insertion (i.e., OMS-1 or OMS-2), orbit, or deorbit burns (unless required for orbiter or crew safety), but will be used for RTLS and TAL abort dumps (since landing weight and C.G. location are of immediate concern for these situations), and ATO dumps required to avoid a TAL abort.

If real-time analysis conclusively shows that the single transducer movement indication is real, then no OMS burns should be performed (even for abort dumps). However, if additional analysis conclusively shows that the single transducer movement indication is false, then that OMS engine may be burned at any time (even for on-orbit OMS burns). The intent of the flight rule is to provide a risk vs. risk trade-off of the risk of blowing up and OMS engine due to a cracked nozzle throat vs. the risk of performing an entry with a Cg that is in the contingency box, or landing at a weight that is heavier than the landing gear is able to support. In any case, it is more likely that performing an abort with an off nominal Cg or landing too heavy (with too much OMS propellant) will result in loss of control during the glided entry, cause excessive entry heating (due to high aeroloads caused by the off nominal Cg), or landing gear failure at touchdown. Igniting an OMS engine with a cracked nozzle throat may or may not result in OMS engine failure/explosion. In either case, if there is uncertainty whether the OMS motion into the airstream actually occurred, the intent of the flight rule is to side with a reduction of OMS propellant (perform the abort dump) and accept the risk of a catastrophic OMS engine bell failure during the abort dump.

The only known single-failure-deep scenario

The only known single-failure-deep scenario that could affect the OMS engine (indicated) position during ascent is an actuator no-back failure. Other two failure deep scenarios that may be combined on the primary and secondary TVC systems to cause OMS engine movement during High-Q are:

- 1) Primary/secondary position instrumentation problem (MDM or GPC feedback error)
- 2) Primary/secondary position LVDT transducer problem
- 3) Primary/secondary transducer commfault (i.e., FA MDM or GPC failure)

Other known failures, such as a gimbal motor failure, a MDM command bias, a degraded- rate actuator, or instrumentation error, will have no effect because in MM 102-103, 601 the gimbal motors are not powered and the software monitors both the primary and secondary position indications before commanding the actuator to drive back to the stow position.

PROCEDURE

A. FAILURE DETECTION

An anomaly in the OMS TVC system during ascent is recognized via the following:

- 1) using RTPLOT plots of gimbal positions, **and**
- 2) using the digital display indication of powered gimbal motors.

If a position plot shows any movement or if a motor becomes powered (i.e., enabled), analysis of the failure mode (and its direction and magnitude) must be performed to determine the usability of the engine.

OMS TVC RM software is not processed in MM 102-103, 106, so no fault messages ("L(R) OMS GMBL") will be annunciated on board.

If no failures are detected (the engines remain in their stow positions), at the end of high dynamic pressure period, the **Control operator informs the GNC the "OMS are go."**

B. MAX Q EXPERIENCE DETERMINATION

First determine if the affect OMS engine was exposed to the period of maximum dynamic pressure by asking yourself:

- A) Did the suspected movement occur between 0:40 and 1:10 MET?
- B) Was the magnitude of the movement (as indicated by either primary (5 s/s) or secondary (1 s/s) position plot) greater than 1.5 degrees?
- C) Was the direction of movement away from the stow position (toward zero)?

If all of these conditions are met, continue with the following analysis. If any of them are not met, the engine movement (if it actually occurred) was not into the airstream; the engine is usable for all purposes, and the Control operator informs the GNC of this fact with an "OMS are go" (or similar) call.

C. FAILURE MODE ANALYSIS

If actuator motion greater than 1.5 degrees was sensed during high dynamic pressure (HI-Q), determine the failure mode using the RTPLOT gimbal position plots.

Only the OMS no-back failure mode is described below because it is the only single-point failure mode that could explain OMS actuator motion during HI-Q. **Other multiple failure deep scenarios should be analyzed on a case-by-case basis** using the known failures (i.e., GPC failures, FA MDM failures, transducer failures, etc), the ascent data, and the procedures as outlined in GNC SCP 7.3 OMS TVC GIMBAL CHECK.

Actuator no-back failure

A failure of the OMS no-back device may allow the engine to move (though it is not clear how it could move) *into* the airstream. The software will respond by powering the primary motor (if the 0.7-degree limit is exceeded) to reposition the engine, and, if unsuccessful, then power the secondary motor. The plots for this failure are shown in Figure 7.6-1.

If both primary and secondary position plots indicate a change, the engine is not usable, and **Control calls to GNC: “L(R) OMS movement into airstream, engine is no-go; L(R) OMS Engine switch to OFF”**. If the flight has an OMS assist burn, then the **OMS Engine switch action must be performed prior to SRB SEP**.

If only a single position transducer is available (due to a previous MDM or GPC failure commfaulting the other position transducer on that actuator), and the remaining position transducer detects motion of the actuator, then the affected OMS engine is no-go for use in all but abort propellant dumps, and **Control’s call to GNC is: “L(R) OMS has one indication of movement into airstream, engine is go for abort dumps only, no-go for OMS burns/OMS Assist; L(R) OMS Engine switch to OFF.”** If the flight has a planned OMS assist burn, then the **OMS Engine switch action must be performed prior to SRB SEP**.

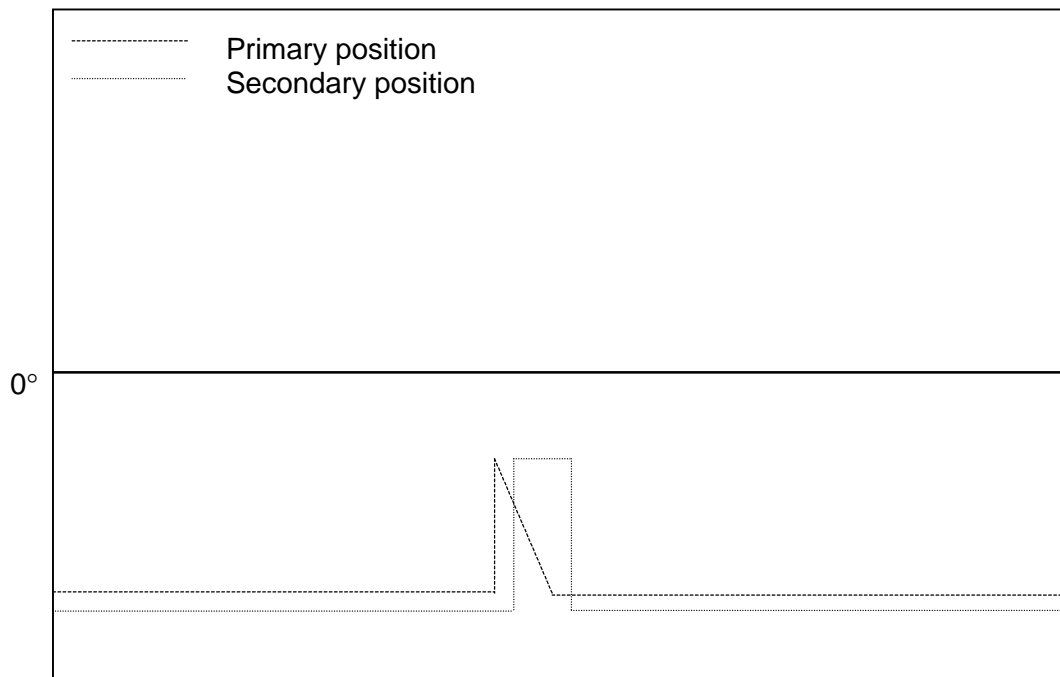


Figure 7.6-1: R OMS Yaw no-back failure

4. Special cases/Multiple Failure Deep Scenarios

There are other potential cases/multiple failure deep scenarios that deserve some consideration, all of which further reinforce the real spirit of the applicable flight rules, and that is, **the engine should not be used if it has moved into the airstream, but this movement must be confirmed (i.e., as indicated by 2 of 2 transducers)** in order to accept the risks in not using the engine for abort dumps (which are critical for vehicle and propellant tank landing weights, vehicle C.G., and ET impact location).

To paraphrase the flight rules for these cases: if sure about the engine movement, do not use the engine; if in doubt, use the engine for abort dumps.

REFERENCES

1. Effectors SOP, FSSR STS 83-0016B, section 4.64.
2. Shuttle Operational Data Book, vol. 1, January 1988, paragraphs 4.3.3.1, 4.3.3.1b, and 4.5.1.1.2.4a.
3. Redundancy Management, FSSR STS 83-0010B (Prin. Funct. 4.92) sec. 4.10.
4. STS Operational Flight Rules, Rules A6-101 and A8-53C.

TITLE

OMS BURN MONITORING

PURPOSE

The purpose of this SCP is to provide a set of operating guidelines for console operators to utilize during an OMS burn. This SCP lists the responsibilities of each console officer and references additional SCPs which should be consulted for certain off-nominal events which may occur during or after a burn.

BACKGROUND

There are nominally three instances during which an OMS burn will be performed. There is an OMS burn following MECO (nominally a single burn, referred to as OMS-2, but some flight plans call for a series of burns, referred to as OMS-1 and OMS-2) to circularize the shuttle's orbit. An OMS burn will be required under some rendezvous scenarios (i.e. a MIR or ISS rendezvous burn). Finally, an OMS burn is required to deorbit the orbiter.

GNC will follow a burn procedure when monitoring an OMS burn. This procedure may be found in an ascent checklist, rendezvous checklist, orbit ops checklist, or entry checklist depending on flight phase and mission. Figure 7.7-1 indicates the checklist to consult for a particular flight phase and type of burn.

Flight Phase	OMS Burn	Procedure	Burn Monitor
Ascent	OMS 1	Ascent Checklist	Ascent Checklist
	OMS 2	Ascent Checklist	Ascent Checklist
On-Orbit	Typical Burn	Orbit Ops Checklist	Ascent Checklist
	Rendezvous Burn	Rendezvous Checklist	*Rendezvous or Ascent Checklist
Entry	Deorbit Burn	Entry Checklist	Entry Checklist
* Typically uses OMS 2 Burn Monitor, but may use specialized Burn Monitor.			

Figure 7.7-1- OMS Burn Checklists.

There are a number of console programs utilized by GNC personnel to monitor an OMS burn. Console operators expecting to be on console during an OMS burn should become familiar with the following programs. (No console operator will utilize ALL of the following programs, but each should become familiar with the data made available on these

programs so that he or she can select the most effective combination of programs for the data he or she is responsible for monitoring.)

RT Plots:

OMS Gimbal Plots
Orbiter Rate Plots
Velocity Difference (Vel Diff)

MSK Displays:

GNC Orbit
A/E Sensors
BFS Sensors
Ascent Control
BFS Control
Transition Control

Other Programs:

SPEC
CRANS
ELOG
OFS

Additionally, right after the burn, gimbal checks may be called for. SCP 7.3 should be performed when a gimbal check is required.

PROCEDURES

Prior to the beginning of the burn, there are several crew steps which GNC should verify have been completed. The GNC Control or Support Officer should watch for the following crew steps and call them out to the GNC FCR Operator as they are completed.

CREW STEPS GNC SHOULD VERIFY:

- DAP and Flight Controller Power configured
- Orbiter in burn attitude
- OMS Engine retrim at TIG - 15 seconds
- EXEC key pressed at TIG - 15 seconds

Additionally, there are several functions which must be performed by GNC during the burn. These responsibilities, listed by the console operator responsible, follow:

CONTROL GNC OFFICER RESPONSIBILITIES:

- Monitor OMS Pc to verify engine burn and cutoff. (Pc values of 103 to 104 during burn, zero at cutoff)
- Monitor Vgo's to ensure all are decreasing (to approximately 0.2 or less by cutoff)

- Monitor RHC deflections. Nominally there should be none, but if any are present GNC should be aware of what is happening and why.
- Monitor orbiter rates to ensure all are small (i.e. ≤ 0.5)
- Monitor OMS gimbal commands and positions to verify they are in agreement with each other and are fairly steady

SENSORS GNC OFFICER RESPONSIBILITIES:

- Monitor IMU accelerometers via Vel Diff RT Plot and appropriate MSK Display.
- Determine if accelerations shown on the Vel Diff plot indicate that scale factors are present. Should any occur, SCP 2.13 is to be consulted to address such scale factors.
- The total accelerations should be in the vicinity of 1.4 to 1.6 for a two engine burn. These accelerations will also indicate if an engine is lost (by dropping to approximately 50% of their original value).
- In the event of an IMU dilemma, SCP 2.3 is to be followed to ensure that the correct IMU is selected.
- IMU accelerometers will also be monitored to verify that there is no vehicle attitude change during the burn and that the vehicle is calculating a good attitude.

SUPPORT GNC OFFICER RESPONSIBILITIES:

- All duties of Control and Sensors Officers

A/E OR ORBIT GNC OFFICER RESPONSIBILITIES:

- Identical to GNC Support

REFERENCES

Consultations with GNC Personnel: David Marquette, Eddie Trlica, Laura Stallard, Sedra Spruell, and Jeff Wyrick.

TITLE

FLIGHT CONTROL SYSTEM CHANNEL MANAGEMENT

PURPOSE

The purpose of this section is to define the procedures for monitoring failures of the aerosurface, main engine, and solid rocket booster actuators. Actuator failure monitoring will be performed during all phases of flight in which the auxiliary power units (APUs) are running and hydraulic systems are pressurized. The Control position will monitor actuator performance using RT Plots, CRANS, and digital data displays.

BACKGROUND

Refer to Systems Handbook drawings 9.11, 9.14, 9.15, and 9.16. The aerosurface servo amplifier (ASA) and ascent thrust vector control (ATVC) actuator systems are similar in many respects. They both have one hydraulic power valve controlling each actuator drive mechanism. This power valve is controlled by four electrohydraulic servo valves, which are in turn driven by each of the four channels of the respective ASA or ATVC amplifiers. The outputs of the servo valves are summed hydraulically at the power valve (i.e., the four servo valves simultaneously control the power valve). The differential pressure measured across the servo valves is referred to as secondary delta pressure (ΔP) and the differential pressure measured across the power valve is referred to as primary ΔP . Under steady state trim conditions, the sum of the secondary ΔP 's should equal zero. However, due to mechanical tolerance, small secondary ΔP 's may develop in an individual channel, which will result in a minor force fight between channels as each servo valve attempts to reach its own null position.

The ASA and ATVC actuator systems are different with respect to the methods of summing position command and feedback. The ASA sums the aerosurface position (actuator) command with an electrical position feedback to generate an electrical drive command to the servo valve. Equalized secondary ΔP and primary ΔP electrical feedbacks are also summed for increased stability. The ATVC sums Space Shuttle main engine (SSME) position command with equalized secondary ΔP electrical feedback. However, the electrical position (actuator command) is summed with mechanical position feedback in the actuator at the servo valve. Mechanical dynamic pressure feedback is also summed in the actuator for increased stability. Table 8.1-I outlines the ASA and ATVC actuator systems.

TABLE 8.1-I. - ASA/ATVC ACTUATOR SYSTEMS

	ELECTRICAL		MECHANICAL
Aerosurface Control	IN	<u>ASA</u> Signal/Source, destination (1) POSN CMD/Aerojet DAP (2) POSN fbk/Act LVDT (3) PRI ΔP fbk/Act LVDT (4) Equal sec ΔP fbk/Act LVDT	<u>Actuator</u> (1) Flapper valve POSN (2) Sec ΔP fbk wire (3) PWR valve fbk wire
	OUT	POSN err CMD/Act servo coil	Hydraulic sec ΔP to PWR valve
SSME Control	IN	<u>ATVC</u> Signal/Source, destination (1) POSN CMD/ASC DAP (2) Equal sec ΔP fbk/Act LVDT	<u>Actuator</u> (1) Flapper valve POSN (2) POSN fbk (3) Dynamic pressure fbk (4) Sec ΔP fbk wire (5) Pwr valve fbk wire
	OUT	POSN CMD/Act servo coil	Hydraulic sec ΔP to power valve

The ASA and ATVC avionics each contain secondary ΔP fault detection circuitry that senses the magnitude of the secondary ΔP in order to determine the health of each channel. The fault detection circuitry consists of a linear voltage differential transformer (LVDT) level detector and an up/down integrator timer that counts up the time the secondary ΔP input signal exceeds the fault trip level (2200 ± 110 psi for ATVCs and 2025 ± 110 psi for ASAs). When the input signal drops below the 2200 psi limit, the counter will count down at one-fourth the rate it counts up for the ASA's (the counter counts down at the rate of 1/4 s/s) and at one-half the rate for the ATVC's. When the time counter counts up to 120 ms, an isolation command will be issued to isolate (bypass) the affected servo valve. The bypass is accomplished by connecting together the two lines across which the ΔP exists by opening a bypass valve. When the servo valve is bypassed, the secondary ΔP input signal goes to 0 psi (no longer presenting a force on the power spool) and the time counter counts down.

For further information on FCS channel management, review the following documents:

FLIGHT RULES

A8-107 FCS CHANNEL MANAGEMENT
A8-56 BFS LRU REQUIREMENTS

FLIGHT DATA FILE

Entry Pocket Checklist
Asc/Ent Systems Proc

FCS CH 1 (2,3,4) (2nd FAIL)
FCS CH 1 (2,3,4) (2nd FAIL)

PROCEDURES

For the following cases, the Control operator should utilize the following data display sources:

Digital data displays:

ATVC: Ascent Control
ASA: Entry Control

CRANS matrices:

ATVC: SRB Actuators
SSME Actuators
ASA: Aero Actuators

RTPLOTS:

ASA: Sec DP: Elevons

HARDOVER FAILURE, SEC $\Delta P > 2200/2025$ PSI, BYPASSED

A. Recognition

Parameter

- sec ΔP
(prior to bypass)

Trend/value

- force fight
- bad ch: ≈ 3000 psi (hydraulic press), large spike

- remaining chs: each \approx , opposite sign of bad ch
 Σ sec $\Delta P \approx$ bad ch, opposite sign

(after bypass)

ALTERNATE

- C&W

- bad ch = 0.0
- remaining channels sec $\Delta P \approx 0$ psi

- FCS CH X message
- 'F' status by bypassed actuator(s) (if byp due to FA MDM, 'F' masked by CF)
- ACT ΔP /BYP

B. Failure Identification

Parameter

- posn fbk
(ASA only)

- driver cmd
(ASA/ATVC output)

- actuator cmd
(MDM output)

- ASA/ATVC
power supply

Trend/value

- verify all other fbk \approx on affected actuator(s)
- identify bad \geq RM limit (if applicable)

- verify all other cmd \approx on affected actuator(s)
- identify bad, $\Delta > \underline{X}$ ma (if applicable)

- verify dynamic cmds (no 'I/O ERR FA X' or output card fail)

- verify at least 1 good input (RPC output status)

C. Action

- 1st ch fail: no action
- 2nd ch fail (same actuator): remaining good FCS ch-OVRD
- if force fight due to FA MDM or GPC: affected FCS ch-OFF (force bypass)

D. Notes

1. If failure identification parameters are good, failure may be servo valve flapper or hydraulic fluid silting.
2. Bad position fbk LVDT will cause ASA driver command to be in error.
3. Simultaneous bypass of all ports on a channel indicates a power supply failure. Internal power supplies may fail and cause bypasses without tripping remote power controller (RPC). Verify all ASA position fbks bad before FCS ch-OFF (elevation = -7.5°, BF = 50 percent, SB = 44°, rudder = 0°).
4. SPEC 53, PORT STAT will display ↓ for bypassed actuator(s).

HARDOVER FAILURE, SEC ΔP > 2200/2025 PSI, UNBYPASSED (DUAL FAILURE)

A. Recognition

<u>Parameter</u>	<u>Trend/value</u>
<ul style="list-style-type: none">• sec ΔP	<ul style="list-style-type: none">• force fight• bad ch: ≈ 3000 psi (hydraulic press), continuous • remaining chs: each ≈, opposite sign of bad ch Σ sec ΔP ≈ bad ch, opposite sign
<ul style="list-style-type: none">• C&W	<ul style="list-style-type: none">• ↓ by affected actuator(s)• no FCS CH <u>X</u> message• no 'F' status by affected actuator(s)• ACT ΔP/BYP

B. Failure Identification

<u>Parameter</u>	<u>Trend/value</u>
	Force Fight
<ul style="list-style-type: none">posn fbk (ASA only)	<ul style="list-style-type: none">verify all other fbk \approx on affected actuator(s)identify bad \geq RM limit (if applicable)
<ul style="list-style-type: none">driver cmd (ASA/ATVC output)	<ul style="list-style-type: none">verify all other cmd \approx on affected actuator(s)identify bad, $\Delta > \underline{X}$ ma (if applicable)
<ul style="list-style-type: none">actuator cmd (MDM output)	<ul style="list-style-type: none">verify dynamic cmds (no 'I/O ERR FA \underline{X}' or output card fail)
<ul style="list-style-type: none">ASA/ATVC power supply	<ul style="list-style-type: none">verify at least 1 good input (RPC output status)
	Fail to Bypass
<ul style="list-style-type: none">isolation valve driver power	<ul style="list-style-type: none">verify at least 1 good isol driver input (RPC output status)

C. Action

- Remaining good FCS ch - OVRD
- if isol pwr good: SPEC 53 - bypass affected actuator(s) (OPS 3/ASA only)

D. Notes

- If isol valve driver is good, fail to bypass may be due to fault detection circuit, isol valve driver circuit or bypass valve.
- SPEC 53 will cause bypass if failure is fault detection circuit.
- Isolation driver power for all ATVCs and ASA 4 is single source.

BIAS FAILURE, 1100 < SEC ΔP < 2200/2025 PSI

A. Recognition

<u>Parameter</u>	<u>Trend/value</u>
<ul style="list-style-type: none"> • sec ΔP 	<ul style="list-style-type: none"> • force fight • bad chan: 1100 < sec ΔP < 2200/2025 psi • remaining chs: each ≈ opposite sign of bad Σ sec Δ P ≈ bad chan, opposite sign
<ul style="list-style-type: none"> • C&W 	<ul style="list-style-type: none"> • ↓ by affected actuator • ACT ΔP/BYP

B. Failure Identification

<u>Parameter</u>	<u>Trend/value</u>
<ul style="list-style-type: none"> • posn fbk (ASA only) 	<ul style="list-style-type: none"> • verify all other fbk ≈ on affected actuator(s) • identify bad (if applicable)
<ul style="list-style-type: none"> • driver cmd (ASA/ATVC output) 	<ul style="list-style-type: none"> • verify all other cmd ≈ on affected actuator(s) • identify bad (if applicable)
<ul style="list-style-type: none"> • actuator cmd (MDM output) 	<ul style="list-style-type: none"> • verify dynamic cmds (no 'I/O Error FA X' or output card fail)

C. Action

Four options exist to handle this situation. Depending on the scenario, crew workload, etc, any one of the following options may be used:

- For an ASA failure during OPS 3 or 6, manually bypass the affected channel on the affected aerosurface on SPEC 53 CONTROLS display. This action is allowed if the secondary ΔP is greater than 1400 psi (see Flight Rule A8-107 G).
- Turn affected channel off (force bypass of bad channel). Isolate bad channel at cost of giving up redundancy on all other surfaces.
- Take other good channels to override (allow time to reconfig after next worst failure). Next worst failure may result in stall of actuator (2-on-2, or 2-on-1-on-1 force fight).
- Do nothing (leave bad actuator in system with force fight above equalization limit). Next worst failure in same direction may result in bypass of remaining good channels.

D. Notes

1. If failure identification parameters are good, failure may be servovalve flapper or hydraulic fluid silting.
2. Constant fbk or driver bias will result in constant force fight regardless of actuator cmd.
3. Static actuator cmd that is close to good cmds will result in force fight that is proportional to the difference between them; affected actuator(s) will bypass when cmd Δ is great enough.
4. Affected actuator position will not equal cmd because good channels are offset from null to fight the bad channel (max $\Delta < 2^\circ$).
5. Equalization circuit is designed to account for mechanical tolerances; will offset steady state bias up to 6 ma limit for ASA.
6. If 2 degree bias channel (same act) identified, take remaining good ch-OVRD.

NULL FAILURE, 0 DRIVER CMD

ASA

A. Recognition

- Null driver failures are readily detectable during secondary actuator check (OPS 8 FCS C/O or OPS 3 secondary actuator check). Null drivers may or may not be detectable during dynamic flight, since the force fight developed against the null driver is a function of the drive rate of the aerosurface.

B. Notes

1. Driver current represents error signal to the actuator; i.e., equals 0 ma when no change in surface position is commanded (steady state trim), not equal to 0 ma during commanded surface activity (mnvr).
2. Channel with null failure will be dragged along by remaining good channels during surface movement. The channel is receiving zero driver current from the ASA but its servovalve will be influenced by the power valve mechanical feedback wire and offer resistance (sec ΔP) to the other channels proportional to the rate that the surface is being driven.
3. Probability of detecting a null failure in real time is low.
4. Flight Control Hydraulics Laboratory (FCHL) testing has shown that the flight control system is capable of handling one null failure on an ASA actuator; however, if there are two channels with null failures on a particular actuator, then there is a possibility that during high surface rates the two good channels will bypass, leaving the

actuator out of control. For this reason if a null failure is discovered during the secondary actuator check, then bypass the null channel.

5. Command/position Δ required for aerosurface bypass is a function of the number of good APU's and aero hinge moment.
6. An open circuit (broken wire) between the ASA and flapper coil will appear as null failure.

ATVC

A. Recognition

Parameter

- sec ΔP

Trend/value

- bad channel: force fight; increase proportional to cmd/posn Δ
- remaining chans: opposing bad

B. Failure Identification

Parameter

- actuator cmd (MDM output)

Trend/value

- verify dynamic cmds (no 'I/O Error FA X' or output card fail)
- driver cmd (ATVC output)
 - constant 0.0
 - driver cmd \neq actuator cmd
- ATVC power supply
 - verify at least 1 good input (RPC status)

C. Action

- 1st fail: no action (bypassed or unbypassed)
- 2nd fail (same actuator): remaining FCS ch-OVRD

D. Notes

1. Driver current represents position command to the actuator; i.e., 0 ma = 0 degrees cmd. Driver current should equal actuator cmd; nominally, driver current \neq 0 ma because SSME position cmd \neq 0 degrees.
2. ATVC null failure is detectable in real-time ascent because failed channel is actively fighting the remaining channels by commanding different position. Magnitude of sec ΔP is proportional to the distance from 0 degrees the remaining channels are being commanded.

3. An open circuit (broken wire) between the ATVC and flapper coil will appear as null failure.

ASA POSITION FEEDBACKS

A. SPEC 53 - deselection

- Deselect channel 4 feedbacks if failed > RM limit (all surfaces)
- for ASA power supply failure, verify all fbks bad before deselecting (elevon = -7.5° , BF = 50 percent, SB = 44° , rudder = 0°)
- deselect fbk for any channel 1, 2, or 3 turned off (e.g., for a DPS (GPC, MDM failure))

B. Notes

1. Selection Filter:
BF - QMVS
elevon/RSB-MVS 1,2,3 until first fail then 4 is substituted
2. Position feedback FDIR: active at 4-level only (PASS only)
3. Due to MVS RM, ch 4 fbk (except BF) can fail > RM limit but not be annunciated. Subsequent RM declared failure of ch 1, 2 or 3 fbk will cause bad ch 4 fbk to be used by SF.
4. All fbks are summed with their respective actuator cmd in the ASA to form driver cmd. However, only elevon and BF are used within the Aerojet DAP to form actuator cmds.
5. No Fault Messages are annunciated to crew for RM posn fbk fail.

TABLE 8.1-II. - FDIR/RM MAJOR MODE APPLICABILITY

Functional module	Major mode						Value
	1 1 1 1 1 1 0 0 0 0 0 0 1 2 3 4 5 6	2 2 0 0 1 2	8 0 1	3 3 3 3 3 0 0 0 0 0 1 2 3 4 5	6 6 6 0 0 0 1 2 3		
Elevon fbk FDIR				X X X X X	X X	2.38°	
Elevon ΔP fbk FDIR	X					600 psi	
Speed brake fbk FDIR				X X X X X	X X	4.04° (4.6%)	
Rudder fbk FDIR				X X X X X	X X	2.22°	
Body Flap fbk FDIR	X X X X X X			X X X X X	X X X	1.76° (5.0%)	

GENERAL NOTES

A. FCS ch switch position monitor (CRANS):

FCS X ORIDE CMD: any of 6 ASA X actuator override commands true

FCS X ORIDE: any of 3 override switch contacts closed

FCS X AUTO: any ASA or ATVC RPC powered

FCS X OFF: no ASA or ATVC RPCs powered (see also the RPC and override switch-contact indications on the digital displays)

B. During powered flight, optimize ch configuration for ATVC. If RTL/TAL/AOA, optimize for ASA post-MECO.

C. FCS ch break-before-make switch:

When the FCS switch is in the auto or override positions, power is applied to ASA/ATVC boxes provided the respective ASA and ATVC switches are on.

- When the FCS switch is moved from the auto posn to the override posn and vice versa, there is always a power interruption to the ASA/ATVC boxes (in the order of milliseconds because of break-before-make switch contacts).
- This power interruption causes all the ports on that FCS chan to temporarily "bypass" until the internal power supplies come back up, which will take from 510 ms to 1370 ms in the ASA and from 210 ms to 520 ms in the ATVC.
- The break-before-make characteristics of the FCS ch sw is such that the reset function can be accomplished by moving the FCS ch sw from auto to override and then back to auto even if the override contacts are "failed open." This is because the reset occurs as a result of the input power cycle rather than the issuance of the GPC override discrete.

D. Momentary SSME actuator override is issued by R/S launch sequencer during main engine start by SSME ops sequencer to prevent inadvertent bypass.

- E. During FCS C/O, the ATVC fail discrettes should be monitored (or looked at post-FCS C/O) to verify that fail did not remain while FCS CH switch is in override position.

REFERENCES

1. Ascent/Entry Flight Techniques meeting #10, Apr. 1984.
2. Computer Program Development Specifications (CPDS), vol. 5, book 5, SS-P-002-5501, p. 4-317, Aug. 1, 1983.
3. GNC Systems Briefs, JSC-18863, Secs. 10, ASA, and 11, ATVC.
4. Space Shuttle Operational Flight Rules, All Flights, NSTS-12820, latest version.
5. Shuttle Calibration Data Book, JSC-16486-28, vol. VIII, July 1988.
6. Space Shuttle Systems Handbook, vol. I, rev. D, secs. 9.11 and 9.15, Mar. 20, 1988.
7. Ascent/Entry Systems Procedure, JSC-48001, latest version.
8. Entry Pocket Checklist, JSC-48021, latest version.

TITLE

ACTUATOR POSITION PROFILES

PURPOSE

To provide a source for verification of correct actuator positions in each OPS.

PROCEDURES

Tables have been provided that give the uncompensated (BFS and crew read) and compensated (PASS) commands for Space Shuttle main engine (SSME), orbital maneuvering system (OMS), solid rocket booster (SRB), and aerosurface actuators.

Tables 8.2-I, 8.2-III, and 8.2-IV are taken from program notes and waivers (OI-8C-37551 Actuator/Hydraulic Subsystem Activation Restrictions; Rev C Nov. 1989).

A. AEROSURFACE ACTUATORS

The uncompensated and compensated positions for each OPS are listed in tables 8.2-I and 8.2-II.

Compensated CMDS are calculated from the equation

$$\text{CMD} = \text{Floor} [(\text{UNCMPCMD}) (\text{SF}) + (\text{BIAS})] 100 (A_1)$$

Where:

UNCMPCMD	= Uncompensated CMD (DEG) (DAP FSSR SOP I-load)
SF	= Scale factor (VDC/DEG) (FSSR SOP I-load)
BIAS	= Bias (VDC) (FSSR SOP I-load)
A ₁	= Calibration coefficient (MCC CALS)
Floor	= Round down to integer value

This equation applies to all the actuators (SSME, OMS, SRB).

In calculating the elevon commands, (and speedbrake), a bias was added to the compensated command to account for the bias built into the Structural PTI Subsystem Operating Procedure (SPTI SOP).

Elevon bias -7.5°
Speedbrake bias 44.89°

B. SSME ACTUATORS

The uncompensated and compensated values for each OPS using the same equation for the compensated values as the aerosurfaces are given in tables 8.2-III and 8.2-IV.

The actual displayed values as seen on the Mission Control Center (MCC) display peculiar to each OPS are in table 8.2-IV.

The SSME's go to DUMP position (same as stow position) in OPS 103 and then stow in 104 where they remain for the rest of the flight (OPS 2 and 3). OPS 602 also commands the stow position. They go to drag chute reposition position for RTLS.

The SSME commands and upper/lower limits for the OPS 9 postlanding repositioning are listed in SCP 8.3 SSME Repositioning Monitoring. During OPS 9, the compensated and uncompensated commands for the SSME's are the same since the SSME TVC SOP is not running.

C. OMS ACTUATORS

The uncompensated and compensated values for the OMS actuators using the same compensation equation are in tables 8.2-V and 8.2-VI.

In MM 104, the OMS TVC CMD SOP processes the I-load OMS 1 positions for a two-engine burn. For a one-engine burn (one engine out), the digital autopilot (DAP) still uses the 2 engine I-loads but the crew can load the OPS 1 single engine burn positions to calculate the correct attitude.

For all subsequent burns, the crew will load the required trim positions. These can be the standard 1 or 2 engine trim values from the appropriate checklist or, as is nominally the case, the more accurate trim values (from the OMS burn pad) which are based on exact vehicle center of gravity (c.g.) provided by the Flight Dynamics Officer.

D. SRB ACTUATORS

The SRB actuators are commanded to 0.0° after the slew check is complete and remain in that position until just after lift-off. Just prior to SRB SEP the TVC's are commanded to 0.0°.

REFERENCES

1. OI-8B Flight Software, Program Notes and Waivers, JSC-19320, DR-37551, Oct. 24, 1988.
2. STS Flight Software Initialization Load, JSC-19350: 1, vol. I, rev 2, Feb, 1986.
3. Rockwell presentation to the Systems Integration Review panel on 2/6/90 by W. A. McDermott (87-985-4225). CR number S609575.

TABLE 8.2-I.-AEROSURFACE UNCOMPENSATED COMMANDS, PASS ACTION
INITIALIZATION (AEROSURFACES)

(SOURCE: USER NOTE OI-8C-037551 - ACTUATOR/HYDRAULIC SUBSYSTEM
ACTIVATION RESTRICTIONS)

Trans/ event	OPS 9 (a)		OPS 101 (b)		OPS 102-106 (c)		OPS 2 (d)		OPS 8 (e)	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
LIB	AI MODE 1	AI MODE 1	0.0	0.0	0.0	0.0	MFB	MFB	FDBK	0.0
LOB	AI MODE 1	AI MODE 1	0.0	0.0	0.0	0.0	MFB	MFB	FDBK	0.0
RIB	AI MODE 1	AI MODE 1	0.0	0.0	0.0	0.0	MFB	MFB	FDBK	0.0
ROB	AI MODE 1	AI MODE 1	0.0	0.0	0.0	0.0	MFB	MFB	FDBK	0.0
RUD	AI MODE 1	AI MODE 1	0.0	0.0	0.0	0.0	MFB	MFB	FDBK	+5.0
SB	AI MODE 1	AI MODE 1	+5.0	-9.9	-9.9	-9.9	MFB	MFB	FDBK	+10.0
BF	AI MODE 1	AI MODE 1	0.0	0.0	0.0	0.0	MFB	MFB	FDBK	0

TABLE 8.2-I.-CONTINUED

Trans/ event	OPS 301-303		OPS 304-305 (f)		OPS 601-603	
	IN	OUT	IN	OUT	IN	OUT
LIB	MFB	THERM	FDBK	A C E M	0.0	G C R M
LOB	MFB	THERM	FDBK	R D O	0.0	T D L
RIB	MFB	THERM	FDBK	J V E A	0.0	S V A
ROB	MFB	THERM	FDBK	T L U	0.0	D L A U
RUD	FDBK	THERM	FDBK	D E A S	0.0	P E S
SB	FDBK	THERM	FDBK	P	-9.9	
BF	FDBK	THERM	FDBK		0.0	

^a AI MODE 1 (CMD = MVS position fbk) must be executed before other actuator command functions are legal (no cyclic outputs to actuators in G9, PL9, and OPS 0).

^b Major Mode 101 cyclic output buffers initialized to IN values shown during OPS initiation. Speedbrake faded to closed position (-9.9°) on reaching event 6 (go for auto sequence start). If event 6 is reached and a recycle is requested the speedbrake is moved to +5.0 degrees from wherever it is.

^c Elevons used for load relief during first stage and returned to zero after first stage.

^d MFB values for load relief during first stage and returned to zero after first stage.

Elevons 0.0
Rudder 0.0
Speedbrake 5.0
TVC (SSME, OMS) STOW

^eThe rudder and speedbrake values are +5.0 and +10.0 respectively only if the aerosurface drive test is executed. Otherwise they are both equal to feedback values at OPS 8 transition.

^fNo speedbrake initialization requirement. On transition to MM 304, speedbrake will be commanded closed (-9.9°) when flight control test: If MACH > 10.0 is true.

TABLE 8.2-II.-AEROSURFACE ACTUATORS COMPENSATED COMMANDS

Transition/ event	OPS 9	OPS 101	OPS 102-106	OPS 2 (a)	OPS 8 (b)	OPS 301-303	OPS 304-305		OPS 601-603	
Actuator										
LIB	AI MODE 1	0.33	0.33	MFB	-0.02	THERM	A	C	G	C
LOB	AI MODE 1	0.49	0.49	MFB	-0.03	THERM	E	M	R	M
RIB	AI MODE 1	0.33	0.33	MFB	-0.02	THERM	R	D	T	D
ROB	AI MODE 1	0.49	0.49	MFB	-0.03	THERM	O		L	
RUD	AI MODE 1	0.0	0.0	MFB	4.97	THERM	J	V	S	V
SB	AI MODE 1	4.94	-10.25	-10.25	+10.21	THERM	E	A		A
BF	AI MODE 1	0.0	0.0	MFB	0.0	0.0	T	L	D	L
							U		A	U
							D	E	P	E
							A	S		S
							P			

^aMFB values same as previous OPS. If MFB obtained from MMU, the following values apply:

Elevons 0.0
Rudder 0.0
Speedbrake 4.94
TVC (SSME, OMS) Stow

^bThe rudder and speedbrake valves are 4.97 and 10.21, respectively, only if the aerosurface drive test is executed; otherwise, they are both equal to feedback valves at OPS 8 transition.

TABLE 8.2-III.-UNCOMPENSATED CMDS, PASS ACTUATOR INITIALIZATION (SSME'S)

(SOURCE: USER NOTE OI-8C-37551 - ACTUATOR/HYDRAULIC SUBSYSTEM
ACTIVATION RESTRICTIONS)

Trans/ event	OPS 9 (g)		OPS 101				OPS 102 (c)		OPS 103		OPS 104		OPS 105-305 (d)	
	In	Out	In	Start (a)	Launch	Out	In	Out	In	Out (ENT STOW)	In	Out (ENT STOW)	In	Out
P1	AI	AI	AI	0.0	0.0	0.0	0.0	A C	A C	0.0	0.0	0.0	0.0	0.0
P2	M	M	M	0.0	0.0	0.0	0.0	S M	S M	-10.0	-10.0	-10.0	-10.0	-10.0
P3	D	D	D	0.0	0.0	0.0	0.0	C D	C D	-10.0	-10.0	-10.0	-10.0	-10.0
Y1				0.0	0.0	0.0	0.0	D V	D V	0.0	0.0	0.0	0.0	0.0
Y2	1	1	1	0.0	-3.5	-3.5	-3.5	A A	A A	-3.5	-3.5	-3.5	-3.5	-3.5
Y3				0.0	3.5	3.5	3.5	P L	P L	+3.5	+3.5	+3.5	+3.5	+3.5
								U	U					
								E	E					
								S	S					

TABLE 8.2-III.- CONCLUDED.

Trans/event	OPS 601-602 (e)		OPS 602 (e)		OPS 601 (f)		ENG OUT STOW
	In	Out	In	Out	In	Out	
P1	A C S M	0.0	0.0	0.0	A C S M	0.0	-3.0
P2	C D	-10.0	-10.0	-10.0	C D	-10.0	3.0
P3	D V A A	-10.0	-10.0	-10.0	D V A A	-10.0	3.0
Y1	P L U	0.0	0.0	0.0	P L U	0.0	0.0
Y2	E S	-3.5	-3.5	-3.5	E S	-3.5	3.0
Y3		+3.5	+3.5	+3.5		+3.5	-3.0

^aMPS slew check, which is initiated via ground inputs, commands SSME's to START position on completion of slew test. If slew check not performed, SSME's are commanded to START positions on event 6 (GO for auto sequence start).

^bSSME's are commanded to launch position at event 18A (MPS thrust > 90 percent).

^cLaunch positions maintained until tower clearance.

^dActuator stow must be completed in OPS 1 prior to entering OPS 201 or 301. MPS TVC command SOP does not run in OPS 2 or 3 and SSME positions are held by cyclic I/O. OPS 8 (VU) S/W commands SSME to entry stow position.

^eAt termination of LH2 dump (event 43A), the SSME's are commanded to the stow position by MPS dump sequencer. For contingency abort (OPS 104 to OPS 602 transition), MM initialization commands SSME's to stow on entry to 602.

^fFor fast SEP in OPS 102, ET SEP sequencer sets SSME stow on entry to 602.

^gAI Mode 1 (CMD = MVS position fbk) performed at initial entry into G9 then again at L-3 hr.

Note: For recycle back to OPS 9, the following G9 initializations apply:

- 1) if SSME slew not performed: AI Mode 1 CMD from G9-G1 transition
- 2) if slew performed but no ignition: Start position
- 3) if ignition/pad abort: Gravity position

When a recycle count is requested, the SSME's are moved from wherever they are (i.e., either the launch or start positions) to the gravity positions.

TABLE 8.2-IV.- SSME COMPENSATED COMMANDS

Trans/ event	OPS 9 (g)	OPS 101		OPS 102 (c)	OPS 104 (ENTRY STOW)	OPS 105-305	OPS 601-602	OPS 602	OPS 601	ENG OUT STOW
		Start	Launch							
P1	AI	-.32	-.32	ASP	-.32	-.32	-.32	-.32	-.32	-3.33
P2	M O D E	.32	.32	DAP	-9.70	-9.70	-9.70	-9.70	-9.70	3.33
P3		-.32	-.32	CMD	-10.35	-10.35	-10.35	-10.35	-10.35	2.66
Y1		.17	.17	VALS	.17	.17	.17	.17	.17	.17
Y2	1	.21	-3.37		-3.37	-3.37	-3.37	-3.37	-3.37	3.25
Y3		.21	3.65		3.65	3.65	3.65	3.65	3.65	-2.75

NOTE: The compensation biases were calculated using the I-loaded scale factors and biases from FLT S/W.

TABLE 8.2-V. - UNCOMPENSATED COMMANDS, PASS ACTUATION INITIALIZATION

Transition/ Event	OPS 9		OPS 101-103		OPS 104 Start OMS 2		OPS 105 Start OMS 2		OPS 202	
	In	Out	In (Stow)	Out	In (b)	Out	In (b)	Out	In (b)	Out
LP	AI	+5.91	5.89	5.89	0.4	L C	L C	T C	L C	L C
LY	AI	+7.29	6.44	6.44	-5.75	A M	A M	R M	A M	A M
RP	AI	+5.91	5.89	5.89	0.4	S D	S D	A D	S D	S D
RY	AI	-7.29	-6.44	-6.44	5.75	T	T	N S	T	T
					2 P	O V	O V	D V	T V	O V
					A	M A	M A	A A	R A	R A
					S L	S L	S L	P L	A L	B L
					N A	1 U	1 U	U E	N U	I U
					G L	E S	E S	S S	S E	T E
					I L	B S	B S	D S	D S	S
					N E	U R	U R	A P	A P	D A
					E L	R N	R N	/ O	R B	A P
						T R	T R	R B	I T	O M
						A N	A N	S S	S	S
						S D	S D	D A	P	B U
						A P	A P	P	P	R N

TABLE 8.2-V - CONTINUED

Trans/event Actuator	OPS 3				OPS 303		OPS 601-603 (c)		OPS 602-603 (d)	
	Trim D/O Burn		Start D/o Burn		In	Out (Stow)	In	Out	In	Out
	In (b)	Out	In	Out						
LP	L C	T D	T D	L C	L C	+5.89	+5.89	+5.89	+5.89	-0.86
LY	A M	R E	R E	A M	A M	+6.44	+6.44	+6.44	+6.44	+6.44
RP	S D	A O	A O	S D	S D	+5.89	+5.89	+5.89	+5.89	-0.86
RY	T N	R B	R B	T V	T V	-6.44	-6.44	-6.44	-6.44	-6.44
	O A	D I	D I	V A	V A					
	R L	A T	A T	E L	E L					
	B U	P	P	O U	O U					
	I E	T	T	R E	R E					
	T S	R	R	B S	B S					
		I	I	I	I					
		M	M	T	T					
		C	C	B	B					
		M	M	U	U					
		D	D	R	R					
		S	S	N	N					
				T	T					
				R	R					
				A	A					
				N	N					
				S	S					
				D	D					
				A	A					
				P	P					

- ^a OMS TRIM for first OMS burn is accomplished in OPS 104 prior to event 36A. The TRIM values shown correspond to I-loaded values and are commanded by the TVC command SOP. The TRIM values may be changed via crew inputs, but engines will not move to the new trim position until ignition (vs. TIG-15 sec).
- ^b OMS TRIM values can be changed by the crew or uplink prior to each OMS burn.
- ^c Stow values shown for OPS 6 are valid for all transitions from OPS 1 prior to MM 104 (102-601 contingency and intact, and 103-601 intact).
- ^d Values shown for OPS 6 valid if the abort is selected post-MECO and contingency dump selected by crew. Otherwise, the OMS engines are left in STOW positions as shown for inputs.

TABLE 8.2-VI.-OMS TVC ACTUATOR POSITIONS

(SOURCE: FLIGHT SOFTWARE)

Event/OPS Actuator	Stow OPS 101-103, 303-305, 602	OMS 1 OPS 104 (I-load)	2 Engine parallel	Single engine c.g.	GMBL Check*	
LP	5.80	0.31	0.31	0.31	5.80	-5.96
LY	6.01	-6.19	-6.19	4.78	6.01	-6.88
RP	5.80	0.31	0.31	0.31	5.80	-5.96
RY	-6.01	6.19	6.19	-4.78	6.88	-6.01

- (1) GMBL CK is done per GNC Flight Rule A8-113C.
- (2) Trims required for 2 engine parallel and single engine c.g. burns will change slightly as a function of orbit operations (propulsive consumables, deploys, retrieval, etc.). Guidance Officer will provide predicted Orbiter c.g. to calculate exact trim values.
- (3) The OMS 1 OPS 104 and Single Engine cg values can change flight-to-flight but not likely.

TITLE

SSME REPOSITIONING MONITORING

PURPOSE

To provide a procedure for monitoring the Space Shuttle Main Engine (SSME) repositioning that must be accomplished by the Shuttle Orbiter crew during postlanding.

BACKGROUND

After each Shuttle Orbiter landing, the SSME's have to be moved from their entry stow or drag chute positions to a unique position. Flight Rule A16-9, SSME Repositioning Constraint, specifies some equipment failures that would prevent successful completion of this procedure in which case the procedure will not be attempted. This procedure is performed with the auxiliary power units (APU's) running and after transition into OPS 9.

PROCEDURE

The crew procedure for performing the SSME repositioning is maintained in the Post Landing section of the Entry Checklist . The onboard CRT display GNC SPEC 105 TCS CONTROL has the capability to perform several operations and is fully described in the DPS Dictionary. However, this procedure utilizes only the rain drain final actuator initialization (AI) mode.

The AI modes 1 and 0 are always performed preceding mode 3.

A. AI MODE DESCRIPTION

The AI process performs five functions

1. Preconditions the actuator MDM's with position feedback values, mode 1
2. Drives each actuator to a specified initial position, mode 0

3. Drives Orbital Maneuvering System (OMS) (see note below), SSME, Body Flap, Elevons, and Speedbrake/Rudder to one of the following positions:

FERRY position, mode 2
RAIN position, mode 3
GRAVITY position, mode 4
NULL position, mode 5
TURNAROUND position, mode 6

NOTE: SPEC 113 NOP OMS ITEM 40 is initialized to the INHIBIT state (*) during OPS G9 initialization process. Therefore, the OMS power discrete and the out-of-tolerance error codes from the AI functions for OMS actuators will be inhibited and the OMS TVC will not move.

Each task can be selected via the TCS Call operator. This procedure does not address modes 2, 4, 5, or 6.

Upon initialization, the AI function is required to run in mode 1 prior to the running of mode 0, and it is required to run successfully in mode 0 prior to running any of the other modes (2, 3, 4, 5, 6).

1. MDM Preconditioning - mode 1

For each aerosurface, the commanded position is the result of a middle-value selection performed on the four actuator feedbacks. At the four-level, RM MVS's the position feedbacks from Channels 1, 2, and 3. If one of those channels is commfaulted, RM will use channel 4 to replace the commfaulted feedback in the MVS scheme. At the two-level, the non-commfaulted feedbacks are averaged, and the single available feedback used at the one-level. RM will downmode for commfaults only. FDIR and manual deselects are not available in OPS 9, and do not carry over from OPS 3. The body flap is sent an inhibit command. For the SSME, rudder, speedbrake, and elevon actuators, the position feedbacks are limit checked against the maximum initialization values listed in Table 8.3-I. If the position feedback value or the middle value for any of these actuators is outside the limits, the position command issued is equal to the maximum initialization value.

2. Initial Positioning - mode 0

The AI function will perform the initialization task by issuing commands to drive the SSME pitch and yaw actuators, aerosurface actuators, and body flap actuators to pre-defined positions in a pre-defined order, as shown in Table 8.3-II.

3. Rain Position - mode 3

The AI function will perform the positioning of the SSME pitch and yaw actuators, the body flap actuator, the speedbrake actuator and the rudder actuator to the Rain (mode 3) position as shown in Table 8.3-III.

Note: KSC has encountered problems with the Turnaround (mode 6) position. The problem arises from SSME drift which occurs following hydraulic system deactivation. As the engines drift out of position, they interfere with OMS/RCS

platform installation which occurs 96 hours after landing. SSME actuator locks are available to hold the engines in place but it is not always possible to install the locks before the engines drift outside of acceptable limits. An attempt was made to improve this situation by changing the commanded turnaround positions (CR91027). It was hoped that new Turnaround positions could be selected which would allow the SSMEs to drift into the proper positions by the time KSC was able to install the SSME locks. Unfortunately, it was found that actuator drift rates are highly actuator dependent and that some of the engines would drift into the proper positions while others would not. Interference with the OMS/RCS platform remained a problem. Therefore, Raindrain (mode 3) is selected for the postlanding position.

B. MCC - GNC/CONTROL ACTIVITY

Prior to landing, the flight director will ask for any postlanding changes to the Entry Checklist. The GNC response is to NO-GO the "SSME Repositioning" if any of the Flight Rule constraints are violated. The procedure should be NO-GO if an ATVC channel is failed and not able to be bypassed.

While in OPS 305, during postlanding, there is a hydraulic load test (on MCC call) procedure callout in the Entry Checklist. The GNC may want to NO-GO this procedure if there has been a body flap fail, cycle, or hold message during entry through landing phase. In addition, the GNC may not be GO for OPS 9 transition with a body flap fail, cycle, or hold condition since body flap command Redundancy Management (RM) is not available in OPS 9 software.

GNC Best Practice: If GPC failures have reduced the number of FCS channels available for postlanding activities, it is best to perform a restring to recover all strings while in OPS 3, prior to the OPS 9 transition. This allows all channels to be returned to auto, and recovers the aerosurface position feedbacks. Not doing so will reduce the fault tolerance of the MVS (at a minimum) or lead to faulty selected positions (worst case) in AI Mode 1, which is performed automatically after the OPS 9 transition.

GNC should verify that the MPS/TVC isolation valves for all good hydraulic systems are open prior to start of the repositioning sequence. Actuator and hydraulic system damage can occur if the isolation valves are opened after the repositioning sequence has begun.

GNC will monitor the "SSME Repositioning" procedure as it automatically goes through its modes 1, 0, and 3 using the appropriate table in this SCP and keeping the flight director informed as necessary. A Postlanding CRANS matrix is available to assist in monitoring the repositioning process (Note: the logic in this tool uses Channel 1 feedbacks, so if these feedbacks are failed or commfaulted, the CRANS matrix cannot be used). It is also helpful to run a real-time plot which displays the SSME positions.

In the event that the crew receives an error message they are to report to the MCC for instructions. The only options for GNC may be to:

1. Have the crew repeat the procedure if the SSME's are not at the desired position for the selected mode. If a second attempt is not successful, then the SB repositioning procedure should be used if the SB was positioned to 21% prior to a AI mode 0 failure and landing was at KSC, otherwise the BF needs to be full down for platform installation (see part D below). Note: There is an automatic repeat of the sequence

(one-time) for an error message so a crew repeat of the procedure is not likely to be successful unless some condition has changed.

2. In most cases, when an error message is reported by the crew, the prudent GNC option is to recommend the crew execute ITEM 5 on GNC SPEC 105 TCS CONTROL to terminate the sequence.

When using SPEC 105, it is important to note that dropping the display also terminates any AI Modes that are active. If the display is dropped, and it is desired to return back to SPEC 105 to resume a sequence, it is necessary to re-load the Explicitly Coded Program (ECP) with an Item 1 +XX EXEC, where XX is the ECP number (2 for SSME REPO).

C. ERROR CODES DISPLAYED TO THE CREW

An appropriate CALL program error response code may be generated relative to the conditions defined below. For all such error conditions, the GPC shall reject the call operator and inhibit the test. The error code shall be made available for the TCS CALL program error response and to the TCS CONTROL display.

<u>Conditions</u>	<u>Error code</u>
Housekeeping data acquisition (HDA) function not active for reading position feedback	102
Actuator position not within tolerance	103
A CALL operator which requests either AI mode 0, mode 2, mode 3, mode 4, mode 5, or mode 6 to run after OPS 9 initialization and prior to running AI mode 1	102
Actuator position feedback values invalid due to I/O errors	104
A CALL operator which requests either mode 2, 3, 4, 5, or 6 prior to AI mode 0	102

D. SPEEDBRAKE AND BODYFLAP REPOSITIONING

In the event rain drain cannot be achieved, there are two additional steps that can be performed to assist ground crews. Both of these actions configure aerosurfaces to allow GSE platforms to be installed. The first is to position the bodyflap full down (100%). This is required at remote sites to allow the A70-1201 platform to be positioned. For simplicity, this is part of the nominal post-landing procedures in OPS 3 with the manual BF switches (doing so is only required at remote sites, but is no impact at KSC). If the BF does not reach 100%, the position should be noted and passed to the convoy commander to allow the team to prioritize accordingly. It is unknown where the BF begins interfering with platform installation, but 100% is known to be adequate.

The second action available is to reposition the speedrake to within 21%. The SB is always closed (15%) by the PLT as one of the first post-landing actions. Fifteen (15) percent is sufficient for OPF access swing installation, however it was observed after STS-46 that the access swings barely cleared a 21% SB. For this reason, a postlanding SB repositioning using SPEC 113 is provided to drive the SB to 8%. This is required only at KSC should SSME repositioning fail in AI Mode 0 (failing AI Mode 0 can result in a SB position of 21%). Note: Because of the interaction of the RUD and SB (see SCP 5.7), a RUD position of 25 degrees or more will result in the trailing edge of the panels exceeding the clearance limit of the access swings. If this is the case (and assuming the vehicle could actually land in this configuration), the resulting panel position should be passed to the ground convoy to allow for a workaround to the access swing interference.

REFERENCES

1. CPDS, SS-P-0002-550Q2, SS Functional Level Requirements, Vehicle Utility, Aug. 1994.
2. Flight Data File Entry Checklist, Mar. 1986. DPS Dictionary, Nov. 1985.
3. KSC Launch Operations Document 80K00086, TCS-S User's Guide VFB 3 rev 11, July 1984, revised Nov. 1984.
4. Space Shuttle Programs PASS User's Guide OI-8, Sept. 1987.
5. STS Operational Flight Rules, JSC-12820, latest version.

TABLE 8.3-I. - AI MODE 1 (INITIAL)

Actuator devices and sequence	Maximum initialization limits			
	LOW VALUE		HIGH VALUE	
	DEG	PCT	DEG	PCT
Body flap	NA		NA	
L OMS yaw (ACT and STBY)	-8.4		8.4	
L OMS pitch (ACT and STBY)	-8.4		8.4	
R OMS yaw (ACT and STBY)	-8.4		8.4	
R OMS pitch (ACT and STBY)	8.4		-8.4	
SSME 1 pitch	9.3 *		-10.0	
SSME 1 yaw	-8.1		8.1	
SSME 2 pitch	-9.3 *		10.0	
SSME 2 yaw	-8.1		8.1	
SSME 3 pitch	10.0		-10.0	
SSME 3 yaw	-8.1		8.1	
Speedbrake	1.6	1.6	98.6	100.0
Rudder	-27.1		27.1	
Left inboard elevon	-35.1		20.1	
Right inboard elevon	-35.1		20.1	
Left outboard elevon	-35.1		20.1	
Right outboard elevon	-35.1		20.1	

* CR91008 (OI-24)

TABLE 8.3-II. - AI MODE 0 (INITIAL)

Actuator devices and sequence	COMMAND POSITION		TOLERANCE RANGES			
			LOW VALUE		HIGH VALUE	
	DEG	PCT	DEG	PCT	DEG	PCT
Body flap	2.5	41.5	0.0	34.2	5.0	48.9
L OMS yaw (ACT and STBY)*	6.9		-0.8		8.1	
L OMS pitch (ACT and STBY)*	5.8		-7.3		7.3	
R OMS yaw (ACT and STBY)*	-6.9		0.8		-8.1	
R OMS pitch (ACT and STBY)*	5.8		-7.3		7.3	
SSME 1 pitch	-3.3		-1.5		-5.2	
SSME 1 yaw	0.2		-1.2		1.5	
SSME 2 pitch	0.8		-0.8		2.5	
SSME 2 yaw	5.1		3.6		8.9	
SSME 3 pitch	0.2		1.8		-1.5	
SSME 3 yaw	-4.9		-8.9		-3.3	
Speedbrake	21.0	21.3	14.8 +	15.1 +	27.2	27.6
Rudder	0.0		-2.3		2.3	
Left inboard elevon	0.4		-1.5		2.2	
Right inboard elevon	0.4		-1.5		2.2	
Left outboard elevon	0.5		-1.5		2.3	
Right outboard elevon	0.5		-1.5		2.3	

* OMS ENGINE WILL NOT DRIVE TO THE COMMANDED POSITIONS IF SPEC 113 NOP OMS ITEM 40 IS IN THE "INHIBIT" STATE (*) WHICH IS THE INITIALIZATION STATE. ERROR CODE FOR OMS OUT-OF-TOLERANCE WILL ALSO BE INHIBITED.

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TABLE 8.3-III - AI MODE 3 (RAIN)

Actuator devices and sequence	COMMAND POSITION		LOW VALUE		HIGH VALUE	
	DEG	PCT	DEG	PCT	DEG	PCT
Body flap	20.7	94.9	18.2	87.5	23.2	102.2
L OMS yaw (ACT and STBY)*	6.9		6.1		7.2	
L OMS pitch (ACT and STBY)*	5.8		5.0		6.2	
R OMS yaw (ACT and STBY)*	-6.9		-6.1		-7.2	
R OMS pitch (ACT and STBY)*	5.8		5.0		6.2	
SSME 1 pitch	9.3 +		11.0		7.1 +	
SSME 1 yaw	.2		-1.2		1.5	
SSME 2 pitch	10.0		7.8		11.8	
SSME 2 yaw	0.2		-1.2		1.5	
SSME 3 pitch	9.3 +		11.0		7.1 +	
SSME 3 yaw	0.2		-1.2		1.5	
Speedbrake * *	5.1	5.1	-1.3	-1.3	11.7	11.9
Rudder	0.0		-2.3		2.3	

* OMS ENGINE WILL NOT DRIVE TO THE COMMANDED POSITIONS IF SPEC 113 NOP OMS ITEM 40 IS IN THE "INHIBIT" STATE (*) WHICH IS THE INITIALIZATION STATE. ERROR CODE FOR OMS OUT-OF-TOLERANCE WILL ALSO BE INHIBITED.

+ CR91008 (OI-24)

** CR90768B (OI-24)

TITLE

ELEVON PARK

PURPOSE

To discuss why and how elevon park is performed for propellant-critical orbit operations.

BACKGROUND

A. FLIGHT OBSERVATIONS

During STS-52, flight controllers observed unusually-high propellant consumption while in periods of attitude hold. This was apparently due to some external force causing a positive pitch moment. Since the attitude being flown was typically a quiescent, low-drag profile (payload bay toward the earth, nose into velocity vector), it was concluded that the pitching moment must be the result of an onboard vent. A closer look revealed that during each of the periods in question, a high rate Topping Flash Evaporator System (FES) dump had occurred (See Figure 8.4-1). It was found that the higher the dump rate, the higher the propellant usage rate. Consumption during these periods was up to twice that originally expected and was a function of the elevon position. The mechanism causing these pitch moments was steam impinging on the inboard elevons which resulted in a net pitching force on the vehicle.

B. ANALYSIS

Research revealed that not only pitch but roll moments had occurred (depending on elevon position) during FES dumps on previous flights as well. As a result, Rockwell International was contracted to perform an analysis to determine the optimal elevon position that would minimize unwanted moments during Topping FES dump periods. The Rockwell team determined that an elevon angle that bisects the FES plume (so as to equalize the force on both sides of the elevon) would minimize resultant vehicle rates. The optimal angle would be in the range of -5° to -10° . It was also determined that the full up position of -33° would result in maximum propellant consumption out of the forward RCS and minimum usage out of the aft RCS. To verify the results of this analysis, two tests were performed on STS-61.

C. FLIGHT TEST

On STS-61, two procedures were developed to park the elevons. One which placed the elevons at -7.5° and one which placed them near -33° these procedures will be discussed in detail in a later section). At a Mission Elapsed Time (MET) of 00/05:34, the procedure was run to park the elevons at -33° . Execution of the procedure actually resulted in an elevon position of -28.5° (it is difficult to place the elevons at exactly -33°). The -28.5° position was considered acceptable for the purposes of the test.

Data collected with the elevons at -28.5° showed an evident negative pitching moment on the vehicle, as predicted. The propellant usage data is summarized in Table 8.4-1. It

shows that considerable aft propellant savings were realized during a FES dump (medium/high force) with the elevons in the -28.5° position vs. the trail position. Unfortunately, the data collected during the flight did not allow a direct comparison of aft propellant usage with the elevons in the -28.5 position and the -7.5° position. While the data was inconclusive, it did tend to indicate that aft usage with the elevons in the -7.5° position would be comparable to usage with the elevons in the -33° position. Therefore, the -33° position probably would not provide a significant benefit over the -7.5° position from an aft propellant point of view. However, the -33° position might be useful for maintaining forward jet temperatures during attitude hold periods where forward jets get cold. The STS-61 data would have to be reviewed in greater detail to confirm this hypothesis.

TABLE 8.4-1: PROPELLANT USAGE (LB/HR) DURING FES DUMP (MED/HIGH FORCE)

Elevon position	Trail (0°)	-28.5 °
Forward RCS	0.67	0.95
Aft Left RCS	1.37	0.76
Aft Right RCS	1.57	0.91

After FCS Checkout, the elevons were parked in the -7.5° position (MET 09/23:30). Data collected after this time was compared to data collected when the elevons were in trail. The data showed that with the elevons in trail, the vehicle experienced a significant positive pitching moment. After the elevons were parked at -7.5°, the pitch rates stabilized and aft propellant consumption decreased by 51%. The propellant usage data is summarized in Table 8.4-2.

TABLE 8.4-2: PROPELLANT USAGE (LB/HR) DURING HIGH LOAD FES DUMP

Elevon position	Trail (0°)	-7.5 °
Forward RCS	0.68	0.53
Left Aft RCS	1.88	0.99
Right Aft RCS	2.03	0.92

D. ELEVON COORDINATE SYSTEM AND ASA ORIENTATION

The coordinate system of the control surfaces on the orbiter is a right-handed coordinate system. This is easily visualized with the right hand rule if the right hand thumb is

pointed along the positive body axis about which the rotation occurs. The direction of the curled fingers reveals the positive direction of rotation. For example, with the thumb aligned along the positive Y body axis, the direction of curl indicates that a downward deflection would place the elevons in a positive position; conversely, an upward deflection would place the elevons in a negative position.

The maximum upward deflection of the elevons is -33° ; the maximum downward deflection is $+18^\circ$. In other words, the elevon can be positioned 15° further in the up direction than in the down direction. Although the elevon travel is offset from the wing chord, the ASA is still able to read equally in both directions. This is possible because the ASA is actually centered across the elevon travel range, making the zero volts value correspond to a position of -7.5° (See Figure 8.4-2).

PROCEDURES

There is no Orbiter software available specifically for parking the elevons. It is therefore necessary to “trick” the existing software into performing this function. Because the existing software was not designed to do this, several of the techniques which have been developed are rather convoluted and complex. This section describes the different techniques which have been identified for parking the elevons (Reference A/E FTP #140). Only one of these procedures, described in part A, is actually in use. The others are described here because they provide valuable insight into how the onboard software operates and also to provide options for parking the elevons should needs change.

A. OPS 2 TO 8 TRANSITION (-7.5°)

This procedure is published in the Orbit Ops C/L, GNC, ELEVON PARK, GNC 201. It would be helpful to refer to this procedure throughout the following discussion.

Before the procedure is executed, it should be noted that the ASAs will be in the zero-volts state since they are powered off in the Post Insertion Timeline. The elevons are commanded to trail (0° position) in OPS 1 and will maintain that position in OPS 2 as long as a circulation pump is not activated after the ASAs are turned off. If a circulation pump does operate while the ASAs are powered off, the elevons will drive away from 0° because of imbalances in the actuator hardware. The positions they drive to are dependent on the hardware tolerances inside the actuator. Most actuators drive to the full-up or full-down position but some actuators drive to intermediate positions.

Given these initial conditions, the crew performs an OPS 2 to OPS 8 transition. Upon transition to OPS 8, the GPC reads the elevon position by midvalue selecting from the channel 1, 2 and 3 feedbacks. Since the ASAs are not powered, a zero-volts value is sent to the MDM which is in turn sent to the GPC. The GPC interprets the voltage as an elevon position of -7.5° (remember, the elevons aren't really at -7.5°). The OPS 8 software then sets the elevon position command equal to the selected position feedback to ensure there are no large command-position deltas. The software is designed this way to avoid large step commands from being present when the hydraulic system is activated. The GPC sends the -7.5° command to the MDM which in turn passes it on to the ASA (see Figure 8.4-3). The ASAs will drive the elevons to this position once they are powered on and hydraulic system pressure is applied. It is only necessary to power on one of the ASAs at this point since a single ASA can drive the elevons to the desired position.

With the GPC command set to -7.5° , one of the ASAs is turned on (45 Watts) and a transition back to OPS 2 is performed. The ASA is turned on in OPS 8 so the elevon positions prior to the repositioning can be determined. The feedback from the ASA becomes valid as soon as it is powered on but the elevon positions are only available in the OPS 8 downlist (only the RIB position is downlisted in OPS 2). The -7.5° position command is retained across the OPS transition. A circulation pump is then turned on and the elevons drive to -7.5° . Approximately three minutes later, circ pump control is given back to the GPC. The elevons normally reach the -7.5° position in less than 30 seconds.

The ASA must remain powered after this time to maintain the elevons at -7.5° . If the ASA was turned off following the elevon park procedure, the elevons would move away from this position (to actuator specific positions) when a circulation pump was turned on by the GPC. The GPC cycles circulation pumps periodically to maintain temperature limits within the hydraulic system.

Since there is a small but finite risk in leaving an ASA powered for a long period of time, it was decided to use ASA 4 to support the elevon park procedure. ASA 4 is less critical than ASAs 1, 2, or 3 because it does not command a body flap channel and its feedback (except for the BF) is not used unless there is a feedback failure in one of the first three channels

Note that it is not necessary to have all of the ASAs powered off prior to the OPS 8 transition. The elevon park procedure is written assuming all ASAs are powered off when entering the procedure because this is the standard OPS 2 configuration. But as long as two of the first three ASAs are powered off at the OPS 8 transition, the GPC will see the elevon position as -7.5° (since it mid value selects from the first three channel feedbacks). This is significant for cases where the elevon park procedure follows shortly after post-insertion. For this case, it is best to leave ASA 4 on in the post-insertion procedures and keep it on throughout the elevon positioning procedure. This avoids an unnecessary power cycle of ASA 4.

Likewise, for scenarios where the Elevon Park procedure is executed following FCS C/O, real time changes can be made to eliminate the needless power cycling of the MLS, ADTAs and MMU2 (for group B powerdowns). These LRUs should remain powered after FCS C/O is complete in anticipation of the OPS 8 transition. It is unlikely that the elevon park procedure will be needed following FCS C/O since there are not many flights which are propellant-critical enough to warrant this. In most cases, there is only one day between FCS C/O and deorbit, and the propellant savings realized over this one day period would be minimal. Because of the infrequency of encountering this situation, the GNC group decided not to incorporate any generic changes to the FCS C/O procedures to accommodate the elevon park following checkout. The savings in propellant between FCS Checkout and entry is minimal compared to the cumulative cost and complication of changes required to add the procedure to the checkout procedure. If FCS C/O is performed nominally, the elevons will be left at trail (0°). This is not the optimal position, but is close enough as to not represent a substantial propellant cost over the time period remaining.

B. OPS 3 SURFACE DRIVE TEST (ANY ELEVON POSITION)

This procedure uses the OPS 3 surface drive test software to position the elevons. It can be used to place the elevons in any desired position. When the drive test is activated, the software issues elevon commands in a sinusoidal fashion (driving first to $+18^\circ$ and then to -33°) at the rate of 5.8 degrees/second. With a known initial elevon position (elevon

command is set to 0° at OPS 3 transition), a sequence run time can be calculated which will set the position command to any desired value. However, since the drive rate is 5.8 degrees/second, it is difficult to obtain precisely the desired command since the crew does not have any way to control the timing precisely. The STS-61 crew performed this procedure and was able to position the elevons within 4.5° of the desired value (-28.5° instead of -33.0°). Because of the difficulty of positioning the elevons accurately with this method, the OPS 8 transition procedure discussed earlier is preferred if the elevons are to be parked at -7.5°.

To execute the procedure, the crew performs an OPS 3 transition and configures CRT1 with the DEORBIT MNVR COAST display. They also set the event timer (or stop watch) to count down to the desired sequence termination time. Upon activation of the SURF DRIVE (ITEM 39 EXEC) the event timer is started. At some pre-determined number of seconds later, the SURF DRIVE is deactivated (ITEM 40 EXEC). The final position will be in error by 5.8° for every second of timing error. The crew cannot verify that the proper elevon commands were achieved; this must be verified by the MCC. Remember that the elevons do not actually move during the drive test since there is no hydraulic pressure to move them.

After the desired elevon command is established, a transition back to OPS 2 is performed. The OPS 3 command is carried over to OPS 2 and subsequent circ pump activation moves the elevons to the desired position. Following elevon positioning, circ pump control is given back to the GPC. As stated above, an ASA must remain powered for the elevons to maintain the desired position.

The procedure used on STS-61 is given below. The elevons were initially at 0° and the OPS 3 drive test was run for 12 seconds to achieve a final commanded position close to -33° ((18° + 18° + 33°)/(5.8 degrees/second)) = 11.8 seconds drive time).

ELEVON PARK OPS 3

1. TRANSITION TO OPS 3
Perform G2 to G3 transition (MAL, DPS SSR-18, G2/G8 to G3 TRANS)
2. PERFORM AEROSURFACE DRIVE

CRT1

DEORBIT MNVR COAST

Config event timer (or stop watch) to count down from 30 seconds
Start timer,

CRT1 T=0 SURF DRIVE ON - ITEM 39 EXEC (*)

T=12 SURF DRIVE OFF - ITEM 40 EXEC (*)

√ MCC to verify elevon commands are near -33 degrees

3. TRANSITION TO OPS 2
Perform G3 to G2 transition (MAL, DPS SSR-19, G3 to G2/G8 TRANS)
4. CIRC PUMP ACTIVATION

O16:F ASA 4 - ON
On MCC Go:
R2 HYD CIRC PUMP 1 - ON
Wait 3 minutes, on MCC Go,
R2 HYD CIRC PUMP 1 - GPC

C. 0° POSITION

A 0° elevon position can be established very easily by leaving one of the ASAs on following ascent. The elevons are commanded to the trail position during ascent and this command is carried across the OPS 1 to OPS 2 transition. The attractive feature of this option is its simplicity. The only crew actions required are to leave an ASA on in the post-insertion procedures. As with the other elevon park procedures, the ASA must be left on throughout OPS 2. The disadvantage of this option is that the elevons are not at the optimal position of -5° to -10°. According to the Rockwell analysis, there is about a 3 to 4 times increase in the elevon impingement force when in the 0° elevon position vs. the -7.5° elevon position. How the differences in impingement forces translates into propellant usage is difficult to quantify without further analysis or flight testing. The 0° position is significantly better than elevon positions of -35° to -15° or +5° to +20°. Given the simplicity of the procedure, there may be cases where it is useful.

D. OPS 8 SECONDARY ACTUATOR CHECK (-13.5° OR -1.5°)

This option involves a transition to OPS 8 and execution of the secondary actuator check using the circulation pump option. When the circulation pump option is used, a one-on-one force fight is established between a good channel and a channel commanded with a positive stimulus (6 degree command bias). The good channel is then turned off and the elevons drive to -1.5°. A transition to OPS 2 could then be performed, leaving the elevons at the -1.5° position. The same procedure, with a minor modification, could be used to place the elevons at -13.5°. Instead of using a positive stimulus, a negative stimulus could be commanded (establishing a -6° command bias) and when the good channel was turned off the elevons would drive to -13.5°. The disadvantage of this option is that there is no way to maintain the -1.5° / -13.5° command once back in OPS 2. The negative/positive stimulus command will be lost upon transition out of OPS 8. As soon as a circulation pump operates in OPS 2, the elevons will drive to their actuator-unique positions.

E. OPS 8 AEROSURFACE DRIVE

This option is similar to the option discussed in part B in that it uses a hydraulic thermal fluid conditioning drive test to park the elevons. In this case the OPS 8 aerosurface drive test is used instead of the OPS 3 drive test. The difference between the two procedures is that it is necessary to operate an APU during the OPS 8 drive test so the elevons will follow the position command throughout the drive. The final elevon position is controlled by stopping the APU when the elevons have reached the desired position. It is necessary to

position the elevons in this way because the OPS 8 command cannot be carried over into OPS 2. When the drive test is terminated in OPS 8, the software commands the elevons back to a position of 0°.

There are two significant drawbacks to the OPS 8 procedure. First, the desired elevon command is not carried over to OPS 2. This means that the operation of a circulation pump in OPS 2 will drive the elevons away from the desired position. The second problem with the procedure is that it is unlikely that the crew could position the elevons with much accuracy using this technique. Residual pressure as the APU shuts down would cause the elevons to continue to drive beyond the desired position.

F. GMEM

This option involves uplinking a GMEM to overwrite the GN2 major function base I-loaded command of 0° with the desired elevon command. An ASA would then be turned on and a circulation pump would be used to drive the elevons to the desired position. The ASA would be left on to maintain the desired elevon position.

The advantage of this procedure is that it could be used to move the elevons to any desired position with a high degree of accuracy. The major disadvantage of it is that it would require the uplink of a hip-pocket GMEM which is viewed as a highly taboo activity by the Orbiter Program.

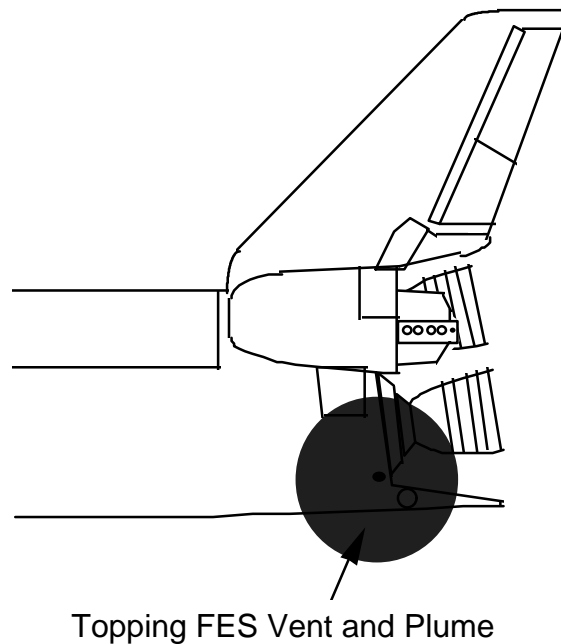
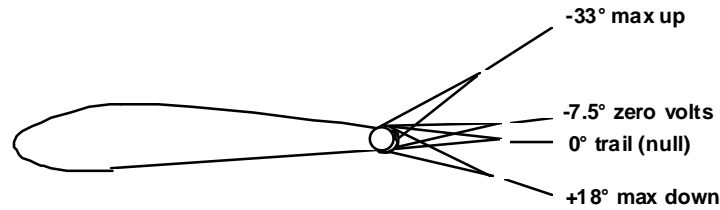


Figure 8.4-1 - Elevon position with respect to Topping FES Vent and expanding Plume



Source: GNC System Handbook Drawing 9.16

Figure 8.4-2 - Elevon maximum, minimum, trail and park positions

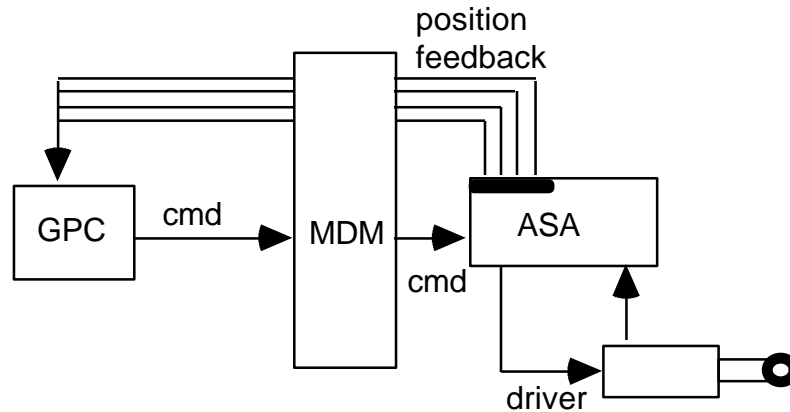


Figure 8.4-3 - ASA Command path

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TITLE

SSME REPOSITIONING FOR DRAG CHUTE DEPLOY

PURPOSE

To explain the main engine repositioning sequence for drag chute deploy and what possible concerns can arise during off nominal scenarios.

BACKGROUND

During entry, the orbiter software automatically commands the main engine bells down, clearing a path for the drag chute riser cords. This repositioning is performed by the Landing Gear Valve Control sequence and the MPS TVC Command SOP, when scheduled by the high-frequency entry executive. For RTLS, repositioning is performed immediately post-MECO when the engines are commanded to the "stow" positions, because the "stow" position I-loads have been changed to the chute stow positions. A summary of the Landing Gear Valve Control sequence used in OPS 3 follows:

1. At Mach = 8: if repositioning is enabled, the three MPS/TVC Isolation valves are commanded open. The repositioning software should be automatically enabled by the GPC software upon transition to OPS 3. The crew has a step in the entry checklist to verify that REPO is enabled (on SPEC 51). If not, an item 19 is required and ENA will appear in the item entry status field. The sequence can be toggled between INH and ENA by repeated item 19's on SPEC 51.

Note: If repositioning is enabled prior to Mach 8, it will initiate at Mach 8. If repositioning is enabled after Mach 8, the process will initiate as long as Mach is greater than 3.5. The sequence can be started anytime between Mach 8 and Mach 3.5. However, the repositioning command is only issued one time. If the repositioning sequence fails when the command is issued, repositioning cannot be attempted again.

2. The sequence checks whether two MPS/TVC Isolation valve positions indicate closed and/or commfaulted, and whether two Hydraulic systems are failed in PRL. If two Hydraulic systems with open isolation valves are not available, the sequence is stopped (repositioning fails), and the isolation valves are commanded closed. Otherwise, the sequence continues.

Note: PRL is a subject in and of itself. For training on the specific of PRL, the reader can access the PRL CBT (Computer Based Training), SCP 5.7 SINGLE APU LANDING and SCP 9.10 PRIORITY RATE LIMITING (PRL) MANAGEMENT

3. The SSME pitch actuator commands are incremented to the chute stow positions.
4. During the sequence, if the number of good hydraulic systems is ever less than 2 or repositioning is inhibited (SPEC 51, item 19), the sequence is stopped (repositioning fails), the position commands stop incrementing, and the isolation valves are commanded closed.
5. When the actuator commands equal the final chute stow commands, the isolation valves are commanded closed.

Note: No active feedback of actual engine positions is employed. That is, the engines are simply commanded to the chute stow positions, with no checks made to ensure they reach the desired positions or that bell collision does not occur.

MONITORING THE SEQUENCE AND UNDERSTANDING FAILURES

A. NOMINAL DATA MONITORING

In OPS 304, the console operator should monitor the hydraulic system supply pressures and the TVC isolation valve positions on the CONTROL ENTRY display. As long as no failures occur prior to Mach 8, at Mach 8, the three MPS TVC isolation valves will be opened by the GPC software and SSME repositioning will begin. When the sequence completes the isolation valves will close and the SSME positions should indicate:

CP	CY	LP	LY	RP	RY
+10	0	0	-3.5	0	+3.5

B. REPO SEQUENCE FAILURES

The SSME repositioning sequence may be affected by various failures, including failures in the orbiter hydraulic systems, MPS TVC isolation valves, Data Processing System, and the electrical distribution system. When any combination of these failures results in the availability of less than two orbiter hydraulic systems and associated TVC isolation valves, then the repositioning sequence will fail. If a hydraulic system is failed by PRL, or its associated MPS TVC isolation valve fails to open or is commfaulted, the hydraulic system will be considered unavailable by the repositioning sequence. Furthermore, the sequence will terminate in progress if two hydraulic systems become unavailable due to an added APU failure during the sequence (Valve positions are only looked at once, at the beginning of the sequence). The repositioning sequence fails under the preceding conditions in order to preclude contact damage of the SSME nozzles as a result of a known loss of TVC control on a SSME.

C. MPS TVC ISO VALVE COMMAND/ENABLE CHANNELIZATION

The OPEN commands for TVC isolation valves 1, 2, and 3 are transmitted by the GPCs across FA1, FA2, and FA3, respectively. If any one of the GPCs or MDMs fail the associated isolation valve will not open. In order for the valve to open, the OPEN command must also be accompanied by an ENABLE command. The ENABLE command for isolation valve 1 is sent through FA2 and FA4 (only one of the 2 MDMs needs to be available). The ENABLE command for isolation valve 2 is sent through FA1 and FA3. The ENABLE command for isolation valve 3 is only sent through FA4. If FA4 or the GPC commanding FA4 fails, isolation valve 3 will not open automatically. Although the open command for the valve is channelized through FA3, the ENABLE command is sent through FA4 (valve 3 is the only one with just one path for its ENABLE command; valves 1 and 2 have two). The status of MPS TVC isolation valves 1, 2 and 3 are routed back to the GPCs via FAs 1, 2 and 3, respectively. If an isolation valve is open and its associated FA MDM is commfaulted, the open status cannot be seen by the GPCs; the valve is assumed to be closed by the repositioning logic.

D. MPS TVC ISO VALVE MANUAL CAPABILITY

The MPS TVC isolation valves can be opened manually through switches on panel R4. The manual capability does not pass through the FA MDMs, rather flows directly to the valves. This capability is useful when the ENABLE command path is blocked due to a bad GPC or MDM. This capability is not normally helpful in cases where the OPEN command channelization path is blocked, since the feedbacks to the GPCs travel through the same paths as the OPEN commands, the GPCs will not be able to see the valve status. The exception to this would be a known FA card problem, where the commands are not going out but feedbacks are coming in.

E. MPS TVC ISO VALVE POWER

When ALC1, ALC2, or ALC3 loses power, TVC isolation valves 1, 2, & 3 respectively, lose operating power. The effected valve will remain in its last physical position. If it is open it will remain open, and if closed it will remain closed. With this in mind, it is important to note that the feedback indication of the isolation valve will always reflect the closed position when the valve loses power, regardless of its true position.

Control Buses

Control bus failures alone do not affect the SSME repositioning sequence. Loss of a control bus may however take away the crew's ability to manually open an isolation valve. The loss of Control Busses AB1 or AB2 will take the ability to manually open isolation valve 1. The loss of Control Busses BC1 or BC2 will take the ability to manually open isolation valve 2. And the loss of Control Busses CA1 or CA2 will take the ability to manually open isolation valve 3. Manual capability is dependent on two control busses for each isolation valve. One control bus acts as the open command and the other acts as the enable. Control bus power can, however, impact the post landing repositioning sequence.

F. FAULT TOLERANCE

The repositioning sequence should be inhibited if the ATVC channels are not single fault tolerant. An example of this scenario would be an unisolated 3 on 1 force fight on an ATVC actuator. The next failure on one of the three remaining good channels could cause an actuator to become uncontrolled opening up the possibility for engine bell damage to occur.

If there exists a known switching valve problem, which leaves the left or right main engine pitch actuators dependent on only one hydraulic system, the repositioning sequence should be inhibited. This failure mode is considered highly unlikely. In this scenario, the loss of one hydraulic system would not stop the repositioning sequence and would cause the left or right engine to stop moving, leaving the affected engine susceptible to colliding with the center engine.

Fault Tolerance can also be lost in cases where manual PRL actions have been taken. If a hydraulic system were manually selected in PRL, a failure on the selected system would not be taken into account by the repositioning sequence logic. If single fault tolerance is lost due to any combination of failures, inhibiting drag chute repositioning should be considered.

It is highly desirable to manually inhibit SSME repositioning for drag chute if single-fault tolerance (SFT) is lost to prevent unnecessarily exposing the SSME bells to damage. However,

in cases where drag chute deployment is mandatory (known directional control problems, aborts), single fault tolerance during the repositioning sequence is not required. Deploying a drag chute without first repositioning the SSME bells exposes the center main engine to riser cord abrasion damage. This known damage outweighs the risk of repositioning the main engines without single fault tolerance. Reference Ascent/Entry Flight Techniques Panel meeting #84, November 15, 1991, DRAG CHUTE IMPACTS.

SSME repositioning is not a constraint to drag chute deploy if required for vehicle control. The advantages of the drag chute in gaining lateral/directional stability or runway margin outweigh the risk of abrasive damage on the center SSME bell. Reference Ascent/Entry Flight Techniques Panel meeting #84, November 15, 1991, DRAG CHUTE IMPACTS.

REFERENCES

1. Space Shuttle Flight Software, STS-110 Final Load.
2. Space Shuttle Orbiter Operational Level C Functional Subsystem Software Requirements, Sequence Requirements, OI-29, STS 83-0026, section 4.5.1, LDG VLV CNTL (4.215).
3. Backup Flight System Sequencing Program Requirements Document, OI-29, MG038120, section 3.3.1.12.1 Landing Gear ISO Valve Control Sequence.

TITLE

NO YAW JET ENTRY PROCEDURES

DESCRIPTION

The No Yaw Jet mode of the Aerojet Digital Autopilot (DAP) (selected by placing the Entry Mode switch in the No Yaw Jet position) is used if (1) aft Reaction Control System (RCS) propellant quantities are reduced to a critical minimum where it becomes necessary to conserve the remaining propellant for Mach < 7 (a flight region of reduced roll/yaw stability), or (2) when there is no aft RCS propellant remaining during entry, or (3) when all 4 yaw jets on one side are lost (ref. Rule A8-19, YAW JET DOWNMODE). Low RCS propellant quantities can result from excessive usage during the deorbit burn or entry, or as a result of RCS malfunctions (leaks, blockages, etc.). The Prop officer may also call for temporary No Yaw Jet selection during RCS leak isolation if an electrical bus has failed that complicates the isolation procedure.

Aerojet DAP reconfiguration to No Yaw Jet causes a gain (GALR) change in the roll channel as well as terminating any yaw jet commands, and forces automatic downmode to manual roll/yaw control (R/Y CSS); the crew must fly the guidance commands.

The corresponding crew procedures are broken into three specific entry Mach regions, as shown on the ARCS QTY (L + R) < 10% procedure on the ENTRY CONTROL cue card (ref. Ent C/L). This card contains special procedures or piloting techniques to maintain vehicle control and conserve propellant. Roll/yaw oscillations and sluggish response can be expected, especially during a maneuver or atmospheric disturbance, because yaw jets are not available to augment aileron control.

The cue card procedures are based on a strategy to handle nominal and aero variation test cases; i.e., they are intended to be universal, not optimal. The decision to use the NYJ mode is ultimately a Propulsion Officer decision, but the use of NYJ should be discussed between PROP and GNC when time permits (which should be the norm verses the exception) prior to being recommended on the Flight Director ("Flight") loop.

PROCEDURES (CHECKLIST)

1. Verify NYJ mode selected

- o ENTRY MODE SW in the NYJ position (Entry Control display)
- o R/Y CSS (CRANS and Entry Control display). Recall that the DAP automatically downmodes to R/Y CSS when NYJ is selected.
- o No yaw jet firings (CRANS)

2. Select fixed elevon schedule

- o Because the FIXED slot has the AFT schedule, select FIXED elevon.

- o If FIXED slot has a different schedule (e.g. FWD schedule for Aero PTI's), select AUTO elevon.

NOTE: The object here is to get on the elevon schedule that provides for the most down (positive elevator) elevon deflection. The more down elevon, the better lateral directional control, since aileron authority is improved as elevon deflection goes further down (more positive).

3. Verify crew flying guidance commands

- o ADI Roll Att errors (Entry Control display)

NOTE: Roll error is stability axis roll (bank) error - this is what you want to use as your cue.

- o RHC Roll commands (Entry Control display)

4. Follow crew on ARCS QTY (L+R) < 10% procedure (ref. ENT C/L)

- o STAY AHEAD of the crew.
- o Coordinate with PROP and anticipate next actions required.

5. Monitor for Roll/Yaw controllability problems

- o This is just standard monitoring for roll/yaw problems (aileron trim, maneuver overshoots, "sloppy control", larger than normal lateral acceleration (N_y), etc).
- o **If RCS > 0%, Secure from NO Y JET for :**
 1. Aileron trim saturation and control problems
 2. Roll rate oscillation > 5 deg/sec and diverging

REMINDERS FOR NYJ

- Whenever possible, use RCS from OPS 304 PRO through initial bank maneuver as it is essential for ranging, loads, and thermal constraints to capture drag reference for prebank or closed-loop guidance initiate.
- Φ/α control will be loose and slow but will improve as \bar{q} (dynamic pressure) increases.
- TOT AFT RCS QTY 2 represents worst case propellant remaining after deorbit and protects sufficient prop for prebank (if required) and initial bank maneuver.
- NYJ relies on adverse yaw ($-C_{n\delta a}$) overpowering direct aileron control ($C_{l\delta a}$) to provide control authority. Down elevon trim (which can be forced by selecting the more down elevon schedule, and by manually driving the BF up (when required)) increases adverse yaw and, therefore, increases control authority.

- At low \bar{q} , vehicle response is slow; control and damping improve as Mach decreases toward Mach 10. Below Mach 10, performance degrades significantly as Mach/ α decrease.
- In NYJ mode, the GALR gain (pronounced "gay-ler") in the roll channel is increased, causing larger than nominal (baseline DAP) aileron deflections for a given RHC roll command. This is required because yaw jets are not available to augment the ailerons. Also, lateral stability ($C_{l\beta}$) decreases as Mach/ α decrease. As a result, for bank maneuver initiations, there will be a larger than normal initial reverse aileron deflection that will produce a large initial roll opposite to the RHC command, especially for Mach < 5. *From Mach 3.0 to the ground, the GALR gain schedule is the same for the NYJ and baseline DAP.*
- β /Ny oscillations may become large enough to produce control and/or OMS pod heating problems.
- Aerojet DAP reconfiguration logic automatically modes R/Y control to CSS in the NYJ mode - crew must follow guidance commands manually.
- NYJ is certified as a contingency DAP mode for Qbar > 20 psf. Under no circumstances should NYJ be selected prior to Qbar 20 psf, except as stated in the ARCS QTY (L+R) < 10% procedure (i.e., if no propellant remains, and jets fail off). In addition, when in NYJ and Qbar < 10, the vehicle will fire roll jets in the incorrect direction because the roll channel "picks off" the roll command before its sign is reversed in the No Yaw Jet software. This is not a problem if all aft RCS tanks are depleted, but if any propellant remains, the vehicle will roll the wrong direction. •
It is possible that the AIL TRIM > 3° (Ref. ENTRY CONTROL cue card) procedure may be required on a NYJ entry day. These procedures should be followed in concert with those in the ARCS QTY (L+R) < 10% procedure, to ensure the greatest possibility of success. In fact, the only time control problems have been encountered during No Yaw Jet flight (the reason for preserving some propellant in the first place) in simulators is when aileron trim is also high.

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7. Cain, L.E. and Nowak, B.M., Investigation of Roll/Yaw Control in the No Yaw Jet (NYJ) DAP Mode in Low Qbar Regimes, Informal Note, Aug. 1991.

TITLE

SPEEDBRAKE MALFUNCTIONS

SPEEDBRAKE (SB) FAILED OPEN

DESCRIPTION

The SB will nominally remain at 81 percent from M9 until M4, where it begins ramping in to 65 percent at M2.5. A failed open SB would mean the SB remains at 81 percent below M4.

A. Flight Rules

None

B. Crew Operations

1. Failure Recognition

<u>Parameter</u>	<u>Value/trend</u>	<u>Displayed</u>
SB Position V72H5105C	81%: M < 4	SPI
SB Command V72H5106C	81%: M > 4 81%-65%: 2.5 < M < 4 65%: 0.95 < M < 2.5 Modulates: M < 0.95	SPI
SB Position V95H8250C	81%: M < 4	VERT SIT 1,2
SB Command V94U1300C	Same as V72H5106C	VERT SIT 1,2

2. Crew procedures

No applicable cue card

3. Crew activity

<u>Step</u>	<u>Activity</u>	<u>Position</u>
1	Monitor: BF @ 90%; should not saturate øe on schedule	CDR/PLT
2	1 < M < 4: CSS-R/Y TAEM I/F and if required	CDR

		for control (avoid large or abrupt maneuvers; decrease maneuver rates)	
	CSS-P	Fly max L/D for ranging (if required)	CDR
3	M < 1:		
	CSS-R/Y	HAC intercept to TD	
	CSS-P	Fly max L/D until intersect upper traj line, VERT SIT. Fly upper traj (-28° OGS) until IGS.	CDR
	BF-MAN	Trail (if additional L/D required)	
4	MCC may provide GCA/energy call if required		

C. MCC Operations

1. Failure Recognition

<u>Parameter</u>	<u>Value/trend</u>	<u>Displayed</u>
SB Position V90H671OC	81%: M < 4	RTPLOT/SCR File AAA_DP&D_A ENTRY CONTROL Display

2. MCC Activity

<u>Step</u>	<u>Activity</u>
1	Monitor SB and BF positions and d trim
2	Monitor F, da, dr, and RHC for control problems
3	Monitor subsonic: \bar{q} @ 300-320 psf EAS @ 280-300 KEAS α @ 3° - 5°

D. Supporting data notes

1. No increase in L/D for placing BF = 0° , M > 1; max 3% increase in L/D for placing BF = 0° ; M < 1.
2. Lateral stability and yaw control will be decreased for M < 4 with SB = 81%.
3. Max rudder deflection (dr) and rudder control effectiveness (Cndr) are both reduced M < 4.
4. Avoid large or abrupt maneuvers to preclude dr saturation.

- | 5. <u>Landing procedure</u> | <u>Advantages</u> | <u>Disadvantages</u> |
|-----------------------------|---|---|
| Increase OGS to -28° | Near nominal TD velocity; some energy margin on OGS | A/L geometry change; short time-to-go near ground |
6. Upper traj line (VERT SIT) represents h vs. range and reflects 100% SB and $\bar{q} = 300$ psf.
7. Flight dynamics officer (FDO) may provide GCA/energy calls from C-band plot with upper traj line overlay equivalent to VERT SIT.

SPEEDBRAKE FAILED CLOSED

DESCRIPTION

The SB is nominally closed until M10, where it starts ramping open to 81% by M9. A SB failed closed means the SB would remain closed at $M < 9$.

A. FLIGHT RULES

None

B. Crew Operations

1. Failure Recognition

<u>Parameter</u>	<u>Value/trend</u>	<u>Displayed</u>
SB Position V72H5105C	0%: $M < 10$	SPI
SB Command V72H5106C	81%: $M > 4$ 81%-65%: $2.5 < M < 4$ 65%: $0.95 < M < 2.5$ Modulates: $M < 0.95$	SPI
SB Position V95H8250C	0%: $M < 10$	VERT SIT 1,2
SB Command V94U1300C	Same as V72H5106C	VERT SIT 1,2

2. Crew Procedures

No applicable cue card

3. Crew Activity

<u>Step</u>	<u>Activity</u>	<u>Position</u>
1	Monitor: BF = 0%, M ≤ 5 de up from schedule; do not trim de back to schedule	CDR/PLT
2	CSS - P/R/Y (if required for control) Caution should be exercised in M5-M1 region	CDR
3	TD Alternate 1: CSS-P decrease OGS to -15°	CDR
4	TD Alternate 2: Gear down at h = 10,000 to 15,000 ft	CDR

C. MCC Operations

1. Failure Recognition

<u>Parameter</u>	<u>Value/trend</u>	<u>Displayed</u>
SB Position V90H6710C	0%: M < 10	SCR File AAA_DP&D_A ENTRY CONTROL Dsisplay

2 MCC activity

<u>Step</u>	<u>Activity</u>
1	Monitor SB and BF positions and δe trim
2	Monitor Φ , δa , δr and RHC for control problem

D. Supporting data notes

1. Lateral aileron control and stability will be degraded below M5 because the elevons are driven above their schedule. Do not trim elevons to schedule or pitch axis mistrim and loss of control will occur.
2. X c.g. forward of nominal will drive elevons further above trim and exacerbate control problems.
3. SMS run showed good control in AUTO-P/R/Y mode given a good nav state.

4. <u>Landing procedure</u>	<u>Advantages</u>	<u>Disadvantages</u>
a. Decrease OGS to -15°	Near nominal TD velocity; some energy margin on OGS	A/L geometry change
b. Deploy landing gear at h = 10,000 ft	Near nominal TD velocity; no change in A/L geometry	maximum speed must not exceed gear limits

REFERENCE

TBS

TITLE

OFF-NOMINAL C.G.

DESCRIPTION

Longitudinal and lateral center of gravity (c.g.) constraints are shown in Flight Rule A4-153. Signatures used to identify a c.g. offset could also indicate a bent airframe or aerodynamic variations. For Y c.g. cases, the lateral trim capability is reduced and caution must be exercised in maneuvering, particularly in the Mach 12 to 8 region. The forward X limits represent lateral-directional stability constraints (due to resultant up elevon trim) and the aft X limits represent longitudinal trim requirements as constrained by thermal limits on the bodyflap and elevons. A significant longitudinal c.g. offset will affect pitching moment and elevon trim. The body flap may saturate and cause the elevons to trim off schedule, which could have a significant impact on vehicle controllability in the pitch and roll/yaw axes.

FLIGHT RULE A8-20

ENTRY ELEVON SCHEDULE SELECTION CRITERIA

The AUTO elevon schedule is selected for the entire range of Orbiter CGs. The FIXED elevon schedule (if aft schedule is l-loaded) is selected if No Yaw Jet is used. The aft schedule positions the elevons further down which improves lateral directional control authority.

MCC ACTIVITY

FORWARD X CG

- A. δe trim up (more negative) off schedule; decreased surface effectiveness
- B. FCS controllability concern with elevons trimmed further up
- C. Potential "FCS SAT POS" fault summary message if elevon position further up than negative 15 degrees.
- D. BF may saturate up (0 percent). Note that many flights that have a X c.g. in the forward part of the envelope will nominally have a full up BF for a significant portion of the entry trajectory.

ACTIVITY

If control is okay, then no action is required, monitor only.

If roll/yaw control problem (indicated by sloppy control and/or high aileron trim), then perform actions given on AIL TRIM $\geq 3^\circ$ on ENTRY CONTROL cue card in the Entry Checklist.

AFT X CG

- A. δ_e trim down (more positive) off schedule; increased surface effectiveness
- B. BF may saturate down (100 percent)
- C. Thermal constraints - potential damage to elevons and BF
- D. Potential "FCS SAT POS" fault summary message if elevator position further down than +12 degrees.

ACTIVITY

Monitor δ_e and BF positions. Approach and Landing Guidance will reposition the BF to the trail position (~ 34 percent) to avoid collision with the runway at touchdown. δ_e will retrim more positive to compensate.

Y CG, BENT AIRFRAME, AERO VARIATIONS

- A. δ_a trim $\neq 0^\circ$ persistent, constant, or increasing during entry (post EI). MCC does not have direct insight into aileron trim, so aileron position must be monitored. Crew can see aileron trim on VERT SIT display. Each inch of Y c.g. offset results in approximately 1° aileron trim (+Y c.g. results in left (negative) aileron trim).
- B. $\beta/N_y \neq 0^\circ$
- C. Yaw jets firing one side
- D. Constraints / flight control limits
 - 1. 5° δ_a auto trim integrator limit for Wrap DAP and NO YAW JET mode.
 - 2. 3° δ_a auto trim integrator limit for baseline DAP.ACTIVITY

If control is okay, then no action is required; monitor only

If lateral/directional control problems occur, perform the actions on the AIL TRIM $\geq 3^\circ$ on the ENTRY CONTROL cue card in the Entry Checklist.

TITLE

RHC BEEP TRIM DEROTATION

CONDITION

A Space Shuttle mission is coming to an end as the main landing gear of the vehicle touches down at the landing site. In the final phase of flight, the crew must safely rotate the nose of the orbiter to the ground such that the peak loads on the nose gear do not exceed structural limits.

DESCRIPTION

Both the Left and Right rotational hand controllers contain a two contact 4 position switch used to input controlled rates into the flight control system. The four positions of the switch input a +pitch (-x), -pitch (+x), +roll (+y), or -roll (-y). Each press of the switch in a given direction is a momentary contact but imparts a rate of 0.6 deg/sec² as long as the switch is pressed, to a maximum rate of 1.5 deg/sec. Although the switches were originally designed for inflight rate adjustment of the flight control system they are almost never used for this purpose. The switch is usually used in the negative pitch direction in order to de-rotate the nose of the orbiter to the ground once the main gear is on the runway. As indicated in the flight rules, "The RHC beep trim switch provides a smooth and predictable orbiter pitch derotation rate. Use of the switch eliminates the derotation rate dispersions introduced during the initiation of derotation when using the RHC and consequently reduces tire and landing gear peak loads". Beep trim for PASS and BFS is different. In the PASS, software logic protects for commfaulted and failed contact combinations that result in a premature uncommanded derotation after main gear touchdown. The engaged BFS has no protection, and is only single fault tolerant to uncommanded pitch inputs at all times. For this reason, actions must be taken post-engage that are not required while on the PASS. An extensive discussion of the beep trim logic and failure modes is provided in GNC Systems Brief 13. The reader is encouraged to read and understand that information prior to proceeding with this SCP.

PROCEDURES

A. *FLIGHT RULES*

A8-101, "BEEP TRIM DEROTATION" (See current flight rules book for actual rules)

B. *CREW OPERATIONS*

The crew monitors equivalent air speed and altitude. At main gear touchdown they deploy the Orbiter drag chute at the target EAS (usually about 195 KEAS). At an KEAS of 185 (immediately if touchdown is late) they use the pitch trim switch on the RHC (neg pitch) to rotate the vehicle nose to the ground at a rate of 1.5 degrees/sec. Caution must be exercised not to add or subtract pitch velocity by inadvertently applying the RHC.

C. MCC OPERATIONS

a. Monitored Parameters

* Page 5, Figure 9.6-1 zones will be indicated by a **bold italicized number**

<u>Parameter</u>	<u>Nomenclature</u>	<u>Value/trend</u>	<u>Displayed</u>	Fig 9.6-1 Zone
V72K1151X	L RHC -P A (or comflt FF1)	"1" - early hot	ENT CNTRL	1
V72K1166X	L RHC -P B (or comflt FF2)	"1" - early hot	ENT CNTRL	1
V72K1196X	R RHC -P A (or comflt FF3)	"1" - early hot	ENT CNTRL	1
V72K1216X	R RHC -P B (or comflt FF4)	"1" - early hot	ENT CNTRL	1

Software Enable/Inhibit MSID's

V72K1160X	LH TRIM INH A	"INH" or "ENA"	ENTRY CONTROL	1
V72K1161X	LH TRIM INH B	"INH" or "ENA"	ENTRY CONTROL	1
V72K1210X	RH TRIM INH A	"INH" or "ENA"	ENTRY CONTROL	1
V72K1211X	RH TRIM INH B	"INH" or "ENA"	ENTRY CONTROL	1
V73S0689E	LH PANEL PWR	"ON" or "OFF"	ENTRY CONTROL	1
V73S0696E	RH PANEL PWR	"ON" or "OFF"	ENTRY CONTROL	1

b. Activity

<u>Step</u>	<u>Activity</u>
1.	Monitor the Flight Director loop for status updates on crosswind violations at the landing site, conditions of the landing gear tires and APU's, and/or any other conditions that may cause lateral control problems at main gear touchdown.
2.	Monitor the Ascent/Entry CRANS matrix as part of your console scan. Premature output on any of the CDR/PLT RHC trim switches other than the +/- pitch (no commfaults) will be indicated in a red CRANS matrix box. Also use the Entry Control display.
3.	At MACH 3 or so and if possible, give the GNC officer a status of the beep trim. If failures exists which will result in auto derotation or manual derotation, inform the crew what to expect as part of the advisories call.
4.	After main gear touchdown (2) monitor EAS (3) and the output of the RHC minus pitch trim switch (1). When the commander (or pilot)

presses the switch verify that the appropriate number of contacts are energized. If the system is operational when this occurs, the derotation pitch rate can be monitored on the top right corner of the ENTRY CONTROL display.

Beep Contact Status Prior to WOW		Result	Advisory
A	B		
HI	HI	Auto Derotation at 195 KEAS	“Expect Auto Derotation at 195 K”
LO	HI	Nominal	None
HI	LO	Nominal	None
CF	HI	Beep Input No-oped	“Perform Manual Derotation On the Left (Right)”
CF	LO	Nominal	None
HI	CF	Beep Input No-oped	“Perform Manual Derotation On the Left (Right)”
LO	CF	Nominal	None

Note that the A and B contacts are powered by the L and R DDU DC power supplies A and B. Known failures of those power supplies will result in the associated contact remaining in a low state, with the resulting consequences.

If the BFS is engaged, verify on the CONTROL BFS display that actions are complete in the BFS Post Engage procedure in the AESP. The steps in that procedure are performed to allow beep trim derotation from the CDR’s RHC (the PLT’s beep trim is not active after BFS engage). The RHC/PANEL ENA is required to enable the beep trim switch on the CDR RHC. The PANEL power is removed to protect for an uncommanded trim input (multiple failures) that the system is susceptible to when the RHC/PANEL TRIM is enabled.

5. If the beep trim input fails, verify that the crew completes derotation manually. The crew is trained to use the RHC if the auto derotation does not occur as expected.
6. Always monitor the pitch rate following main gear touchdown to ensure that derotation occurs as desired (4).

End Activity

STS-96 OV-105		OGMT190/16:50:51		MET000/00:06:24		ENTRY CONTROL				MM103		BFS		TFL129		GNC 21		BFS 12													
DAP		ENT MODE SW		AEROSURF		LOB		LIB		RIB		ROB		RUD		SB		BF		DES		DPS FAIL		ATT		ROLL		PITCH		YAW	
P AUTO	LG	NYJ	D	CMD	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	L	2.0	2.0	2.0	2.0	34.3	34.3	34.3	34.3	L ADI	M	M	M	M	M	M	
R/Y AUTO	D	D	D	1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	RGARTE	-2.8	-0.3	-0.3	-0.5	-0.6		
BF AUTO	D	D	D	2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	L RTE	-3.5	-0.4	MED	MED	-0.6		
SB AUTO	D	D	D	3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	L ERR	-1.1	-0.1	MED	MED	-0.6		
WRAP DAP	D	D	D	4	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	L ERR	-1.1	-0.1	MED	MED	-0.6		
RHC	LEFT	RIGHT		OI POS	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	BFS	M	M	M	M	M	M	
ROLL	A	0.0	D	1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	ATT	M	M	M	M	M	M	
	B	0.0	D	2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	ERR	-2.3	-0.1	-0.1	-0.5	-0.5		
	C	0.0	D	3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2								
	SEL	0.0	D	4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2								
PITCH	A	0.0	D	DRVR	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	ATVC RPC	1	2	3	4	AD TO G&C	MMMM	
	B	0.0	D	1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	SW CMD	A	B	C	C	MAX	M	
	C	0.0	D	2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	PWR	A	B	A	A	THETA	26.4	
	SEL	0.0	D	3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	B	C	C	C	MIN	M	
	SEL	0.0	D	4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	C	A	B	B			
YAW	A	0.0	D	SEC DP	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	0.2	A	B	C	C	PTI	D	
	B	0.0	D	1	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	0.2	B	C	A	A	NUM	D	
	C	0.0	D	2	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	0.2	C	A	A	A	ACT	D	
	SEL	0.0	D	3	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	0.2	A	B	C	C			
	SEL	0.0	D	4	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	0.2	C	A	B	B			
SBTC	A	0.0	D	PRI DP	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	0.2	A	B	C	C	AERO CMD	EL	0.0
	B	0.0	D	1	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	0.2	D	D	D	D	AIL	D	
	C	0.0	D	2	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	0.2	D	D	D	D	FCS SAT		
	SEL	0.0	D	3	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	0.2	D	D	D	D			
	SEL	0.0	D	4	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	0.2	D	D	D	D	GUID	D/	D
RPTA	A	0.0	D	OMS TVC	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	0.2	A	B	C	C	HDG	358	
	B	0.0	D	PRI POS	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03	0.2	D	D	D	D			
	C	0.0	D	SEC POS	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	0.2	D	D	D	D			
	SEL	0.0	D	HYD	1	2	3																	0.2	A	B	C	C	NAV	CMD	
DDU PS OFF				PRESS	A	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	0.2	NAV	TRACK	NAV	NAV	ALPHA	12.0	
RHC TRIM	-P TRIM	-P TRIM		B	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	0.2	6.0	254	ALPHA	BETA	0.8	0.0	
A	INH	INH		C	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	0.2	14494	VREL	PHI	3.5	0.0		
B	INH	INH		TVC ISO	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	0.2	355605	ALT	QBAR	6			
PNL POWER	ON	ON		ARMY1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	ALT (RA) D	ALT RATE	NY	0.7			
				CHUTE	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	-218	DELAZ	NZ	-15.2			
				ARMY1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	D	RANGE					
				ARMY1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	314741						

FIG 9.6-1. GNC ENTRY CONTROL DISPLAY

REFERENCES

1. STS Operational Flight Rules, All Flights, JSC-12820, Rule A8-101, latest version.
2. Shuttle Software Change Request #91050
3. OI-28 Flight Software, DRD 1.4.3.3-q, STS83-0015-28, "Space Shuttle Operational Level C Functional Subsystem Software Requirements Guidance, Navigation and Control Part E Flight Control Sensor/Controller Subsystem Operating Programs, April 30, 1998".
4. OI-28 Flight Software, DRD 1.4.3.3-q, STS83-0015-28, "Space Shuttle Operational Level C Functional Subsystem Software Requirements Guidance, Navigation and Control Part D Redundancy Management, April 30, 1998".
5. GNC workstation display software.

TITLE

DEFAULT AIR DATA

CONDITION

In the Air Data System, below Mach 1.5, if RM declares a dilemma, then Guidance and Flight Control will use I-loaded values of \bar{q} and α , while Mach number and airspeed will be NAV derived. The above is only true in PASS. BFS defaults to NAV derived parameters in the absence of Air Data (default Air Data is not available in the BFS).

DESCRIPTION

When the Air Data System defaults, Flight Control uses a fixed value of α (7.5°). \bar{q} is derived from an I-loaded table as a function of NAV ground relative velocity (V_{REL}). Since Guidance no longer limits α by protecting the low \bar{q} boundary, it is necessary for the crew to follow theta limits on the vertical situation display. Note, in this situation, the displayed α is not reliable. Keeping theta between the NOSE HI and NOSE LO region will ensure that the vehicle alpha is within acceptable limits. Allowing theta to exceed NOSE HI increases the chances of stall while allowing theta to fall below NOSE LO could cause Q-bar increase to unacceptable limits.

PROCEDURES (WHEN FLYING PASS SYSTEM)

A. FLIGHT RULES

SEE CURRENT FLIGHT RULES BOOK FOR ACTUAL RULES

A8-111
A2-261

B. CREW OPERATIONS

Monitor theta limits using the vertical situation display and/or the ADI.

C. **MCC OPERATIONS**

a. Failure Recognition

<u>Parameter</u>	<u>Value/trend</u>	<u>Displayed</u>
V90X4840X	"ADTA DLMA"	CRANS element
V98U1590C	$\alpha = 7.5^\circ$ (M < 1.5)	ENTRY CONTROL
M04G5000C	Theta MAX	ENTRY CONTROL
M05G5000C	Theta MIN	ENTRY CONTROL
V90H2217C	Theta	ENTRY CONTROL

b. Activity

<u>Step</u>	<u>Activity</u>
1	Report "flight control on default gains, monitor theta limits"
2	Monitor theta limits using theta MAX/MIN computations.

REFERENCES

1. Guidance and Control Systems Briefs, JSC-18863, Sec. 4.6.2, latest version.
2. STS Operational Flight Rules, All Flights, JSC-12820, Rule A8-111, latest version.
3. OI-8B Flight Software, GZVVER, p. 16.

TITLE

ROLL REVERSAL MONITOR

DESCRIPTION**A. GENERAL**

The entry guidance task from transition to MM 304 until M2.5 is to control drag acceleration to satisfy entry range requirements. The I-loaded drag reference profile is designed to maintain equilibrium flight and satisfy \bar{q} , N_z and thermal constraints. The drag acceleration level is adjusted during flight to achieve the required ranging (Orbiter range potential = range-to-go) through bank angle modulation. Since drag acceleration and vertical lift component are the same for positive or negative roll angle, the resultant trajectory is a series of bank reversals across the great circle flight path used to control drag and crossrange. α modulation and H_d (altitude rate) are also used to maintain the drag reference profile. α is modulated to achieve the reference on a short period basis and reduce the phugoid induced as bank angle direction is reversed. The resulting guidance control law is given by:

$$(L/D)_C = (L/D)_o + f_1(D - D_o) + f_2(h - h_o) + f_4 \int (D - D_o) dt$$

where, $(L/D)_o = f(a, \Phi)$

B. LIMITS

1. Azimuth Error

Bank angle reversals, performed to null downrange and crossrange errors, are determined by an azimuth error deadband. The azimuth error is the angle between the plane formed by the Orbiter position and velocity vectors and the plane formed by the Orbiter position vector and a vector from the Orbiter to a tangent point on the Heading Alignment Circle (HAC) (WP1). When the azimuth error exceeds an I-loaded value, the sign of the commanded roll angle is reversed. The deadband is $\pm 10.5^\circ$ for the first reversal then increases to $\pm 17.5^\circ$ for subsequent reversals. At M4, the azimuth error is ramped down to 10° to achieve nominal Terminal Area Energy Management (TAEM) interface. As the crossrange requirement for an end of mission (EOM) profile increases, the relative velocity at which the first bank reversal occurs decreases (the later the first bank reversal, the greater the crossrange).

2. Φ_c

Roll angle command limits are established in entry guidance to assure its ability to achieve ranging targets and maintain vehicle structural and thermal constraints. Maximum roll angle command is limited to ensure that large altitude rates do not occur during transition subphase. Minimum roll angle command limits are established through a maximum vertical L/D limit to ensure that crossrange and total energy requirements are satisfied for low L/D or high crossrange entries.

C. MANEUVER MONITOR

1. Φ

During the roll reversal, vertical lift component increases as the lift vector sweeps through zero bank angle. Drag and H_d decrease and α modulation compensates for this by increasing α by about 2° to help keep drag on DREF. At reversal completion, vertical lift decreases as Φ increases in the opposite direction and Φ_c and Φ may overshoot about 20° to converge drag back to the reference. This increased Φ will shallow out and α will ramp back to schedule as drag reconverges.

2. Phugoid, P/R/Y Coupling

The change in lift vector and α modulation during the reversal causes a long-period oscillation in flight path angle and H_d called longitudinal phugoid. The entry guidance control law causes cross-coupling between the pitch and roll/yaw axes and, as Φ_c varies, the resulting H_d will nominally decrease to 0 fps and then increase to approximately -250 fps at reversal completion. As a worst case, if nav or control problems occur, H_d can oscillate between +200 fps to -600 fps. Problems associated with the phugoid include: exceeding thermal limits, flight control instability due to high \bar{q} , payload bay venting below 100K feet and extreme trajectory dispersions.

Phugoid problems will most likely occur when α modulation is saturated ($\alpha > \alpha_{ref} + 3^\circ$) and guidance uses H_d to converge drag to DREF. H_d/H_{dd} pilot techniques can be used to control the phugoid (see reference 4).

3. $\Phi / \dot{\Phi}$

The desired roll rate during reversals is 5 deg/sec as established by PCLIM in the auto mode. This rate represents a compromise between guidance requirements and Flight Control System (FCS) stability limits. Phugoid control represents the upper rate requirement (minimizing time that the lift vector is vertical) and vehicle controllability is the lower rate requirement (minimizing overshoot/high frequency oscillation and maintaining capability to stop the maneuver with yaw jet failures). The actual rate may vary ± 0.5 deg/sec but 5 deg/sec should be attained when going through $\pm 30^\circ \Phi$. Roll angular acceleration is of equal importance in achieving the desired rate. 5 deg/sec should be achieved over a $30^\circ \Phi$ change rather than instantaneously. This reduces β excursions (necessary to maintain thermal limits), provides better controllability (minimizes overshoot/high frequency oscillation critical in NO YJET mode) and reduces Reaction Control System (RCS) usage.

4. Yaw Jet Activity

RCS command lights indicate Digital Autopilot (DAP) jet commands and are a prime indicator of FCS activity during roll reversals. When a roll reversal command is issued, a steady 4 yaw jet command of longer than pulse duration will be issued on the side of the commanded roll (left jet for left roll) to start the maneuver. Jet activity should cease as the steady state roll rate is achieved. As the desired Φ is approached,

a steady 4 yaw jet firing of the opposite jets is commanded to damp the roll rate. Pulsing yaw jet activity may occur as the vehicle establishes a steady state Φ .

5. The FCS uses NAV-derived α in trig functions to compute stability axis rate errors and aerosurface/jet commands. For proper turn coordination, the ratio of roll rate command for a given yaw rate command is expressed by $p/r = \cot \alpha$. Alpha error will produce improper turn coordination, errors in rate damping terms and may cause control problems during maneuvers in the M7-M5 region (with aero variations and yaw jet failures). For this reason lateral accelerometer feedback was added to the DAP with a gain that is a function of the body roll rate. This gain was referred to as the "boosted" N_y and was sent to both the roll and yaw channels of the Aerojet DAP. This signal was designed to limit the increase in sideslip during a roll reversal to a level that two yaw jets could control. The concern for α errors was eliminated with the combination of this software change and the reduction of the aerodynamic uncertainties following the flight test program. The following discussion on α errors remains here for historical purposes.

Alpha error contributions may be due to IMU-related problems but are most likely due to strong winds. In a roll reversal, the orientation of the wind component with respect to the vehicle changes causing a difference between environment and nav-derived alpha. Two alpha error cases can be defined:

- a. $\alpha_{ENV} < \alpha_{NAV}$, wind on top: β builds on the side the vehicle is rolling away from and aids the roll (β builds to increase p); p_c is too small for a given r_c and p increases to "chase" β to coordinate the turn, and
- b. $\alpha_{ENV} < \alpha_{NAV}$, wind on bottom: β builds on the side the vehicle is rolling toward (β builds to damp p); p_c is too large for a given r_c and p decreases to coordinate the turn. The critical control case is the vehicle banked away from then rolling into the wind. In this case, p buildup will be sluggish with excessive jet activity required to achieve the commanded rate. Near wings level jet activity should decrease to zero as $p = 5$ deg/sec is eventually attained and at about 30° past wings level, p will accelerate to greater than 5 deg/sec with excessive jet activity required to damp the rate.

SYMBOLS

L/D	lift/drag
$(L/D)_c$	L/D command
$(L/D)_0$	L/D reference
D_0	drag reference
H_d	altitude rate
H_{d0}	H_d reference
H_{dd}	altitude acceleration
WP1	Way Point 1
α	angle of attack
Φ	roll angle
$\dot{\Phi}$	roll angle rate
$\ddot{\Phi}$	roll angle acceleration
p	body roll rate
r	body yaw rate
β	sideslip angle
\bar{q}	dynamic pressure

REFERENCES

1. Barnes, H., Orbiter Entry/GRTLS FCS, Aerodynamic Stability, FCS Control Boundaries and FCS Procedures, p. 67, Sept. 1982.
2. Flight Procedures Handbook, Entry, Final, rev. A, pp. 4.1-87 and 88, Feb. 1982.
3. Harpold, J.; Graves, C.: Shuttle Entry Guidance, July 1979.
4. Stewart, R., Entry Flight Training for CDR and PLT, pp. 11-17, 39-40, 44-47, and 71-76.

TITLE

PTI MONITORING

DESCRIPTION/CONSTRAINTS

The Program Test Input (PTI) is an automatic sequencing of predefined effector commands into the Flight Control System (FCS) that is performed to gather data on the aerodynamic behavior of the orbiter (though since 1997 and the implementation of the wraparound mode in the aerojet DAP, none have been scheduled). Each PTI is a sequence of doublets or pulses that are executed during their defined time period, firing RCS jets and/or commanding the aerosurfaces. Each doublet is defined by five parameters (1) amplitude, (2) doublet width, (3) interval between doublet pulses, (4) damp time for each doublet, and (5) the effector which is to be driven. Multiple inputs can be commanded simultaneously during a given sequence, and in most cases, jet firings will occur in the same window as aerosurface deflections. There can be up to four sequence inputs per PTI window, and they can consist of roll/pitch/yaw jets and aileron/elevator/rudder commands. Note that for forward PTI's, a forward yaw jet pulse may be active at the same time as an aft jet, or aerosurface PTI. For example, an aileron doublet, rudder doublet, aft yaw jet doublet, or elevator doublet may be executed while the forward jets are firing.

The PTI software is made up of two major functions, the PTI sequencer module and the PTI driver module, both of which reside in the Aerojet DAP. In general, the sequencer module decides which PTI should be executed, if the PTI should be executed, and when to execute the PTI. The driver module then executes the PTI and terminates it if necessary (ref. FSSR STS83-0007, Flight Control Entry-GRTLS, and Software I-loads CD).

The PTI sequencer module monitors the vehicle trajectory and automatically selects maneuvers for execution based on either the dynamic pressure, Qbar (for PTIs in early part of entry) or the Mach number, M (for PTIs in remainder of entry). The software provides for a maximum of 10 "PTI windows" which define the allowed segment of the trajectory during which each maneuver can legally be selected. The windows are defined by I-loads (of Qbar or Mach) which specify the leading edge and trailing edge of each window.

The software initiates, executes, and terminates PTIs based on the following (reference figure 9.9-1).

- A. A counter, PTI_NUMBER, is set up to track the current PTI. The counter sequences forward only, and increments only when the limits of the current window are passed, or when the PTI_ACT_D signal from the PTI_DRIVER changes from true to false. (The latter is a situation where the PTI driver module sends an indication to the PTI sequencer that the PTI is inactive or terminated, PTI_ACT_D false, and the PTI sequencer then increments the counter by one to prepare for the next PTI.)
- B. The following constraints must be met for four consecutive passes (3.84 sec) before the PTI sequencer will initiate a PTI.
 1. Vehicle body rates are below I-loaded limits.

Roll rate < 1.5 deg/sec
Pitch rate < 0.5 deg/sec
Yaw rate < 0.5 deg/sec

2. ADTA data is being used by Flight Control (G&C) if $M < 2.5$. AD to G&C must be in AUTO (or FORCE) and the AD Data Good set true.
3. PITCH and ROLL/YAW axes in AUTO.
4. PTIs enabled via keyboard entry on SPEC 50, Horizontal Situation Display, Item 1 EXEC. This is a toggle function to inhibit (INH) or enable (ENA) PTIs and is valid in MM 304 and MM 305 only. Note that this display is initialized with PTIs inhibited.
5. Guidance constraints (Qbar and M) are met.

When all constraints have been met for four consecutive passes, the PTI_EXECUTE flag is set to true and sent to the PTI driver. PTIs are executed when the PTI driver receives the PTI_EXECUTE true command from the PTI sequencer. Once the PTI begins, the PTI_ACT_D flag will be received from the PTI driver. When the PTI_ACT_D flag modes from true to false (PTI inactive), the PTI_EXECUTE flag is set to false, the counter (PTI_NUMBER) is advanced by one, and the four-pass counter is reset to zero.

- C. If the commander or pilot engage control stick steering (CSS) in either PITCH or ROLL/YAW with the pbi, and/or take the RHC out of detent, the PTI_INHIBIT flag will be set true. No PTIs will be executed until AUTO flight control is engaged and PTI's are re-enabled on SPEC 50.
- D. The PTI driver module will stop execution of a PTI that is in progress if any of the following occur:
 1. Flight control system is moded to CSS (as explained above).
 2. PTI's inhibited (INH) on SPEC 50.
 3. ADTA data not being used by Flight Control (G&C) and $M < 2.5$.
 4. Vehicle body rates exceed I-loaded limits.

Roll rate < 7.0 deg/sec
Pitch rate < 3.0 deg/sec
Yaw rate < 3.0 deg/sec

NOTE: These specific I-loads can change as a function of the PTIs being executed (e.g., rate limits opened-up for subsonic maneuvers) and the flight specific I-loads should generally be verified.

If any of these constraints are violated, the PTI_INHIBIT flag is set true, the PTI_ACT_D flag is set false, and the PTI is terminated. The exception here is for constraint #3 above, and although the PTI will become inactive (PTI_ACT_D set false) and the PTI number will be incremented, the PTI_INHIBIT flag is not set true. However, the result is the same because the driver tells the sequencer that the PTI is not active (PTI_ACT_D false), and the sequencer in turn sets the PTI execute command to false (PTI_EXECUTE false) upon receiving the

PTI_ACT_D false flag. This effectively terminates the PTI without setting the PTI_INHIBIT flag false.

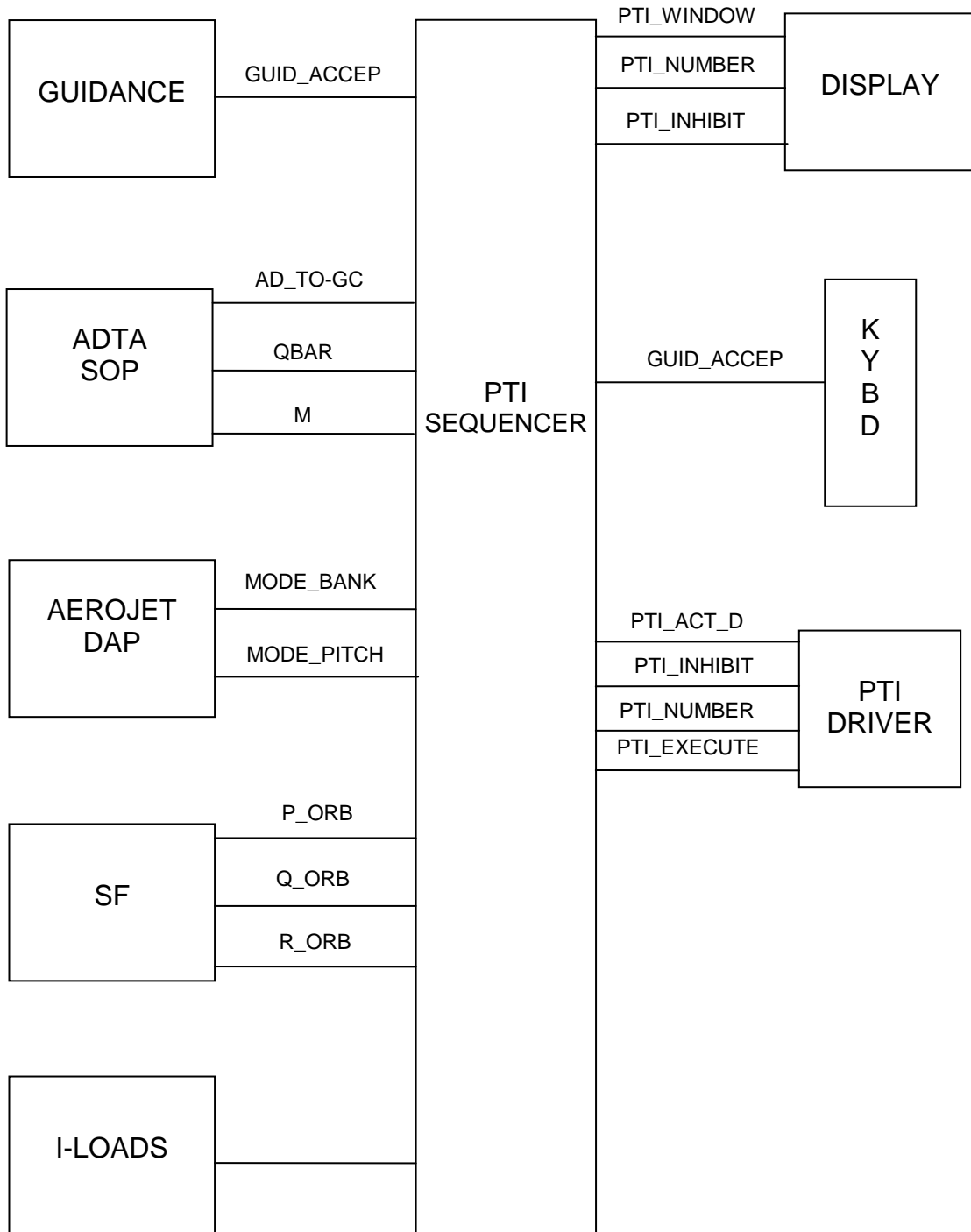


Figure 9.9-1. - PTI_SEQUENCER block diagram.

FCS MODING

During execution of PTIs, the roll axis guidance is open loop, meaning guidance roll angle commands are not input to the flight control system during this time. This leads to roll angle error propagation, which can show up as step changes in the roll rate command once the PTI is terminated.

Inputs to the aileron and rudder trim integrators are set to zero causing the output of these modules to retain their current value.

GJET command, which schedules a gain as a function of Qbar to convert pitch jet commands into pitch trim rates, is also set to zero.

Finally, the PTI effector commands are summed with the normal digital autopilot (DAP) commands to ensure controllability.

PROCEDURES

The flight controller can verify the status of the PTIs on the Entry Control Display. Once enabled initially, the PTI's are assumed enabled unless the space next to the INHIBIT shows the INH indication. When enabled, or prior to MM 304, this space will be blank. (As mentioned earlier, for the loss of ADTA data below M = 2.5, the INH will not appear although PTIs will be disabled in the software.)

PTI-related crew procedures and monitoring information are listed on the PTI MONITOR cue card. This cue card is on a flight-specific flight supplement (FS) page of the Entry C/L. The GNC flight controllers should use this cue card and the Flight Rule A2-261, ENTRY DTO/AUTO MODE/CROSSWIND DTO GO/NO-GO, for monitoring and making GO/NO-GO calls on the PTI's, respectively. The ENTRY MANEUVERS cue card should be referenced also, since this card contains the initial procedures for enabling PTI's on SPEC 50 and for configuring the forward RCS when applicable for forward PTI's. The following defines the nomenclature used on the PTI MONITOR cue card for the various aerosurface and RCS jet PTIs.

Roll Maneuvers

- R_A - Positive ROLL (ROLL right) due to AILERON deflection.
- $R_{\downarrow A}$ - Negative ROLL (ROLL left) due to AILERON deflection.
- R_J - Positive ROLL (ROLL right) due to JET firing.
- $R_{\downarrow J}$ - Negative ROLL (ROLL left) due to JET firing.
- R_R - Positive ROLL (ROLL right) due to RUDDER deflection.
- $R_{\downarrow R}$ - Negative ROLL (ROLL left) due to RUDDER deflection.

Pitch Maneuvers

- P_E - Positive PITCH due to ELEVATOR deflection.
- $P_{\downarrow E}$ - Negative PITCH due to ELEVATOR deflection.

- P_J - Positive PITCH due to JET firing.
- $P_{\downarrow J}$ - Negative PITCH due to JET firing.

The flight controller procedures for monitoring PTIs should include verification of the expected vehicle response for the execution of each PTI. Given a PTI-induced roll maneuver, one can expect that the change in the lift vector orientation will affect Hdot (altitude rate). For a PTI-induced pitch maneuver, the angle-of-attack (ALPHA) should reflect the vehicle pitch, for example. Other aero parameters will also be affected for a given PTI and the overall aerodynamic and flight control configuration of the vehicle should be so noted. On a non-interference basis, the Control and GNC operators should report the initiation of each PTI.

TITLE

PRIORITY RATE LIMITING MANAGEMENT

PURPOSE

This SCP provides the procedures for manual management of the priority rate limiting (PRL) system using the OVERRIDE display (SPEC 51).

DESCRIPTION

The PRL portion of the ascent and aerojet digital autopilot (DAP) software provides automatic management of the loads on the hydraulic systems during ascent and entry when one or two of the three hydraulic systems are failed. The PRL software establishes the elevons and rudder at a higher priority than the speedbrake in cases where the demand for all three systems cannot be met. In addition, PRL will reduce the maximum rate of movement of the aerosurfaces to reduce the hydraulic demand. For single APU cases, the elevon/aileron rates are further reduced post-WONG to avoid overdemanding the APU during touchdown. Touchdown is a particularly sensitive time due to high activity of the aerosurfaces, landing gear, nose wheel steering (NWS), and brake systems. Reducing the elevon/aileron rates after the vehicle has achieved a three point stance reduces hydraulic demand during load relief, thus providing more capability for brakes and NWS. A more in-depth discussion of this subject is provided in SCP 5.7 Single APU Landing. Aerosurface drive rate reductions for the loss of one or two hydraulic systems are shown in table 9.10-I. The body flap drive rate is not limited by PRL software. The drive rate is a function of the number of hydraulic systems available.

TABLE 9.10-I.- AEROSURFACE DRIVE RATE LIMITS (DEG/SEC)

HYD SYS AVAIL	Elevator/aileron (I-Load)	SB closing/opening (I-Load)	Rudder (I-Load)
3	20*	10.86 / 6.1	14
2	20*	10.86 / 6.1	12
1 or 0	13.9 & 10.5 (Post WONG)	6.06/5.43	7

* The elevon rate limit is 20 deg/sec (30 deg/sec if true airspeed is less than 600 ft/sec).

Redundancy management (RM) receives hydraulic system supply pressure values from triple redundant sensors A, B, and C on each hydraulic system through the flight critical FA MDM's (fig. 9.10-1). RM selection filter mid-value selects the indicated pressure values at the three-level, averages the values at the two-level, or prime selects the last remaining pressure value. RM passes these values to the HYD SOP. RM declares a hydraulic system failed when the sensed pressure is less than 1760 psi. RM also operates on the pressure transducer feedbacks. It will fail any sensor which differs from the other two sensors by >250 psi. RM declares a dilemma when the last two remaining pressure sensors on a system disagree by more than 250 psi. An RM DILEMMA PRL message will annunciate and the DATA GOOD flag will be set to BAD. The HYD SOP will use the last pressure value before the dilemma was declared; i.e., before the DATA GOOD flag was set to BAD. The hydraulic pressures are available on the Ascent Control and the Entry Control Displays. The 1B, 2B, and 3B pressures

are downlisted through the OI MDM's only. The remaining pressures are GPC downlisted measurements. The HYD SYS SOP and HYD SYS FDI are active from Redundant Set Auto Sequence Start (T-28 sec) to MECO and in OPS 3 and 6.

FA MDM	HYD SYS		
1	1A	2B	-
2	1B	2A	3C*
3	-	2C	3A
4	1C	-	3B

* All hydraulic pressures are on FA X BCE STRING D (where X indicates 1 through 4) except HYD PRESS 3C which is on its own string entitled FA2 HYD SYS 3 PRESS C.

Figure 9.10-1.- Hydraulic system MDM locations.

PRL and hydraulic system statuses are displayed to the crew on the OVERRIDE display (SPEC 51) as shown in figure 9.10-2. For each of the three hydraulic systems, auto (AUT) and deselect (DES) items are provided to allow the crew to (1) place the system in automatic systems management, (2) manually deselect (declare failed) a system, or (3) place a system in manual systems management. A system which has been automatically downmoded; i.e., declared unavailable to PRL, will display a down arrow (↓) in the system status column. The failed system may be forced back into PRL availability by executing its AUT item entry which blanks the "↓" in the status column and blanks the asterisk (*) next to AUT. This establishes manual system management. A repeat execution of the AUT item entry restores the automatic systems management and restores an "*" in the AUT column. The DES item entry allows the option of forcing the HYD SOP to declare a system failed. Executing the DES while an "*" is displayed next to AUT removes automatic systems management; i.e., drives an "*" next to DES, blanks the "*" next to AUT and drives a "↓" in the system status column. (See system 2 in figure 9.10-2.) A repeat execution of DES establishes manual systems management; i.e., blanks both the "↓" and the "*" next to DES. Manual systems management has been established for system 3 as shown in figure 9.10-2. AUT, DES, and manual systems management are mutually exclusive. The hydraulic systems are initialized in the AUTO mode. A question mark is displayed in the status column when an RM dilemma is declared unless the system was previously declared failed in which case a "↓" is displayed taking precedence over the "?". When a dilemma is declared, PRL leaves the system status (good or failed) as it was prior to the dilemma. Figure 9.10-2 shows system 2 manually deselected. The AUT and DES items are available for execution in MM's 101 to 103, 601 to 603, 304, and 305.

OVERRIDE Display (SPEC 51)		
SYS	PRL	
	AUT	DES
1?	28*	31
2↓	29	32*
3	30	33

Figure 9.10-2. - PRL Status as Displayed on SPEC 51.

A graphic mnemonic aid to reconfiguring PRL is provided in Figure 9.10-3. To use this aid, begin in a box that describes the current PRL configuration of the system to be managed.

Determine the desired end-state of the system and read the label of the arrow that leads to the desired end state. For example, if System 1 is currently Manually Deselected (MAN DES), to reselect System 1 and return PRL to Auto (AUTO SEL), an AUTO item entry is required (SPEC 51 Item 28).

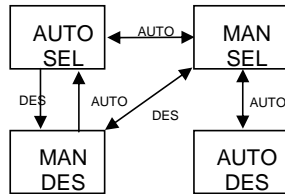


Figure 9.10-3. - PRL Management Graphic Aid

PROCEDURE

There are four cases where the crew may be required to manage PRL using the OVERRIDE display. These cases are described below. Hydraulic pressures in pounds per square inch and failures, indicated by FL, are displayed on the Entry and Ascent Control Displays.

A. Case 1

System status: System declared failed by RM
 Indications: "↓" on SPEC 51, FL on Control Display
 Actions:

1. Contact MMACS operator to determine if the system is really good or bad.
2. If system is BAD: No action required
 If system is GOOD: Manual systems management required (crew executes AUT)

B. Case 2

System status: RM declares a dilemma and system NOT failed
 Indications: "?" on SPEC 51, no FL on Control Display
 Actions:

1. Contact MMACS operator to determine if the system is really good or bad.
2. If system is GOOD: No action required
 If system is BAD: Manual deselection required (crew executes DES)

C. Case 3

System status: RM declares a dilemma and system was previously failed "↓" on SPEC 51 ("?" masked), FL on Control Display
 Indications: "↓" on SPEC 51 ("?" masked), FL on Control Display
 Actions:

1. Contact MMACS operator to determine if the system is really good or bad.
2. If system is BAD: No action required
 If system is GOOD: Manual systems management required (crew executes AUT)

D. Case 4

System status: Sensors fail high but not failed by RM
Indications: No "↓" or "?" on SPEC 51, no FL on Control Display
Actions: 1. MMACS operator informs GNC the system is bad but not declared failed by RM.
2. Since the system is BAD: Manual deselection required (crew executes DES)

SUMMARY

- A. The body flap drive rate is not limited by PRL software.
- B. RM declares a failure for pressures less than 1760 psi.
- C. RM declares a dilemma for pressure miscompare greater than 250 psi.
- D. The HYD SOP uses the last pressure value before a dilemma was declared.
- E. All systems are initialized in AUTO.
- F. PRL leaves the system status where it was prior to a dilemma.
- G. A system with a "?" displayed is available to PRL.
- H. A system with a "↓" displayed is unavailable to PRL.
- I. A "↓" takes precedence over a "?".
- J. Manual system management is established on a system by executing the item (AUTO or DES) with the "*". A repeat execution of the item returns the system to its previous state.

REFERENCES

- 1. Displays and Controls FSSR (STS83-0020, vol 1), Override Display, p. 4.2.31-1, Feb. 15, 1986.
- 2. Flight Control Effector FSSR (STS83-0016), HYD SYS SOP, PF 4.52. p. 4.52-1, June 30, 1985.
- 3. Flight Control Entry - GRTLS FSSR (STS83-0007), PRL for Aerosurface Commands, p. 4-307, June 30, 1985.
- 4. Instrumentation Database, SCAP, STS-26, Nov. 1987.
- 5. Redundancy Management FSSR (STS83-0010), HYD SYS FDIR, PF 4.249, p. 4-20, June 30, 1987.
- 6. Shuttle Software CR 92384B, Priority Rate Limiting Improvement
- 7. Shuttle Software CR 92422A, Priority Rate Limiting Improvement - BFS

TITLE

MAXIMUM L/D CONFIGURATION

PURPOSE

To determine the vehicle configuration (attitude and control surface positions) for maximum lift to drag (L/D) during entry.

DESCRIPTION

During entry, because of a low-energy situation, the flight dynamics officer (FDO) may request maximum L/D configuration. This involves flying as close as constraints will allow to the alpha profile for L/D max.

Above Mach 3, significant changes in the alpha profile from nominal are not desirable because of range, energy, thermal, and stability constraints. Above Mach 10, flying at an alpha very far above the nominal results in unacceptable heating loads on the vehicle. Below Mach 10, alpha is limited by the C_{ng} dynamic boundary, where lateral direction control is significantly degraded or may be lost.

From Mach 3 to Mach 1, the following table is used to determine the alpha profile for L/D max.

M	3	2	1
α (for L/D max)	17	15	12

An upper limit for alpha of 15° should be enforced throughout the transonic speed regime (M = 1.2 to 0.9). Loss of lateral control will occur at an alpha between 15° and 20°. The transonic speed regime is also a time of abrupt changes in pitching moment causing the body flap and elevons to be very active. Buffeting at this time is also an important consideration and increases as alpha increases above 10° to 12°. In fact, significant amounts of buffeting may occur at alpha's lower than the 15° limit.

Below Mach 0.95, the L/D max configuration is as follows:

- Speedbrake closed
- Body flap to trail
- alpha = 10° to 12°

Above Mach 0.95, the nominal schedule for the speedbrake and body flap is followed.

PROCEDURES

A. FLIGHT RULES

None

B. CREW OPERATIONS

- Go to CSS and fly alpha for L/D max as stated in the Entry Alpha cue card.
- Above Mach 3, fly the lower part of the $\pm 3^\circ$ deadband above the nominal alpha profile.
- Below Mach 3, fly the following alpha profile.

M	3	2	1
α (for L/D max)	17	15	12

- $1.2 < M < 0.9$, upper limit on α of 15°

Note: Buffeting may become a problem at transonic speed as α increases above 10° to 12° . If control problems occur, the crew action is to decrease the angle of attack.

- $M < 0.95$:
 - Close speedbrake
 - Body flap to trail
 - Fly at an α of 10° to 12°

C. MCC OPERATIONS

<u>Parameter</u>	<u>Value/trend</u>	<u>Displayed</u>
V95L3029C M (GNC)	Monitor values	Entry Control
V98U1590C GNC α	specified in	Entry Control
V90H6410C Body flap	Crew Operations	Entry Control
V90H6710C Speedbrake		Entry Control

ACTIVITY

Monitor alpha and aerosurface positions to confirm that they are maintained as specified above. Be especially aware of the 15° upper alpha limit on flight control during the transonic speed regime. Loss of lateral control will occur at an alpha between 15° and 20° . The 15° upper alpha limit is a hard limit.

RELEVANT EDTE DISPLAYS

<u>EDTE</u>	<u>TITLE</u>
0446	AERO TAB
1409	GNC CONTROL - ENTRY

REFERENCES

1. Flight Data File, ENT/26/BAS A,2 JSC-18540, p. FS 4-8.
2. RTLS Simulation, SCR 603, 604, 613, GNC MPSR, Jan. 5, 1988.

TITLE

OPTIONAL TAEM TARGETING (OTT)

DESCRIPTION

The terminal area energy management (TAEM) guidance will nominally guide the Orbiter to an altitude (h) and dynamic pressure (\bar{q}) versus range profile. It controls energy by modulating drag through speedbrake deflection commands to null out the \bar{q} errors and by nulling out h errors through the normal load factor (Nz) command. If excess energy exists and the heading alignment cylinder (HAC) turn angle is less than the max HAC turn angle for an S-turn, the logic executes an S-turn to dissipate additional energy. If an extremely low energy condition exists, the minimum entry point (MEP) alert is annunciated and the crew has the option to downmode to this approach.

The name Optional TAEM Targeting (OTT) is a bit of a misnomer in that OTT is the only TAEM targeting scheme available. The standard approach in OTT is for an overhead approach which brings the Orbiter over the runway with high energy and a variable-radius spiral around the furthest HAC to final approach. For cases in which the energy state falls below a minimum value, the system automatically downmodes to the nearest HAC for a "straight-in" approach. In downmoding, the Orbiter will pick up the nearest HAC (now, heading alignment cone). The OTT software has algorithms to adjust speedbrake commands and spiral radius, and to downmode (crew option) to the MEP, if required. The software also has options for high energy cases which include S-turns, pull-up maneuvers, and crew toggling of the mode function to redesignate HAC selection. In the overhead mode, the left or right HAC is selected at entry interface (EI) to be on the opposite side of the runway centerline of the Shuttle position. This selection remains latched independent of Shuttle position unless the selected HAC is manually toggled.

There are two possible sources of approach mode changes that may occur subsequent to initialization. Since the approach mode may be designated independently for both primary and secondary runways for redesignation cases, the OVHD lag can change status at redesignation, which may occur any time during entry or TAEM. A change of approach mode may also be exercised by input of the manual HAC toggle velocity (VTOGL). When the Shuttle velocity goes below this input value, the current approach mode (OVHD or STRT) will be reversed.

For all guidance phases (S-turn, acquisition, heading alignment, and pre-final) (IPHASE = 0, 1, 2, 3, respectively), the Guidance Nz command is based on the altitude and altitude rate (h and \dot{h}) errors from the reference profile, and the speedbrake command is based on the dynamic pressure error. All guidance phases are internally determined.

For the lateral axis, if guidance is in the S-turn phase, a constant bank angle is sent to the flight control system. In the acquisition phase, guidance commands a bank angle that is proportional to the Orbiter heading deviation from the tangent point (DELAZ) on the selected alignment cone. In the HAC phase, guidance commands a bank angle which assures that the Orbiter follows the HAC. During prefinal phase, it commands a bank

angle from a linear combination of Orbiter lateral deviation and deviation rate from the runway centerline.

Phase	Label	Description
0	S-Turn	Dissipates excess energy
1	Acquisition	Vehicle turns until tangent to selected HAC and continues until HAC is reached
2	Heading Alignment	HAC is followed until alignment with runway direction is within $\pm 12^\circ$
3	Prefinal	Prefinal Pitch down to acquire glide slope and maintain airspeed required for A/L interface.

ENERGY CONTROL

The amount of energy the vehicle has determines whether or not it will make the runway. There are two types of energy: potential and kinetic.

Potential energy is a function of altitude and is scheduled against range to the runway. Altitude is controlled by attitude through normal acceleration commands. Kinetic energy is determined by the vehicle's velocity or dynamic pressure ($\bar{q} = 1/2 \rho V^2$). \bar{q} is easily altered through speedbrake deflection, which in turn alters drag ($D = \bar{q} S C_D$). Energy during the TAEM phase is modified by nulling altitude error through the speedbrake (subsonic) and/or Nz commands to achieve the desired energy level. If these commands are not sufficient to accomplish the desired changes, then a redesignation to the closer HAC (or an addition of the S-turn phase) is introduced to account for a lack (or an excess) of energy.

TAEM GUIDANCE FUNCTIONS

TAEM guidance sends three commands to flight control: normal acceleration (Nz), speedbrake, and roll angle. It receives the state and velocity vectors from navigation through the user parameter processing (UPP), aero data from the air data transducer assembly (ADTA), and the crew commands via the displays (keyboard item entries) and controllers (if CSS). These inputs are used in functions and subfunctions within TAEM guidance to derive the output commands that are sent to flight control.

Once TAEM is initialized, the HAC's are set up and the range to go calculated. With the range to go known, the energy is calculated from altitude and dynamic pressure and these three are differenced with reference profiles to obtain E/W, h and \bar{q} errors. These determine the current phase and transition to A/L guidance.

The Nz command sent to flight control is determined from the h error and a computed h error. Speedbrake command is calculated as a function of \bar{q} , and roll command is different for each phase:

- Phase 0: Φ_{cmd} is set at one of two max values depending on whether the vehicle is subsonic or supersonic,
- Phase 1: Φ_{cmd} is proportional to DELAZ,
- Phase 2: Φ_{cmd} follows the HAC
- Phase 3: Φ_{cmd} is calculated from the lateral deviation and rate from the runway centerline.

MISSION CONTROL CENTER (MCC) OPS

Upon transition to TAEM guidance (MM305 Vrel = 2.5K), the flight controller's task is monitoring the dynamics of the vehicle and making certain nominal calls:

- A. HAC acquisition
- B. MAX Nz on HAC

Off-nominal calls would include any deviations from nominal dynamics:

- A. Aileron/rudder force fight
- B. Oscillations in roll
- C. Off-schedule elevons, BF, SB, α
- D. Excessive Nz
- E. Excessive rates

CREW PROCEDURES

For the off-nominal situations mentioned above, appropriate crew response would be:

- A. Trim aileron to zero (ENA RHC/Panel Trim, and use roll panel trim to trim to 0 deg).
- B. CSS roll/yaw and damp rates.
- C. CSS pitch, MAN BF to bring elevons, α back on schedule.
- D. CSS with corrective action. Decrease α /shallow bank.
- E. AUTO/CSS, whichever is better. If in CSS, use minimal stick inputs.

REFERENCE

Stewart, R., Entry Flight Training for CDR and PLT, TD-328, p. 1-19, Aug. 1985.

TITLE

LOSS OF CONTROL PROCEDURES

PURPOSE

The purpose of this SCP is to instruct the Ascent GNC in the operation of the loss of control (LOC) signal software and hardware.

BACKGROUND

The Ascent GNC is responsible for assessing vehicle controllability during first stage and for advising the Flight Control Officer (FCO) if the Shuttle has violated the loss of control limits during first stage. This advisory is implemented via a hardware/software capability on the GNC console that is tied directly to the controllability light on the FCO console in the Range Operations Control Center (ROCC) at Cape Canaveral. This direct link between the GNC and the FCO was implemented in an effort to minimize the FCO's reaction time to situations involving an uncontrollable vehicle. The Flight Director will provide verbally confirmation of the loss of control to the FCO via a code word on the Flight Director loop. The LOC signal is a primary cue in the FCO's decision tree to determining whether or not the flight can continue.

PROCEDURE

HOW TO ACTIVATE THE LOC PBI SOFTWARE

The following procedure will allow the Ascent GNC to start the software that enables the pushbuttons on the GNC White FCR console. There are three buttons on the console which enable, execute, and clear the LOC signal. Before starting the LOC application, the A/B switch under the left console access panel (the panel to the left of the panel that conceals the console light dimmer switch) must be in the proper configuration. The switch must be in the A position if starting the application on the center or left workstation heads. If the right workstation head is used, the B position must be selected.

Once the A/B switch is properly configured, the software can then be started via the GNC Display DNAV menu by selecting the *Ascent GNC LOC* function. The *Ascent GNC LOC* menu will then appear with the following functions: LOC SW & HW start, LOC HW start, and LOC shutdown as shown below.

-	Ascent GNC LOC
Loss of Control Application For Ascent GNC ONLY	
LOC SW & HW start	
LOC HW start	
LOC shutdown	

The *LOC SW & HW start* performs two functions. It not only enables the hardware PBIs, but also opens a window that allows the user to change the intensity of the PBI lettering. However, since the default light level is adequate, most controllers only need to use the *LOC HW start* function. This will enable the PBIs without opening any new windows. Successful execution of this function will result in the top PBI illuminating with “ENA” in it, as shown below.

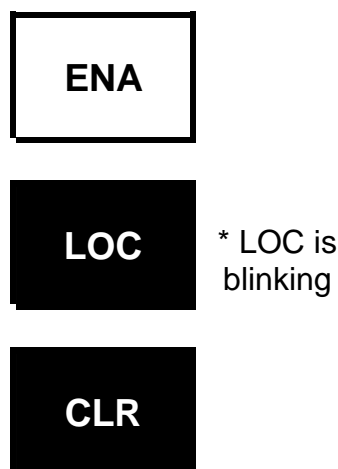


From this point, the software is activated and ready for use. If the ENA PBI does not light up, verify that the A/B switch under the access panel is in the proper configuration; A for the center and left workstation heads and B for the right workstation head. If this still does not work, contact either the workstation Group Administrator or WSS.

To turn off the software and the PBI, select the *LOC shutdown* option from the pull down menu.

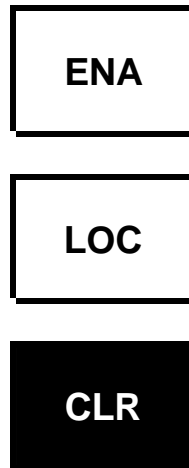
HOW TO ISSUE THE CONTROLLABILITY LIGHT

Once the software is activated and the PBIs are active, the LOC signal is ready for use. This system has an arm/fire/clear operating sequence. When the ENA PBI is the only lit PBI, the system is active, but disabled. To enable/arm the LOC PBI, simply press the ENA PBI. This will result in the following PBI configuration.



The blinking LOC PBI indicates that the LOC signal is armed. To send the LOC signal, simply press the LOC PBI and the controllability light on the FCO console will illuminate. The LOC PBI

will then become backlit and non-flashing to indicate that the signal has been sent as shown below.



Finally, to clear the signal and turn off the FCO's controllability light, simply press the CLR PBI. This will take the application back to its original state, which is active but disabled/unarmed.

WHEN TO ISSUE THE CONTROLLABILITY LIGHT

A complete end-to-end checkout of the controllability light is performed as part of the prelaunch S0007 OMI. This occurs shortly after the Ascent team arrives on console. The Flight Dynamics Officer (FDO) operator will coordinate the test with the FCO and GNC. The test consists of arming, executing, and clearing the LOC signal. The FCO will relay through the FDO that the light was or was not illuminated. If the light does not work, contact GC to begin troubleshooting the problem.

Once the controllability light test is complete, the LOC signal should only be sent for a subsequent loss of control as defined in Flight Rule A8-54. For the purposes of Range Safety decisions, loss of vehicle control during first stage (MM102) is defined as pitch or yaw rates greater than 5°/sec sustained for more than 5 seconds. If this condition occurs during first stage, the Flight Director (FD) must be informed that the vehicle is "uncontrollable" and the controllability light must be illuminated. The FD will then inform the FCO that the vehicle is "uncontrollable" followed by a verification code word. At that point in time, the FCO will make the final decision on whether the flight should continue or be terminated. For all of the Flight Rules governing the FCO's actions, refer to Range Safety Flight Rules Section R (located at the end of Section A4).

TITLE

MEDIN USER'S GUIDE

PURPOSE

The MEDIN program is used to send MED files from the MCC workstations to the MCC host computer. This SCP describes the use of the MEDIN program.

BACKGROUND

The workstations are connected, through a local area network (LAN) called the OPS LAN (and associated sub-LANs, i.e. White, SVO, ISS, etc.), to other MCC workstations and the Mission Control Center host computers (MOC & DSC). Commands to the hosts, called MED's, can be transmitted from workstations over the OPS LAN.

The MEDIN program reads a properly formatted file containing positional MED's, and requests the UNIX operating system to transmit these MED's to the MCC hosts. The proper format for the positional MED's themselves is found in the "MED list" document, STSOC-UD-600315.

PROCEDURE

The MEDIN program transmits a MED file, containing positional MED's, to the MCC host. It requires one command-line argument: the name (and path if not in the working directory) of the MED file you wish to send.

MEDIN can be run from the gmenu in GNC^Apps or the command line.

In the following examples, it will be assumed that the user wishes to send a MED file named "orth.med" to the Mission Operations Computer (MOC, one of the MCC hosts). To send a MED file with a different name, simply substitute that name in the following procedures wherever "orth.med" appears. To send a MED to other MCC host computers such as the Dynamic Standby Computer (DSC) you must change the host designation field in the data file. Acceptable host designations are both (MOC & DSC), MOC, and DSC.

A. TO RUN MEDIN FROM THE GNC MENU PROGRAM:

1. Select Applications by typing its name, typing in its line number, or using the cursor highlight. Select the MEDIN program by typing its name, by typing its line number, or by moving the highlight cursor to the MEDIN line.
2. Type a space, the "Selection:" line will show the word "medin" followed by a space. The menu program is now waiting for you to type the arguments to the MEDIN program.
3. Type the name (and path if not in the flight directory) of the MED file you want to send (e.g. "orth.med").

4. Hit the <RETURN> key. The screen will clear, and then display "medin orth.med" in highlight. The MEDIN program is now running.
5. After a few seconds, the message "MED file orth.med successfully sent" will appear.

NOTE

The "MED file <filename> successfully sent" message is only an indication that medin sent the load to the MOC (DSC), not that it was accepted.

To see if the MED was actually accepted by the MOC, look at the advisory window. Messages in green which start with "OOMOC" are transmitted by the MOC. If a green message reading " INPUT DECODED" appears, and no other green message appears for a few seconds, the MED was probably accepted. (There is no positive confirmation that the MED was accepted via the advisory window.) Additional messages may give cause as to why a MED was not accepted. (I.e., LOAD ON RECORD, etc.)

6. The MEDIN program has now finished running. The message "Hit any key to continue" will appear, in highlight. Hit a key (any key, it does not matter which), and you will return to the GNC menu.

B. TO RUN MEDIN FROM THE COMMAND LINE:

1. Type "medin" " at the command prompt.
2. Type a space.
3. Type the name (and path if not in the working directory) of the MED file you want to send (e.g "orth.med").
4. Hit the <RETURN> key. The MEDIN program is now running.
5. After a few seconds, the message "MED file orth.med successfully sent" will appear.

NOTE

The "MED file <filename> successfully sent" message is only an indication that medin sent the load to the MOC (DSC), not that it was accepted.

To see if the MED was actually accepted to the MOC, look at the advisory window. Messages in green which start with "OOMOC" are transmitted by the MOC. If a green message reading " INPUT DECODED" appears, and no other green message appears for a few seconds, the MED was probably accepted. (There is no positive confirmation that a MED was accepted via the advisory window.) Additional messages may give cause as to why a MED was not accepted. (i.e., LOAD ON RECORD, etc.)

6. The MEDIN program has now finished running. Another command prompt will appear.

REFERENCE

GNC Off-line Program MEDIN Documentation Folder.

TITLE

DETERMINATION OF STAR AVAILABILITY IN LVLH ATTITUDE HOLD

PURPOSE

To describe the procedure for using the PC computer program STARS to determine the stars that will pass through the field of view of a star tracker as the orbiter traverses a full orbit revolution in LVLH attitude hold.

CONCEPT

As the orbiter traverses one full revolution while in any LVLH attitude hold, each star tracker sweeps out a band of the celestial sphere. Any star that is in this band will be available to be tracked unless there is interference from some object (primarily earth, sun, and moon).

The program performs calculations in an inertial frame, hereafter referred to as FLVLH, defined parallel to the LVLH frame at a specific time. The selected tracker field of view centerline vector and each star catalog vector are transformed into this frame. The angle between the star tracker field of view centerline and the orbit momentum vector is constant throughout the orbit revolution. A default band of 10 degrees approximating the star tracker field of view width defines a ring centered about the orbit momentum vector (FLVLH -Y axis). This ring is the area of the celestial sphere that will be swept out in one orbit revolution. Provision is made to alter the bandwidth by keyboard input. Each star which makes an angle with the orbit momentum vector that is within this band will pass through the star tracker field of view at some time during the orbit revolution. Although the sun and moon can interfere with tracking the star, no provision is made at this time for the program to make such a determination. Interference by the earth is determined by the program.

Since the star catalog is defined in the M50 reference frame, the program requires an input of the transformation from M50 to LVLH or other information from which this transformation can be derived. Since the star tracker field of view center line is defined in orbiter body coordinates, the program also requires an input of the transformation from body frame to the FLVLH frame or information from which this transformation can be determined. The body to FLVLH transformation is always entered as an LVLH attitude pitch, yaw, roll Euler sequence which can come from various sources; the detailed procedure will further explain where to get this information. The M50 to FLVLH transformation is derived from one of three possible input options: direct quaternion input, an inertial attitude pitch, yaw, roll Euler sequence, or the orbiter state vector; the detailed procedure will further explain which option to use for particular circumstances and where to get this information.

Euler sequence inputs are converted to quaternion form. State vector input is used to derive the M50 to FLVLH transformation by first building a transformation matrix using the definition of LVLH and then converting the matrix to quaternion form. The M50 to FLVLH

transformation is built from the state vector radius vector R and velocity vector V (definition of LVLH) as follows:

1. Matrix row 3 = -(UNIT R)) LVLH Z axis is defined as unit vector directed along -R.
2. Matrix row 2 = -(UNIT (RXV)) LVLH Y axis is defined as a unit vector directed along negative orbit momentum vector
3. Matrix row 1 = (Matrix row 2)X(Matrix row 3) LVLH X axis is defined as completing the right hand triad.

The final result is two quaternions, QFLVLH_B and QFLVLH_M50 which are used to transform the body axis star tracker field of view centerline vector and M50 star vectors to the FLVLH frame.

For a detailed description of how Euler sequence angles and transformation matrices are converted to quaternion form and how quaternion vector transformations are performed see GNC SCP 10.5 MATRIX,QUATERNION,AND EULER SEQUENCE PROGRAM (MQEUT).

With the star tracker field of view centerline vector and star vectors transformed to FLVLH simple trigonometry determines the needed information. The half cone angle of the ring being swept out by the tracker is determined from the tracker centerline vector and the orbit momentum vector (-Y FLVLH axis) by the dot product method. Since the Orbit momentum vector is 0,-1,0) the dot product is simply the negative of the star tracker vector Y component in the FLVLH frame and the angle is:

$$\arccos (-(\text{star tracker Y component})).$$

Similarly, the angle between the orbit momentum vector and the star is $\arccos(-(\text{star Y component}))$. If this star angle is within half the bandwidth of the tracker half cone angle it will pass through the tracker field of view sometime during one complete orbit revolution. In order to get an idea of the sequence of star acquisition and the relative position of the stars around the ring, an azimuth angle is determined from the X and Z components of the star vector as $\arctan (X/Z)$. The FORTRAN function ARCTAN2 is used to resolve the quadrant ambiguity of the ARCTAN function. ARCTAN2 operates on the two arguments and does all the necessary math, including protecting for divide by zero.

The closest approach of the star to the star tracker centerline is determined as the absolute value of the difference of the star tracker half cone angle and the corresponding star angle:

$$\text{Angle of closest approach} = \text{ABS}((\text{star tracker half cone angle})-(\text{star equivalent angle}))$$

The program outputs to screen and, optionally, to the printer all the angular information of the stars found to pass through the field of view and the star magnitude in both IDT and SST sensitivities and the M50 vector components.

The program also provides a utility function which calculates the angular separation of any two input stars as the arcs of the dot product of the two stars:

$$\text{Angular separation} = \arccos(\text{star 1 DOT star 2})$$

The program output (screen or printer) provides the following information:

Output heading:

1. The half cone angle of the star tracker centerline is -Y(Z) LVLH DEC.
2. The band width
3. The upper and lower angles of the ring as measure from the orbit angular momentum vector (-Y axis).

NOTE: Even for stars in the southern half of the orbit plane angles are measured from the (positive) orbit momentum vector. This means that a half cone or star declination angle which is 10 degrees away from the negative angular momentum vector will appear as 170 degrees. The choice of this approach greatly simplified the programming and output design complexity and is a minimal inconvenience, especially since the nominal station attitude and docking geometry is expected always to point the -Y star tracker near the positive orbit momentum vector.

Output body:

1. Star ID number
2. LVLH relative azimuth of the star
3. LVLH declination of the star. This is the angle between the star and the orbit angular momentum vector.
4. FOVDELTA - the angle of closest approach of the star to the star tracker centerline.
5. IDT magnitude
6. SST magnitude
7. M50 catalog coordinates of the star

PROCEDURE

1. The first step is to determine which of the input options is best for the circumstances.

A. If it is desired to know which stars will pass through or near the field of view for the next 2 or 3 revs there are several options to consider:

1) The simplest option is to hardcopy the GNC Orbit display and use the LVLH and the inertial Euler attitudes; the FLVLH frame is then the LVLH frame at the time the hardcopy is made. Deadband considerations are:

a) While docked to an operational space station under CMG control, deadband errors are not a consideration. Unless there is a means available for predicting short term attitude changes due to expected Torque Equilibration Attitude (TEA) Euler angle input for corresponding inertial and LVLH attitudes is the best that can be done for predicting stars in the near term.

b) For orbiter alone flights, deadband considerations can be handled in one of several ways:

(1) If deadbands are small (1 degree or less) they may generally be ignored.

(2) If it is desired to minimize errors due to deadbanding, the hardcopy should ideally be made when all three axes are at the center of the deadband. However, capturing all three axes at zero errors is not reasonable in practice. It is fortunate that one axis can be eliminated as a consideration for each tracker. Yaw error is not a significant factor for the -Z tracker and pitch error is not a significant factor for the -Y tracker; these axes are near the centerline of the associated tracker and therefore essentially only rotate the tracker about its line of sight. There is another axis for which a deadband error merely makes the tracker look forward or backward in the ring being swept out and therefore does not affect which stars will pass through the field of view, but rather only shifts the time of acquisition of all the stars. In the expected attitude while docked to station for the critical tracker (-Y) this second unimportant axis is roll; the only axis that needs to be captured near the center of the deadband is yaw. Generally the second unimportant axis will be closely aligned with one orbiter axis, but for some biased attitudes this may not be true. In most cases it is necessary to capture only one axis near the center of the deadband and in the worst case only two axes need be considered.

(3) Complicating this situation somewhat is the fact that in the case of single side deadbanding it may be desirable to capture the attitude data near the center of the average deviation within the deadband rather than near the center of the deadband.

(4) The program allows for input of DAP errors (taken from the same display hardcopy that was used to capture attitudes) to correct the transformation quaternions for the deadband errors. Star availability is calculated as if the

hardcopy had been taken at the center of the deadband for all three axes for both LVLH and inertial attitudes. This option does nothing for the single side deadbanding case.

- 2) As an alternative to inertial attitude input the downlisted LVLH quaternion QM50-LVLH can be used. This data is obtained by hardcopying the GNC REFS/ROLLS/QUATS display (as before the taking of the hardcopy establishes the FLVLH frame). When using this input option the LVLH Euler attitude should be calculated from the Universal Pointing track pitch, yaw, and omicron values using GNC offline program PYOM SCP 5.2 UNIVERSAL POINTING BODY VECTOR OMICRON/LVLH ATTITUDE CALCULATION (PYOM). This input method represents the center of the deadbands; there is no simple way to correct for single side deadbanding with this option.
- B. If it is desired to predict star availability beyond three orbit revolutions, the state vector input option must be used because orbit precession begins to be a significant factor. The LVLH Euler attitude must be calculated from Universal Pointing pitch, yaw, and omicron values as described above or from some other source such as predicted station attitude transformed into orbiter attitude. State vector prediction can be obtained from FDO.
2. After the input method has been selected and the necessary data gathered, execute the program STARS and follow the menu for inputting the attitude/quaternion/state vector data. The LVLH attitude is required for all cases. The inertial attitude/quaternion/state vector options are mutually exclusive - entering any one will clear a previous entry for either of the other two options.
 3. Modify the bandwidth if desired. Bandwidth might be decreased to eliminate stars that are near the edge of the field of view and thus may not be trackable due to small attitude deviations such as deadband or it might be increased to include stars that are slightly outside the expected field of view. Increasing the band would be desirable if very few stars are available in the particular attitude and it is desired to be able to take advantage of small attitude deviations if they should occur in a convenient direction and at a convenient time.
 4. Select the tracker - toggle item entry
 5. Select the catalog to be used - toggle between the I-loaded onboard catalog only and the full uplinkable catalog (which includes the I-loaded onboard catalog).
 6. To obtain the results of the program execute the item entry for display or print.
 7. If it is desired to determine the angular separation of any two stars, execute the ang diff item and then enter the two star ID numbers. The separation angle is displayed on the screen menu; printout is not available.

TITLE

DETERMINATION OF STAR AVAILABILITY IN INERTIAL ATTITUDE HOLD

PURPOSE

To describe the procedure for using PC program ISTARS to identify the stars that are in a star tracker field of view (FOV) while in an inertial attitude.

CONCEPT

The pitch, yaw, roll Euler sequence inertial attitude is used to generate a quaternion QM50_B where B represents the body frame of reference. The nominal navigation base (NB) to body transformation matrix and the nominal NB to each the selected star tracker are converted to the quaternion form QB_NB, QNB_-Y(-Z). These quaternions are then appropriately multiplied to produce the quaternion Q-Y(-Z)_M50. This quaternion is then used to transform the M50 catalog vector for each star into the star tracker frame. See GNC SCP 10.5 MATRIX, QUATERNION, AND EULER SEQUENCE PROGRAM (MQEUT) for details of how quaternion math and vector transformations are performed. The star vector in star tracker coordinates is then converted into star tracker deflection angles H and V:

$$H = \text{ARCTAN}(Y/Z); \quad V = \text{ARCTAN}(-X/Z)$$

If both the H and the V deflection angles are less than the nominal field of view (+/-5 degrees) the star is identified as being in the FOV. The program provides for changing the FOV used for identifying stars. A smaller FOV can be used for eliminating stars near the edge of the FOV and a larger FOV can be used to identify stars that are near to the actual star tracker FOV. There is a 25 degree maximum for the input FOV. The program provides a utility calculation for determining the angular separation of any two stars.

The program output (screen or printer) provides the following information:

Output heading:

1. Star tracker
2. FOV used to identify stars (H, V LIMIT).
3. The input Euler sequence inertial attitude.

Output body:

1. Star ID number
2. H and V deflection of the star position in the FOV
3. Star magnitude in IDT and in SST sensitivity
4. Star M50 catalog vector
5. Angular separation of two input stars is displayed on the screen menu only; printout is not available.

PROCEDURE

1. Determine the pitch, yaw, roll inertial attitude to be used. This can be the current attitude from the GNC Orbit display or it can be some future inertial attitude.
2. Execute the program and follow the menu to enter the attitude.
3. Select the catalog to be used. The menu item toggles between the I-load onboard catalog and the full catalog of uplinkable stars (which includes I-load catalog).
4. Select the star tracker to be used - toggle between the -Y and the -Z star trackers.
5. To obtain the results of the program execute the item entry for screen display or print.
6. If it is desired to determine the angular separation of any two stars execute the ang diff item and then enter the two star ID numbers. The separation angle is displayed on the screen menu only - printout is not available.

TITLE

MATRIX, QUATERNION, AND EULER ANGLE SEQUENCE PROGRAM (MQEUT)

PURPOSE

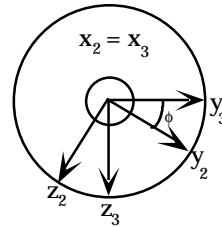
This SCP provides the user the tool necessary to manipulate matrices, quaternions, and Euler angle sequence.

BACKGROUND

Euler angles ψ , θ , ϕ completely specify the orientation of one system relative to a second system. If we generate a rotation matrix describing each of the Euler angle rotations (a total of three) numerically, we could then form a single product matrix, using matrix multiplication, describing the complete rotation as follows. (Note: The rotation matrices below describe the rotation transformation from the rotated axis back to the original axis.)

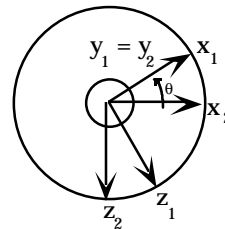
A single rotation about the x-axis (roll rotation ϕ) results in the matrix

$$R_1 = \begin{vmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & -\sin \phi \\ 0 & \sin \phi & \cos \phi \end{vmatrix}$$



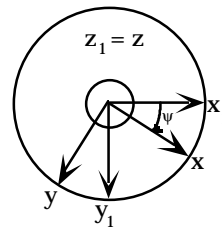
A single rotation about the y-axis (pitch rotation θ) results in the matrix

$$R_2 = \begin{vmatrix} \cos \theta & 0 & \sin \theta \\ 0 & 1 & 0 \\ -\sin \theta & 0 & \cos \theta \end{vmatrix}$$



A single rotation about the z-axis (yaw rotation ψ) results in the matrix

$$R_3 = \begin{vmatrix} \cos \psi & -\sin \psi & 0 \\ \sin \psi & \cos \psi & 0 \\ 0 & 0 & 1 \end{vmatrix}$$



The product matrix then follows as

$$R = R_1 * R_2 * R_3$$

$$R = \begin{vmatrix} 1 & 0 & 0 \\ 0 & \cos f & -\sin f \\ 0 & \sin f & \cos f \end{vmatrix} \begin{vmatrix} \cos q & 0 & \sin q \\ 0 & 1 & 0 \\ -\sin q & 0 & \cos q \end{vmatrix} \begin{vmatrix} \cos y & -\sin y & 0 \\ \sin y & \cos y & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

such that

$$R = \begin{bmatrix} (\cos q \cos y) & (-\cos q \sin y) & (\sin q) \\ (\cos f \sin y + \sin f \sin q \cos y) & (\cos f \cos y - \sin f \sin q \sin y) & (-\sin f \cos q) \\ (\sin f \sin y - \cos f \sin q \cos y) & (\sin f \cos y + \cos f \sin q \sin y) & (\cos f \cos q) \end{bmatrix}$$

The resultant rotation matrix R defines the rotation between two independent systems, namely the direction cosine matrix. The above direction cosine matrix is derived using a roll, pitch, yaw angle rotation. The same matrix can be derived using any combination of rotations of the three angles.

The representation of the direction cosine matrix can also be performed by the use of quaternions. The whole idea of quaternions makes use of Euler's theorem, which states that "any rotation of one coordinate system with respect to another may be described by a rotation through some (one) angle about a single fixed axis." The quaternion would be represented by a scalar plus a vector, totaling four elements. Three of the elements describe a vector, and this vector describes an axis of rotation as shown below.

$$\text{Quaternion } Q = \begin{bmatrix} \text{scalar } (q_1) \\ \text{x axis vector } (q_2) \\ \text{y axis vector } (q_3) \\ \text{z axis vector } (q_4) \end{bmatrix}$$

The fourth element, a scalar, defines the magnitude of the rotation angle.

The four elements of a quaternion can be found as

$$Q = \begin{matrix} q_1 & q_1 = \cos \frac{\mu}{2} \\ q_2 & q_2 = \sin \frac{\mu}{2} * \cos \alpha \\ q_3 & q_3 = \sin \frac{\mu}{2} * \cos \beta \\ q_4 & q_4 = \sin \frac{\mu}{2} * \cos \gamma \end{matrix} \text{ where}$$

such that μ is the amount of rotation (fig. 10.5-1), and α, β, γ are the angles between the rotation axis and the x, y, z axes, respectively (fig. 10.5-2).

It must be pointed out that even though quaternions are based on Euler's theorem, the Euler angles are not defined by the quaternion itself, but can be extracted from the quaternion transformation matrix. The elements of the quaternion transformation matrix (M_{11}, M_{12}, M_{13} , etc.) in terms of the quaternion elements (q_1, q_2, q_3 , and q_4) can be found in paragraph D ("Quaternion to Matrix Transformation: ($Q_n > M_n$)") on page 10.5-17.

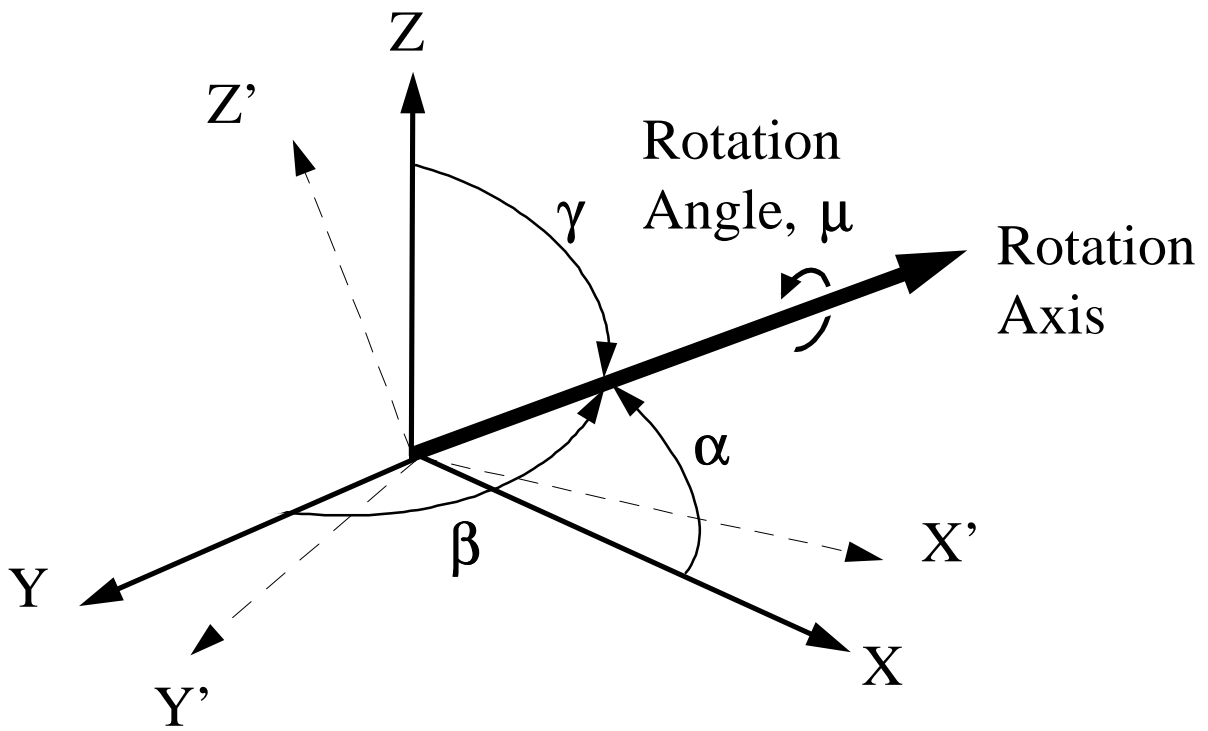


Figure 10.5-1.- Rotation axis or "vector" about which the x, y, z axes are rotated in order to coincide with the u, v, w axes.

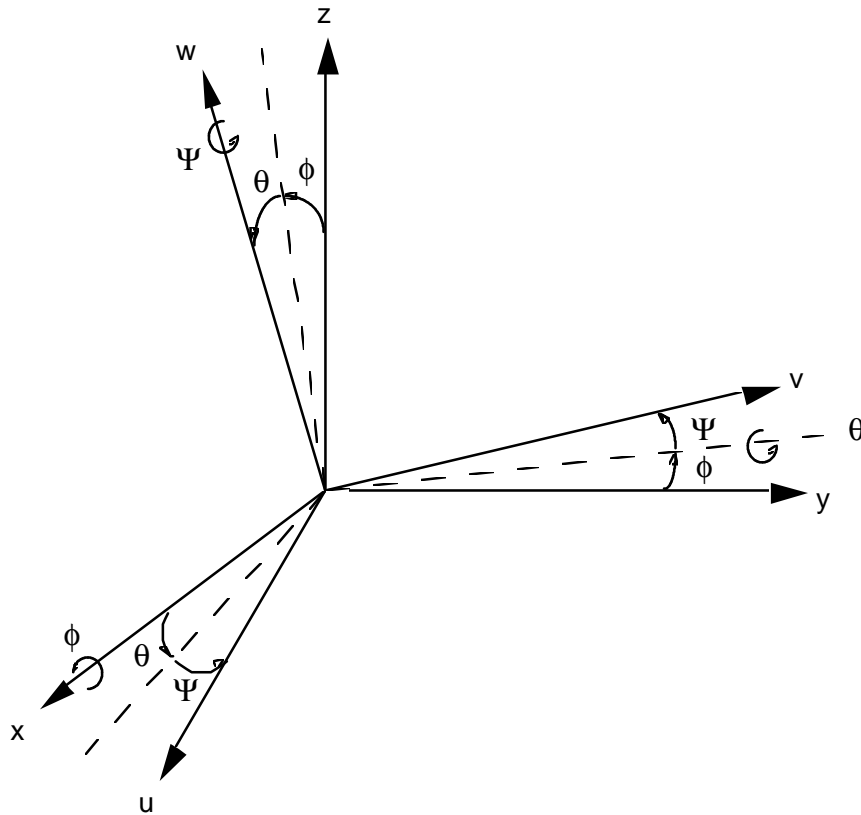


Figure 10.5-2.- Euler angle rotations required to rotate the x , y , z axes to coincide with the u , v , w axes.

PROCEDURE

In the MCC, select the MQEUT program directly from the GNC DNAV MENU, under "Apps".

The CRT will display general information about the program and the mathematical and general operation which can be executed (a total of 35 operations presently exists). The program provides the capability to store up to 100 matrices and quaternions with their respective labels.

An explanation of the program, labels, or any operation can be obtained by entering "EXPLAIN PROGRAM", "EXPLAIN LABELS", and "EXPLAIN Mn > Mn", respectively (Mn > Mn is just an example of one of the operations).

A copy of the "EXPLAIN PROGRAM" listing is contained in the Program Description section. It provides a brief description of all operations available.

The operations to be performed are entered when prompted by the display under "ENTER OPERATION" and executed by depressing <return>.

There is no termination point in the program. It will be on standby until an operation is entered and executed. To exit the program, type END followed by <return>.

NOTE: "MQEUT" is strictly a utility program for matrix, quaternion, and Euler angle manipulation. Therefore, all information or data to be manipulated must be entered correctly.

PROGRAM DESCRIPTION

Matrices and quaternions, as they relate to attitude uses, are two different mathematical descriptions of the same physical quantity: the relationship between two sets of orthogonal axes. Each can be visualized in different ways. The confusion between them arises largely from the fact that matrices are commonly visualized one way and quaternions are commonly visualized another way. If one refers to a matrix as MA_{toB} , this usually means the matrix will transform a vector (expressed as a column vector in system A coordinates) into a column vector (expressed in system B coordinates) by the equation $MA_{toB} * VA = VB$. If one refers to a quaternion as QA_{toB} , this usually means the quaternion which represents the maneuver of a body which initially has its axes aligned with system A axes and, after maneuvering, has its axes aligned with system B axes. Both interpretations are correct, but their sense is opposite (i.e., $MA_{toB} \equiv QB_{toA}$). MA_{toB} could just as well be thought of as a maneuver from B to A, and QA_{toB} could be thought of as a quantity that will transform a vector B into a vector in A by the equation $QA_{toB} * VB * QB_{toA} = VA$.

Another interpretation of M's and Q's is sometimes used in an attempt to define them in a common sense. This interpretation uses the phrase "with respect to" (wrt) in place of the word "to." It is highly questionable whether wrt is helpful or harmful to the understanding of matrices and quaternions. MA_{wrtB} is identical to maneuvering from A to B, that is MA_{wrtB} (or QA_{wrtB}) = MB_{toA} = QA_{toB} .

Those who have a good understanding of the use of matrices, quaternions, and Euler sequences may wish to skip to the description of program label operations.

Any two coordinate frames A and B have an axis in common (the eigen axis). The relationship between them is simply a rotation of some number of degrees about this common axis. This axis can be written as an eigen vector with components X, Y, and Z which have the same values in either system. There are two eigen vectors each of which is an equally valid representation of the eigen axis where one is simply the negative of the other. To write the quaternion describing relationship between the two systems, the angle of rotation u , and the X, Y, Z components of the eigen vector must be known. The quaternion elements are then $Q(1)=\text{COS}u/2$, $Q(2)=X\text{SIN}u/2$, $Q(3)=Y\text{SIN}u/2$, and $Q(4)=Z\text{SIN}u/2$.

If B were rotated from A about one of the primary axes, the quaternion would be simple to write. For example, rotate B 30° from A about the X-axis. The eigen vector is $X=1$, $Y=0$, $Z=0$ and $Q(1)=\text{COS}15$, $Q(2)=\text{SIN}15$, $Q(3)=0$, and $Q(4)=0$. A Euler sequence is simply three successive rotations about the three primary axes. Note that the first rotation is about a body axis which corresponds to the same system A axis. The second rotation will not be about any axis of system A or system B but will be about a primary axis of the body rotating between A and B. This second rotation will align the remaining body axis with the corresponding system B axis. The third rotation will then be about the axis which is now common to the body and system B. This final rotation brings the other two body axes into alignment with the corresponding system B axes completing the maneuver from A to B. If the three quaternions representing the three Euler rotations are multiplied in the proper sequence, the result is a single quaternion representing the complete maneuver from A to B as if it had been a single rotation about the eigen axis between A and B.

A full understanding of matrix, quaternion, and Euler sequence attitude uses is generally very difficult to obtain because of the tedious mathematics necessary to experiment with them. This program provides a tool for experimentation without the user having to perform (or even to understand) the mathematical details. The storage in memory of up to 100 matrices and quaternions will also minimize the keyboard entry of multiple digit, multiple component quantities.

Although the program does not have a specific operation designed for vector transformations, it can be used to do them. If the user wishes to transform a vector from system A to system B, he may do so by matrix or by quaternion in the following sections.

A. MATRIX

In this example, locations 1, 2, and 3 will be used. Any others would do as well.

1. Enter the transformation matrix M_{AtoB} in M1.
2. Enter the vector as a column vector in elements 11, 21, and 31 of M2.

A second and third vector can be entered into elements 12, 22, 32, and 13, 23, 33 if it is desired.

3. Perform the operation $M1 * M2 > M3$.

The vector in system B is now stored as a column vector in M3 elements 11, 21, and 31. The second and third vectors, if any, are stored in elements 12, 22, 32, and 13, 23, 33.

B. QUATERNION

In this example locations 1, 2, 3, 4, and 5 will be used. Any others would do as well.

1. Enter the quaternion QBtoA in Q1.
2. Perform the operation CONJQ1>Q3.
3. Enter the vector in Q2 where Q(1)=0, Q(2)=X, Q(3)=Y, Q(4)=Z.
4. Perform the following operations:

$$Q1*Q2>Q4 \text{ and } Q4*Q3>Q5$$

Note: The explanation of $Q_n*Q_n>Q_n$ recommends changing signs of Q if the scalar element Q(1) is negative. This must not be done for vector transformations.

Q5 now contains the vector in system B in elements Q(2), Q(3), and Q(4). Element Q(1) should be zero.

The above steps evaluate the basic quaternion vector transformation equation $QBtoA*VA*QAtoB=VB$.

LABELS

All operations ending in the storage and/or display of M or Q can also be used to assign a label by appending a / followed by up to 10 characters. For example, M22/ABCD assigns the label ABCD to the matrix stored in location 22 and Q14*Q64>Q37/EFG assigns the label EFG to the quaternion stored in location 37. Labels can be anything meaningful to the user and they will be displayed as subscripts any time a matrix or quaternion is displayed.

No program operations are done on labels unless they contain an underscore. If the underscore is present, the characters to the left will be interpreted as a label describing one set of axes and the characters to the right will be interpreted as a label describing the other set of axes associated with the M or Q.

A transpose or conjugation operation will reverse the two halves of the label. A multiplication, where both multipliers have labels with underscores, will check for compatibility and assign the correct label to the product. If labels are found to be incompatible, the user will be notified and no label will be assigned by program control.

In any case, if the user assigns a label by /, it will override any label assigned by the program. Matrix labels containing an underscore will display the left half as subscript and the right half as superscript. Due to line width limits, matrix labels displayed with multiplier and eigen extractions are limited to five characters.

OPERATIONS AVAILABLE

MATRIX, QUATERNION, EULER TRANSFORMATION (MQEUT) PROGRAM

This program allows the user to manipulate matrices, quaternions, and Euler sequence angles. The program provides 100 locations for storing both matrices and quaternions. Matrices and quaternions are referenced by M or Q followed by 1, 2, or 3 digits identifying the location (e.g., M29). The operations are as follows:

- | | | | |
|-----------------------|-------------|-------------|---------------|
| 1. Mn>Mn | 11. Mn | 21. CLEARQn | 31. OFFPRINT |
| 2. Qn>Qn | 12. Qn | 22. EIGENMn | 32. ALTEULER |
| 3. Mn>Qn | 13. TNSPMn | 23. EIGENQn | 33. X#Y#Z#>Qn |
| 4. Qn>Mn | 14. CONJQn | 24. DUMPM | 34. CHECKMn |
| 5. Mn>PYR(Any seq) | 15. CHSQn | 25. DUMPQ | 35. MENU |
| 6. Qn>PRY(Any seq) | 16. ORTHMn | 26. LOAD | 36. EDITMn |
| 7. P#Y#R#>Mn(Any seq) | 17. NORMQn | 27. RECORD | 37. EDITQn |
| 8. P#Y#R#>Qn(Any seq) | 18. ENTERMn | 28. LDREFS | 38. SAVE |
| 9. Mn*Mn>Mn | 19. ENTERQn | 29. RCDREF | 39. END |
| 10. Qn*Qn>Qn | 20. CLEARMn | 30. ONPRINT | |

For an explanation of any of these operations type EXPLAIN followed by the instruction (no spaces) (e.g., EXPLAINMn>Mn). For an explanation of how to use labels type EXPLAINLABELS. For a printed description of program use and some fundamentals on matrices and quaternions, type EXPLAINPROGRAM.

GENERAL

The matrix and quaternion representations in the mathematical procedures shown below are as follows.

$$M = \begin{vmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{vmatrix} \quad \text{and} \quad q = \begin{vmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \end{vmatrix}$$

where q₁ is the scalar and q₂, q₃, and q₄ represent the magnitudes of the x, y, and z vectors, respectively.

All Euler angles are expressed by:

Pitch --- Θ
Yaw --- Ψ
Roll --- Φ

The "n" in the notation Mn and Qn specifies the storage location of the matrix and quaternion, respectively, where "n" can be between 1 and 100.

MATHEMATICAL EQUATIONS

The mathematical equations which follow are used by the program to compute the mathematical expressions for each operation available in the MQEUT program.

NOTE: Unless otherwise stated in each specific paragraph that follows, all mathematical expressions were extracted from the Mission Planning and Analysis Division (MPAD) document JSC-12960 (July 1977) titled "Euler Angles, Quaternions, and Transformation Matrices."

A. EULER ANGLE SEQUENCE TO MATRIX TRANSFORMATION (P#Y#R# > MN (ANY SEQ))

1. Pitch, Yaw, Roll Sequence (PYR)

$$M_{11} = \cos\Theta \cos\Psi$$

$$M_{12} = -\cos\Theta \sin\Psi \cos\Phi + \sin\Theta \sin\Phi$$

$$M_{13} = \cos\Theta \sin\Psi \sin\Phi + \sin\Theta \cos\Phi$$

$$M_{21} = \sin\Psi$$

$$M_{22} = \cos\Psi \cos\Phi$$

$$M_{23} = -\cos\Psi \sin\Phi$$

$$M_{31} = -\sin\Theta \cos\Psi$$

$$M_{32} = \sin\Theta \sin\Psi \cos\Phi + \cos\Theta \sin\Phi$$

$$M_{33} = -\sin\Theta \sin\Psi \sin\Phi + \cos\Theta \cos\Phi$$

2. Roll, Pitch, Yaw Sequence (RPY)

$$M_{11} = \cos\Theta \cos\Psi$$

$$M_{12} = -\cos\Theta \sin\Psi$$

$$M_{13} = \sin\Theta$$

$$M_{21} = \sin\Phi \sin\Theta \cos\Psi + \cos\Phi \sin\Psi$$

$$M_{22} = -\sin\Phi \sin\Theta \sin\Psi + \cos\Phi \cos\Psi$$

$$M_{23} = -\sin\Phi \cos\Theta$$

$$M_{31} = -\cos\Phi \sin\Theta \cos\Psi + \sin\Phi \sin\Psi$$

$$M_{32} = \cos\Phi \sin\Theta \sin\Psi + \sin\Phi \cos\Psi$$

$$M_{33} = \cos\Phi \cos\Theta$$

3. Roll, Yaw, Pitch Sequence (RYP)

$$M_{11} = \cos \Psi \cos \Theta$$

$$M_{12} = -\sin \Psi$$

$$M_{13} = \cos \Psi \sin \Theta$$

$$M_{21} = \cos \Phi \sin \Psi \cos \Theta + \sin \Phi \sin \Theta$$

$$M_{22} = \cos \Phi \cos \Psi$$

$$M_{23} = \cos \Phi \sin \Psi \sin \Theta - \sin \Phi \cos \Theta$$

$$M_{31} = \sin \Phi \sin \Psi \cos \Theta - \cos \Phi \sin \Theta$$

$$M_{32} = \sin \Phi \cos \Psi$$

$$M_{33} = \sin \Phi \sin \Psi \sin \Theta + \cos \Phi \cos \Theta$$

4. Pitch, Roll, Yaw Sequence (PRY)

$$M_{11} = \cos \Theta \cos \Psi + \sin \Theta \sin \Phi \sin \Psi$$

$$M_{12} = -\cos \Theta \sin \Psi + \sin \Theta \sin \Phi \cos \Psi$$

$$M_{13} = \sin \Theta \cos \Phi$$

$$M_{21} = \cos \Phi \sin \Psi$$

$$M_{22} = \cos \Phi \cos \Psi$$

$$M_{23} = -\sin \Phi$$

$$M_{31} = \cos \Theta \sin \Phi \sin \Psi - \sin \Theta \cos \Psi$$

$$M_{32} = \cos \Theta \sin \Phi \cos \Psi + \sin \Theta \sin \Psi$$

$$M_{33} = \cos \Theta \cos \Phi$$

5. Yaw, Roll, Pitch Sequence (YRP)

$$M_{11} = -\sin \Psi \sin \Phi \sin \Theta + \cos \Psi \cos \Theta$$

$$M_{12} = -\sin \Psi \cos \Phi$$

$$M_{13} = \sin \Psi \sin \Phi \cos \Theta + \cos \Psi \sin \Theta$$

$$M_{21} = \cos \Psi \sin \Phi \sin \Theta + \sin \Psi \cos \Theta$$

$$M_{22} = \cos \Psi \cos \Phi$$

$$M_{23} = -\cos \Psi \sin \Phi \cos \Theta + \sin \Psi \sin \Theta$$

$$M_{31} = -\cos \Phi \sin \Theta$$

$$M_{32} = \sin \Phi$$

$$M_{33} = \cos \Phi \cos \Theta$$

6. Yaw, Pitch, Roll Sequence (YPR)

$$M_{11} = \cos \Psi \cos \Theta$$

$$M_{12} = \cos \Psi \sin \Theta \sin \Phi - \sin \Psi \cos \Phi$$

$$M_{13} = \cos \Psi \sin \Theta \cos \Phi + \sin \Psi \sin \Phi$$

$$M_{21} = \sin \Psi \cos \Theta$$

$$M_{22} = \sin \Psi \sin \Theta \sin \Phi + \cos \Psi \cos \Phi$$

$$M_{23} = \sin \Psi \sin \Theta \cos \Phi - \cos \Psi \sin \Phi$$

$$M_{31} = -\sin \Theta$$

$$M_{32} = \cos \Theta \sin \Phi$$

$$M_{33} = \cos \Theta \cos \Phi$$

B. EULER SEQUENCE TO QUATERNION TRANSFORMATION (P#Y#R# > QN (ANY SEQ))

1. Pitch, Yaw, Roll Sequence (PYR)

$$q_1 = -\sin \frac{\Theta}{2} \sin \frac{\Psi}{2} \sin \frac{\Phi}{2} + \cos \frac{\Theta}{2} \cos \frac{\Psi}{2} \cos \frac{\Phi}{2}$$

$$q_2 = \sin \frac{\Theta}{2} \sin \frac{\Psi}{2} \cos \frac{\Phi}{2} + \sin \frac{\Phi}{2} \cos \frac{\Theta}{2} \cos \frac{\Psi}{2}$$

$$q_3 = \sin \frac{\Theta}{2} \cos \frac{\Psi}{2} \cos \frac{\Phi}{2} + \sin \frac{\Psi}{2} \sin \frac{\Phi}{2} \cos \frac{\Theta}{2}$$

$$q_4 = -\sin \frac{\Theta}{2} \sin \frac{\Phi}{2} \cos \frac{\Psi}{2} + \sin \frac{\Psi}{2} \cos \frac{\Theta}{2} \cos \frac{\Phi}{2}$$

2. Roll, Pitch, Yaw Sequence (RPY)

$$q_1 = -\sin \frac{\Phi}{2} \sin \frac{\Theta}{2} \sin \frac{\Psi}{2} + \cos \frac{\Phi}{2} \cos \frac{\Theta}{2} \cos \frac{\Psi}{2}$$

$$q_2 = \sin \frac{\Phi}{2} \cos \frac{\Theta}{2} \cos \frac{\Psi}{2} + \sin \frac{\Theta}{2} \sin \frac{\Psi}{2} \cos \frac{\Phi}{2}$$

$$q_3 = -\sin \frac{\Phi}{2} \sin \frac{\Psi}{2} \cos \frac{\Theta}{2} + \sin \frac{\Theta}{2} \cos \frac{\Phi}{2} \cos \frac{\Psi}{2}$$

$$q_4 = \sin \frac{\Phi}{2} \sin \frac{\Theta}{2} \cos \frac{\Psi}{2} + \sin \frac{\Psi}{2} \cos \frac{\Phi}{2} \cos \frac{\Theta}{2}$$

3. Roll, Yaw, Pitch Sequence (RYP)

$$q_1 = \sin \frac{\Phi}{2} \sin \frac{\Psi}{2} \sin \frac{\Theta}{2} + \cos \frac{\Phi}{2} \cos \frac{\Psi}{2} \cos \frac{\Theta}{2}$$

$$q_2 = \sin \frac{\Phi}{2} \cos \frac{\Psi}{2} \cos \frac{\Theta}{2} - \sin \frac{\Psi}{2} \sin \frac{\Theta}{2} \cos \frac{\Phi}{2}$$

$$q_3 = -\sin \frac{\Phi}{2} \sin \frac{\Psi}{2} \cos \frac{\Theta}{2} + \sin \frac{\Theta}{2} \cos \frac{\Phi}{2} \cos \frac{\Psi}{2}$$

$$q_4 = \sin \frac{\Phi}{2} \sin \frac{\Theta}{2} \cos \frac{\Psi}{2} + \sin \frac{\Psi}{2} \cos \frac{\Phi}{2} \cos \frac{\Theta}{2}$$

4. Pitch, Roll, Yaw Sequence (PRY)

$$q_1 = \sin \frac{\Theta}{2} \sin \frac{\Phi}{2} \sin \frac{\Psi}{2} + \cos \frac{\Theta}{2} \cos \frac{\Phi}{2} \cos \frac{\Psi}{2}$$

$$q_2 = \sin \frac{\Theta}{2} \sin \frac{\Psi}{2} \cos \frac{\Phi}{2} + \sin \frac{\Phi}{2} \cos \frac{\Theta}{2} \cos \frac{\Psi}{2}$$

$$q_3 = \sin \frac{\Theta}{2} \cos \frac{\Phi}{2} \cos \frac{\Psi}{2} - \sin \frac{\Phi}{2} \sin \frac{\Psi}{2} \cos \frac{\Theta}{2}$$

$$q_4 = -\sin \frac{\Theta}{2} \sin \frac{\Phi}{2} \cos \frac{\Psi}{2} + \sin \frac{\Psi}{2} \cos \frac{\Theta}{2} \cos \frac{\Phi}{2}$$

5. Yaw, Roll, Pitch Sequence (YRP)

$$q_1 = -\sin \frac{\Psi}{2} \sin \frac{\Phi}{2} \sin \frac{\Theta}{2} + \cos \frac{\Psi}{2} \cos \frac{\Phi}{2} \cos \frac{\Theta}{2}$$

$$q_2 = -\sin \frac{\Psi}{2} \sin \frac{\Theta}{2} \cos \frac{\Phi}{2} + \sin \frac{\Phi}{2} \cos \frac{\Psi}{2} \cos \frac{\Theta}{2}$$

$$q_3 = \sin \frac{\Psi}{2} \sin \frac{\Phi}{2} \cos \frac{\Theta}{2} + \sin \frac{\Theta}{2} \cos \frac{\Psi}{2} \cos \frac{\Phi}{2}$$

$$q_4 = \sin \frac{\Psi}{2} \cos \frac{\Phi}{2} \cos \frac{\Theta}{2} + \sin \frac{\Phi}{2} \sin \frac{\Theta}{2} \cos \frac{\Psi}{2}$$

6. Yaw, Pitch, Roll Sequence (YPR)

$$q_1 = \sin \frac{\Psi}{2} \sin \frac{\Theta}{2} \sin \frac{\Phi}{2} + \cos \frac{\Psi}{2} \cos \frac{\Theta}{2} \cos \frac{\Phi}{2}$$

$$q_2 = -\sin \frac{\Psi}{2} \sin \frac{\Theta}{2} \cos \frac{\Phi}{2} + \sin \frac{\Phi}{2} \cos \frac{\Psi}{2} \cos \frac{\Theta}{2}$$

$$q_3 = \sin \frac{\Psi}{2} \sin \frac{\Phi}{2} \cos \frac{\Theta}{2} + \sin \frac{\Theta}{2} \cos \frac{\Psi}{2} \cos \frac{\Phi}{2}$$

$$q_4 = \sin \frac{\Psi}{2} \cos \frac{\Theta}{2} \cos \frac{\Phi}{2} - \sin \frac{\Theta}{2} \sin \frac{\Phi}{2} \cos \frac{\Psi}{2}$$

**C. MATRIX TO EULER SEQUENCE TRANSFORMATION
(MN > PYR (ANY SEQ))**

NOTE: Mathematical expressions in this paragraph were extracted from the "MQEUT" program.

1. Pitch, Yaw, Roll Sequence (PYR)**a. Yaw Angle (Ψ)**

$$\Psi = \sin^{-1} (M_{21})$$

If alternate Euler angle is desired (set with the yaw angle between 90° and 270°), then $\psi = 180 - \Psi$

If $\psi < 0$, then $\psi = 360 + \psi$

b. Pitch Angle (θ)

$$\arg = \frac{M_{11}}{\cos(\Psi)}$$

$$\text{If } \text{abs}(\arg) > 1, \text{ then } \arg = \frac{\arg}{\text{abs}(\arg)}$$

$$\theta = \cos^{-1}(\arg)$$

$$\text{If } \frac{-M_{31}}{\cos(\Psi)} < 0, \text{ then } \Theta = 360 - \Theta$$

c. Roll Angle (Φ)

$$\arg = \frac{M_{22}}{\cos(\Psi)}$$

$$\text{If } \text{abs}(\arg) > 1, \text{ then } \arg = \frac{\arg}{\text{abs}(\arg)}$$

$$\Phi = \cos^{-1}(\arg)$$

$$\text{If } \frac{-M_{23}}{\cos(\Psi)} < 0, \text{ then } \Phi = 360 - \Phi$$

2. Roll, Pitch, Yaw Sequence (RPY)**a. Pitch Angle (θ)**

$$\theta = \sin^{-1}(M_{13})$$

If alternate Euler angle is desired (set with the pitch angle between 90° and 270°), then $\theta = 180 - \theta$

If $\theta < 0$, then $\theta = 360 + \theta$

b. Roll Angle (Φ)

$$\arg = \frac{M_{33}}{\cos(\Theta)}$$

$$\text{If } \text{abs}(\arg) > 1, \text{ then } \arg = \frac{\arg}{\text{abs}(\arg)}$$

$$\Phi = \cos^{-1}(\arg)$$

$$\text{If } \frac{-M_{23}}{\cos(\Theta)} < 0, \text{ then } \Phi = 360 - \Phi$$

c. Yaw Angle (Ψ)

$$\arg = \frac{M_{11}}{\cos(\Theta)}$$

$$\text{If } \text{abs}(\arg) > 1, \text{ then } \arg = \frac{\arg}{\text{abs}(\arg)}$$

$$\Psi = \cos^{-1}(\arg)$$

$$\text{If } \frac{-M_{12}}{\cos(\Theta)} < 0, \text{ then } \Psi = 360 - \Psi$$

3. Roll, Yaw, Pitch Sequence (RYP)**a. Yaw Angle (ψ)**

$$\Psi = \sin^{-1}(-M_{12})$$

If alternate Euler angle is desired (set with the yaw angle between 90° and 270°), then $\psi = 180 - \psi$

$$\text{If } \Psi < 0, \text{ then } \Psi = 360 + \Psi$$

b. Roll Angle (Φ)

$$\arg = \frac{M_{22}}{\cos(\Psi)}$$

$$\text{If } \text{abs}(\arg) > 1, \text{ then } \arg = \frac{\arg}{\text{abs}(\arg)}$$

$$\Phi = \cos^{-1}(\arg)$$

$$\text{If } \frac{M_{32}}{\cos(\Psi)} < 0, \text{ then } \Phi = 360 - \Phi$$

c. Pitch Angle (Θ)

$$\arg = \frac{M_{11}}{\cos(\Psi)}$$

$$\text{If } \text{abs}(\arg) > 1, \text{ then } \arg = \frac{\arg}{\text{abs}(\arg)}$$

$$\Theta = \cos^{-1}(\arg)$$

$$\text{If } \frac{M_{13}}{\cos(\Psi)} < 0, \text{ then } \Theta = 360 - \Theta$$

4. Pitch, Roll, Yaw Sequence (PRY)**a. Roll Angle (Φ)**

$$\Phi = \sin^{-1}(-M_{23})$$

If alternate Euler angle is desired (set with the roll angle between 90° and 270°), then $\Phi = 180 - \Phi$

$$\text{If } \Phi < 0, \text{ then } \Phi = 360 + \Phi$$

b. Pitch Angle (Θ)

$$\arg = \frac{M_{33}}{\cos(\Phi)}$$

$$\text{If } \text{abs}(\arg) > 1, \text{ then } \arg = \frac{\arg}{\text{abs}(\arg)}$$

$$\Theta = \cos^{-1}(\arg)$$

$$\text{If } \frac{M_{13}}{\cos(\Phi)} < 0, \text{ then } \Theta = 360 - \Theta$$

c. Yaw Angle (Ψ)

$$\arg = \frac{M_{22}}{\cos(\Phi)}$$

$$\text{If } \text{abs}(\arg) > 1, \text{ then } \arg = \frac{\arg}{\text{abs}(\arg)}$$

$$\Psi = \cos^{-1}(\arg)$$

$$\text{If } \frac{M_{21}}{\cos(\Phi)} < 0, \text{ then } \Psi = 360 - \Psi$$

5. Yaw, Roll, Pitch Sequence (YRP)

a. Roll Angle (Φ)

$$\Phi = \sin^{-1}(M_{32})$$

If alternate Euler angle is desired (set with the roll angle between 90° and 270°), then $\Phi = 180 - \Phi$

If $\Phi < 0$, then $\Phi = 360 + \Phi$

b. Yaw Angle (Ψ)

$$\arg = \frac{M_{22}}{\cos(\Phi)}$$

If $abs(\arg) > 1$, then $\arg = \frac{\arg}{abs(\arg)}$

$$\Psi = \cos^{-1}(\arg)$$

If $\frac{-M_{12}}{\cos(\Phi)} < 0$, then $\Psi = 360 - \Psi$

c. Pitch Angle (Θ)

$$\arg = \frac{M_{33}}{\cos(\Phi)}$$

If $abs(\arg) > 1$, then $\arg = \frac{\arg}{abs(\arg)}$

$$\Theta = \cos^{-1}(\arg)$$

If $\frac{-M_{31}}{\cos(\Phi)} < 0$, then $\Theta = 360 - \Theta$

6. Yaw, Pitch, Roll Sequence (YPR)

a. Pitch Angle(Θ)

$$\Theta = \sin^{-1}(-M_{31})$$

If alternate Euler angle is desired (set with the pitch angle between 90° and 270°), then $\Theta = 180 - \Theta$

If $\Theta < 0$, then $\Theta = 360 + \Theta$

b. Yaw Angle (Ψ)

$$\arg = \frac{M_{11}}{\cos(\Theta)}$$

$$\text{If } \text{abs}(\arg) > 1, \text{ then } \arg = \frac{\arg}{\text{abs}(\arg)}$$

$$\Psi = \cos^{-1}(\arg)$$

$$\text{If } \frac{M_{21}}{\cos(\Theta)} < 0, \text{ then } \Psi = 360 - \Psi$$

c. Roll Angle (Φ)

$$\arg = \frac{M_{33}}{\cos(\Theta)}$$

$$\text{If } \text{abs}(\arg) > 1, \text{ then } \arg = \frac{\arg}{\text{abs}(\arg)}$$

$$\Phi = \cos^{-1}(\arg)$$

$$\text{If } \frac{M_{32}}{\cos(\Theta)} < 0, \text{ then } \Phi = 360 - \Phi$$

D. QUATERNION TO MATRIX TRANSFORMATION: (QN > MN)

$$M_{11} = (q_1)^2 + (q_2)^2 - (q_3)^2 - (q_4)^2$$

$$M_{21} = 2 * ((q_2 * q_3) + (q_1 * q_4))$$

$$M_{12} = 2 * ((q_2 * q_3) - (q_1 * q_4))$$

$$M_{22} = (q_1)^2 - (q_2)^2 + (q_3)^2 - (q_4)^2$$

$$M_{13} = 2 * ((q_2 * q_4) + (q_1 * q_3))$$

$$M_{23} = 2 * ((q_3 * q_4) - (q_1 * q_2))$$

$$M_{31} = 2 * ((q_2 * q_4) - (q_1 * q_3))$$

$$M_{32} = 2 * ((q_3 * q_4) + (q_1 * q_2))$$

$$M_{33} = (q_1)^2 - (q_2)^2 - (q_3)^2 + (q_4)^2$$

E. QUATERNION TO EULER SEQUENCE TRANSFORMATION (QN > PYR (ANY SEQ))

This type of transformation is not a direct one. A quaternion has to first be converted to a matrix following the sequence outlined in part D above. Once the process has been made, to convert the matrix into Euler angles in any sequence, the procedure as described in part C above is to be followed. The Euler angle sequence desired will determine which procedure is to be followed (1 to 6 of part C).

F. MATRIX TO QUATERNION TRANSFORMATION (MN > QN)

This type of transformation is not a direct one. First, an Euler angle sequence of PYR (a sequence of YPR is needed if $M_{21} > 0.8$) has to be derived as in part C1 (part C6 for YPR). The resulting angles can then be applied to the equations of part A1 for PYR or part A6 for YPR.

G. MATRIX MULTIPLICATION (MN * MN > MN)

$$A = \begin{vmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{vmatrix} \quad B = \begin{vmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{vmatrix}$$

and $C = A * B$

$$C = \begin{vmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{vmatrix}$$

where

$$\begin{aligned} C_{11} &= A_{11} * B_{11} + A_{12} * B_{21} + A_{13} * B_{31} & C_{31} &= A_{31} * B_{11} + A_{32} * B_{21} + A_{33} * B_{31} \\ C_{12} &= A_{11} * B_{12} + A_{12} * B_{22} + A_{13} * B_{32} & C_{32} &= A_{31} * B_{12} + A_{32} * B_{22} + A_{33} * B_{32} \\ C_{13} &= A_{11} * B_{13} + A_{12} * B_{23} + A_{13} * B_{33} & C_{33} &= A_{31} * B_{13} + A_{32} * B_{23} + A_{33} * B_{33} \end{aligned}$$

$$\begin{aligned} C_{21} &= A_{21} * B_{11} + A_{22} * B_{21} + A_{23} * B_{31} \\ C_{22} &= A_{21} * B_{12} + A_{22} * B_{22} + A_{23} * B_{32} \\ C_{23} &= A_{21} * B_{13} + A_{22} * B_{23} + A_{23} * B_{33} \end{aligned}$$

H. QUATERNION MULTIPLICATION (QN * QN > QN)

Two quaternions Q_A and Q_B as shown below can be multiplied in the following way.

$$Q_A = \begin{vmatrix} q_{A1} \\ q_{A2} \\ q_{A3} \\ q_{A4} \end{vmatrix} \quad Q_B = \begin{vmatrix} q_{B1} \\ q_{B2} \\ q_{B3} \\ q_{B4} \end{vmatrix} \quad Q_C = \begin{vmatrix} q_{C1} \\ q_{C2} \\ q_{C3} \\ q_{C4} \end{vmatrix}$$

The result, stored in Q_C , is calculated as

$$\begin{aligned} q_{C1} &= (q_{A1} * q_{B1}) - (q_{A2} * q_{B2}) - (q_{A3} * q_{B3}) - (q_{A4} * q_{B4}) \\ q_{C2} &= (q_{A1} * q_{B2}) + (q_{A2} * q_{B1}) + (q_{A3} * q_{B4}) - (q_{A4} * q_{B3}) \\ q_{C3} &= (q_{A1} * q_{B3}) - (q_{A2} * q_{B4}) + (q_{A3} * q_{B1}) + (q_{A4} * q_{B2}) \\ q_{C4} &= (q_{A1} * q_{B4}) + (q_{A2} * q_{B3}) - (q_{A3} * q_{B2}) + (q_{A4} * q_{B1}) \end{aligned}$$

I. TRANSPOSE OF A MATRIX (TNSPMN)

The transpose of a matrix M can be obtained by interchanging the rows and columns of M; that is, the i-th row of M becomes the i-th column of the transpose M for all i.

An example is

$$\text{If } M = \begin{vmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{vmatrix}$$

$$\text{then TNSPM} = \begin{vmatrix} M_{11} & M_{21} & M_{31} \\ M_{12} & M_{22} & M_{32} \\ M_{13} & M_{23} & M_{33} \end{vmatrix}$$

J. CONJUGATE OF A QUATERNION (CONJQN)

The conjugate of a quaternion Q can be obtained by changing the sign of the elements q2, q3, and q4 within Q as shown below.

$$\text{i.e., if } Q = \begin{vmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \end{vmatrix}, \text{ then CONJQ} = \begin{vmatrix} q_1 \\ -q_2 \\ -q_3 \\ -q_4 \end{vmatrix}$$

K. CHANGE OF SIGN OF QUATERNION ELEMENTS (CHSQN)

This operation's only function is to change the sign of each element of the quaternion as shown below. Its purpose is to provide a way to make the scalar component positive. Although the quaternions before and after the operation are mathematically equivalent regarding the initial and final attitudes, a negative scalar represents maneuvering the long way around (e.g., 350 degrees about the negative of a vector rather than 10 degrees about the vector). It is better form to express a final quaternion (after all operations in a given sequence are completed) with a positive scalar component. Note that an eigen extraction from a quaternion with a negative scalar shows an eigen angle greater than 180 degrees, which violates the eigen angle definition as an angle in the range 0 to 180 degrees.

$$\text{i.e., if } Q = \begin{vmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \end{vmatrix}, \text{ then CHSQ} = \begin{vmatrix} -q_1 \\ -q_2 \\ -q_3 \\ -q_4 \end{vmatrix}$$

L. NORMALIZING A QUATERNION (NORMQN)

A quaternion may be normalized first by finding the square root of the sum of the squares of the element and dividing each element by such root as follows.

$$\text{If } Q = \begin{pmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \end{pmatrix} \text{ and } x = \sqrt{(q_1)^2 + (q_2)^2 + (q_3)^2 + (q_4)^2},$$

$$\text{then } \text{NORM}Q = \begin{pmatrix} q_1 / x \\ q_2 / x \\ q_3 / x \\ q_4 / x \end{pmatrix}$$

M. EIGEN ANGLE AND EIGEN VECTOR EXTRACTION FROM A MATRIX (EIGENMN)

NOTE: Mathematical expressions in this paragraph were extracted from the "MQEUT" program.

The method used is to convert the matrix to a quaternion using a pitch, yaw, roll Euler sequence (steps 1-3), then to extract the eigen angle and vector from the quaternion (step 4). If the yaw angle happens to be very near 90 or 270 degrees, a yaw, pitch, roll Euler sequence is used.

1. To calculate ang(2):

$$\text{ang}(2) = \sin^{-1}(M_{21})$$

If alternate Euler angle is desired (set with the ang(2) angle between 90° and 270°), then $\text{ang}(2) = 180 - \text{ang}(2)$

If $\text{ang}(2) < 0$, then $\text{ang}(2) = 360 + \text{ang}(2)$

2. To calculate ang(1):

$$\text{arg} = \frac{M_{11}}{\cos(\text{ang}(2))}$$

$$\text{If } \text{abs}(\text{arg}) > 1, \text{ then } \text{arg} = \frac{\text{arg}}{\text{abs}(\text{arg})}$$

$$\text{ang}(1) = \cos^{-1}(\text{arg})$$

$$\text{If } \frac{-M_{31}}{\cos(\text{ang}(2))} < 0, \text{ then } \text{ang}(1) = 360 - \text{ang}(1)$$

3. To calculate $ang(3)$:

$$arg = \frac{M_{22}}{\cos(ang(2))}$$

$$\text{If } abs(arg) > 1, \text{ then } arg = \frac{arg}{abs(arg)}$$

$$ang(3) = \cos^{-1}(arg)$$

$$\text{If } \frac{-M_{23}}{\cos(ang(2))} < 0, \text{ then } ang(3) = 360 - ang(3)$$

Above angles are then stored in a quaternion form as:

$$Q101 = \begin{bmatrix} \cos\left[\frac{ang(1)}{2}\right] \\ 0 \\ \sin\left[\frac{ang(1)}{2}\right] \\ 0 \end{bmatrix} \quad Q102 = \begin{bmatrix} \cos\left[\frac{ang(2)}{2}\right] \\ 0 \\ 0 \\ \sin\left[\frac{ang(2)}{2}\right] \end{bmatrix}$$

$$Q103 = \begin{bmatrix} \cos\left[\frac{ang(3)}{2}\right] \\ \sin\left[\frac{ang(3)}{2}\right] \\ 0 \\ 0 \end{bmatrix}$$

Quaternion multiplication as in step 10 ($Q_n * Q_n > Q_n$) would have to be made as:
 $Q101 * Q102 = Q104$, where $Q104$ is an intermediate result.

Then, $Q104 * Q103 = Q$,

where Q can then be represented as

$$Q = \begin{bmatrix} q_A \\ q_B \\ q_C \\ q_D \end{bmatrix}$$

4. The eigen angle = $2 * \cos^{-1}(q_A)$

The non-unitized eigen axes will be

$$x_1 = q_B, y_1 = q_C, z_1 = q_D$$

To unitize the vector, then

$$A = \sqrt{(q_B)^2 + (q_C)^2 + (q_D)^2}$$

such that the unitized eigen vector is

$$x = \frac{q_B}{A}, \quad y = \frac{q_C}{A}, \quad z = \frac{q_D}{A}$$

The rotation axes are

$$x' = x * \text{eigen angle}$$

$$y' = y * \text{eigen angle}$$

$$z' = z * \text{eigen angle}$$

N. EIGEN VECTOR AND EIGEN ANGLE EXTRACTION FROM A QUATERNION (EIGENQN)

The extraction of an eigen vector and angle from a quaternion is the same as the process described in step 4 above.

O. CONVERSION OF EIGEN AXIS ROTATIONS TO A QUATERNION (X#Y#Z# > QN)

The rotations for x, y, and z can be converted into a quaternion as follows.

ang(1) = x axis rotation

ang(2) = y axis rotation

ang(3) = z axis rotation

To obtain the root of the sum of the squares (RSS),

$$RSS = \sqrt{ang(1)^2 + ang(2)^2 + ang(3)^2}$$

The elements of the quaternion are as follows:

$$Q = \begin{pmatrix} \cos\left(\frac{RSS}{2}\right) \\ \frac{ang(1)}{RSS} * \sin\left(\frac{RSS}{2}\right) \\ \frac{ang(2)}{RSS} * \sin\left(\frac{RSS}{2}\right) \\ \frac{ang(3)}{RSS} * \sin\left(\frac{RSS}{2}\right) \end{pmatrix}$$

MQEUT APPLICATIONS

MQEUT is a powerful matrix and quaternion manipulation program. Learning a few concepts of quaternion multiplication operations will allow the user to easily perform any kind of coordinate systems transformations. This portion of the SCP will explain the basic concept of performing quaternion multiplication to derive any coordinate system transformation, or more explicitly, derive the rotation to move from one coordinate system to another. In order for the following concepts to be utilized, it is imperative to label every quaternion to determine the order of multiplication and/or the need for conjugation. The author has chosen the labeling convention of "from_to". For example, the quaternion $[Q]_{cur_req}$ can be thought of as "the rotation that is required to move from the current reference frame to the required reference frame."

Using this labeling convention, the quaternion multiplication should be done as follows:

$$[Q]_{A_C} = [Q]_{A_B} * [Q]_{B_C}$$

This allows the rotations to be from one reference frame to another reference frame (i.e. going down the path "from A to B" then "from B to C"). The final quaternion results in the rotation from A to C since the B reference frame cancels out of the equation. This method allows more than two quaternions to be multiplied to get a specific result. For example, if the quaternion $[Q]_{a_d}$ needed to be determined, the following equation would be used:

$$[Q]_{A_D} = [Q]_{A_B} * [Q]_{B_C} * [Q]_{C_D}$$

Using this convention will allow the user to do an infinite number of rotations as long as this convention is followed. The simplest approach to solving a problem involving a set of known rotations is shown here in cookbook form:

1. Determine the label of the final answer using the "from_to" convention:
 $[Q]_{a_f}$
2. Determine all of the given rotations required to achieve the final answer:
 $[Q]_{a_b}$, $[Q]_{b_c}$, $[Q]_{d_c}$, $[Q]_{d_e}$, $[Q]_{f_e}$
3. Write the equation that is required to determine the final answer given the known quaternions.
 $[Q]_{a_f} = [Q]_{a_b} * [Q]_{b_c} * [Q]_{c_d} * [Q]_{d_e} * [Q]_{e_f}$
4. Conjugate all known quaternions whose labels are reversed from the required equation.
Conjugate $[Q]_{d_c} = [Q]_{c_d}$
Conjugate $[Q]_{f_e} = [Q]_{e_f}$
5. Use MQEUT to solve the equation in step 3.

Using this procedure, MQEUT will allow the user to perform a multitude of quaternion mathematics. One of the two basic concepts to grasp is to determine a final coordinate system/attitude given an initial coordinate system/attitude and a set of Euler rotations. The other concept is to determine a set of Euler rotations given an initial coordinate system/attitude and a final coordinate system/attitude. These are explained in detail in the remainder of this SCP.

COMPUTE REQUIRED ATTITUDE GIVEN CURRENT ATTITUDE AND EULER COMMANDS

MQEUT can be used to compute a vehicle inertial attitude given its current attitude and a set of Euler commands. Using the following equations with MQEUT will allow the user to determine this new attitude

$$[Q]_{M50_REQ} = [Q]_{M50_CUR} * [Q]_{CUR_REQ}$$

1. Current inertial attitude => Q1/M50_CUR
2. Euler commands needed to move from the current attitude to the required attitude => Q2/CUR_REQ
3. Q1 * Q2 => Q3
4. Q3 => PYR

Examples 1 and 2 demonstrate different applications of this equation.

COMPUTE EULER COMMANDS GIVEN REQUIRED AND CURRENT ATTITUDES

MQEUT can also be used to extract a set of Euler commands given a current attitude and a required attitude:

$$[Q]_{CUR_REQ} = [Q]_{CUR_M50} * [Q]_{M50_REQ}$$

1. Current Attitude => Q1/M50_CUR
2. Required Attitude => Q2/M50_REQ
3. Conjugate Q1 => Q3
4. Q3 * Q2 => Q4
5. Q4 => PYR

Example 1

One possible application of this capability is to determine the right ascension and declination of the point in the celestial sphere that the -Z axis is pointing given the vehicle inertial attitude of R=30, P=45, and Y=60.

1. Load the current attitude into a quaternion Q1 using the label M50_BDY since it defines the rotation from the reference frame (M50) to the current body attitude.

Input: P45Y60R30>Q1/M50_BDY

Output: Requested operation: P45Y60R30>Q1/M50_BDY

$$\begin{array}{l} P \ 45.00 \\ Y \ 60.00 \\ R \ 30.00 \end{array} > \begin{array}{|l} .7233174114 \\ .3919038373 \\ .4396797395 \\ .3604234057 \end{array} \Bigg| \text{M50_BDY}$$

2. Since the -Z axis can be defined as a +90 degree pitch rotation from the principle body axis +X, load that rotation into a quaternion Q2 using the label BDY_-Z.

Input: P90Y0R0>Q2/BDY_-Z

Output: Requested operation: P90Y0R0>Q2/BDY_-Z

$$\begin{array}{l} P \ 90.00 \\ Y \ .00 \\ R \ .00 \end{array} > \begin{array}{|l} .7071067812 \\ .0000000000 \\ .7071067812 \\ .0000000000 \end{array} \Bigg| \text{BDY_Z}$$

3. Input: Q1*Q2>Q3

Output: Requested operation: Q1*Q2>Q3

$$\begin{array}{|l} .723317411 \\ .391903837 \\ .439679740 \\ .360423406 \end{array} \Bigg|_{\text{M50_BDY}} * \begin{array}{|l} .7071067812 \\ .0000000000 \\ .7071067812 \\ .0000000000 \end{array} \Bigg|_{\text{BDY_Z}} > \begin{array}{|l} .200562121 \\ .022260027 \\ .822363172 \\ .531975695 \end{array} \Bigg|_{\text{M50_Z}}$$

- To determine the right ascension and declination, the quaternion needs to be transformed into a YPR Euler sequence.

Input: Q3>YPR

Output: Requested operation: Q3>YPR

.2005621211			Y	164.77484299
.0222600267			> P	17.82954385
.8223631719			R	111.80140949
.5319756952		M50_-Z		

- To extract the right ascension and declination the following equations must be used:

RA = Y
RA = 164.8

DEC = -P
DEC = -17.8

Example 2

Another example of MQEUT's versatility is the capability to determine the inertial attitude of the Orbiter as seen on the aft ADI with the sense switch in the -Z position. For this example, the attitude R=30, P=45, and Y=60 will be used.

- Load the current attitude into a quaternion Q1 using the label M50_BDY since it defines the rotation from the reference frame (M50) to the Orbiter body.

Input: P45Y60R30>Q1/M50_BDY

Output: Requested operation: P45Y60R30>Q1/M50_BDY

P	45.00	>	.7233174114		
Y	60.00		.3919038373		
R	30.00		.4396797395		
			.3604234057		M50_BDY

2. Since the -Z sense ADI axis can be defined as a +90 degree pitch and +180 degree roll rotation from the principle +X body coordinate system, load that rotation into a quaternion Q2 using the label BDY_-ZADI.

Input: P90Y0R180>Q2/BDY_-ZADI

Output: Requested operation: P90Y0R180>Q2/BDY_-ZADI

$$\begin{array}{l} P\ 90.00 \\ Y\ .00 \\ R\ 180.00 \end{array} > \begin{array}{l} .0000000000 \\ .7071067812 \\ .0000000000 \\ -.7071067812 \end{array} \Bigg|_{BDY_ZADI}$$

3. Input: Q1*Q2>Q3

Output: Requested operation: Q1*Q2>Q3

$$\begin{array}{l} .723317411 \\ .391903837 \\ .439679740 \\ .360423406 \end{array} \Bigg|_{M50_BDY} * \begin{array}{l} .0000000000 \\ .7071067812 \\ .0000000000 \\ -.7071067812 \end{array} \Bigg|_{BDY_ZADI} > \begin{array}{l} -.022260027 \\ .200562121 \\ .531975695 \\ -.822363172 \end{array} \Bigg|_{M50_ZADI}$$

4. The following step determines the Orbiter inertial attitude that would be indicated on the aft ADI when the sense switch is in the -Z position.

Input: Q3>PYR

Output: Requested operation: Q3>PYR

$$\begin{array}{l} -.022260027 \\ .200562121 \\ .531975695 \\ -.822363172 \end{array} \Bigg|_{M50_ZADI} > \begin{array}{l} P\ 161.56505118 \\ Y\ 14.47751219 \\ R\ 116.56505118 \end{array}$$

Example 3

An example of extracting the Euler angles given two attitudes, is shown below. Given the Orbiter inertial attitude and the -Z sense aft ADI attitude, determine the rotation required to transform from the body axis to the -Z sense aft ADI inertial attitude.

1. Load the current attitude into a quaternion Q1 using the label M50_BDY since it defines the rotation from the reference frame (M50) to the current body attitude.

Input: P45Y60R30>Q1/M50_BDY

Output: Requested operation: P45Y60R30>Q1/M50_BDY

P 45.00	>	.7233174114	M50_BDY
Y 60.00		.3919038373	
R 30.00		.4396797395	
		.3604234057	

2. Load the -Z sense aft ADI attitude into a quaternion Q2 using the label M50_-ZADI since it defines the rotation from the reference frame (M50) to the -Z sense aft ADI attitude.

Input: P161.56505118Y14.47751219R116.56505118>Q2/M50_-ZADI

Output: Requested operation: P161.56505118Y14.47751219
R116.56505118>Q2/M50_-ZADI

P 161.56505118	>	-.022260027	M50_-ZADI
Y 14.47751219		.200562121	
R 116.56505118		.531975695	
		-.822363172	

3. Conjugate Q1 into Q3 to change the rotation from M50_BDY to BDY_M50.

Input: CONJQ1>Q3

Output: Requested operation: CONJQ1>Q3

.7233174114	BDY_M50
-.3919038373	
-.4396797395	
-.3604234057	

4. Multiply Q3 times Q2 and load into Q4. Notice that the M50 reference frame in the two quaternions cancel out.

Input: Q3*Q2>Q4

Output: Requested operation: Q3*Q2>Q4

$$\begin{array}{c} \left| \begin{array}{l} .723317411 \\ -.391903837 \\ -.439679740 \\ -.360423406 \end{array} \right| \\ \text{BDY_M50} \end{array} * \begin{array}{c} \left| \begin{array}{l} -.022260027 \\ .200562121 \\ .531975695 \\ -.822363172 \end{array} \right| \\ \text{M50_ZADI} \end{array} > \begin{array}{c} \left| \begin{array}{l} .000000000 \\ .707106781 \\ .000000000 \\ -.707106781 \end{array} \right| \\ \text{BDY_ZADI} \end{array}$$

5. To extract the Euler angles required for the BDY_-ZADI rotation into a PYR sequence perform the following:

Input: Q4>PYR

Output: Requested operation: Q4>PYR

$$\begin{array}{c} \left| \begin{array}{l} .000000000 \\ .7071067812 \\ .0000000000 \\ -.7071067812 \end{array} \right| \\ \text{BDY_ZADI} \end{array} > \begin{array}{l} \text{P} \quad 90.00 \\ \text{Y} \quad .00 \\ \text{R} \quad 180.00 \end{array}$$

Example 4

The following equation can be used to compute the Orbiter inertial attitude given a set of IMU data (i.e. REFSMMAT, gimbal angles, RGAO and RGPO, nav base to case matrix, and nav base to body matrix):

$$[Q]_{M50_BDY} = [Q]_{M50_CL} [Q]_{CL_RL} [Q]_{RL_CASE} [Q]_{CASE_NB} [Q]_{NB_BDY}$$

$$(Q45 = Q1 * Q2 * Q3 * Q4 * Q5)$$

[Q]_{M50_CL} 1. Enter the REFSMMATs into M1/M50_CL.

2. M1 > Q1

3. CONJQ1 > Q1

[Q]_{CL_RL} 4. Enter IMU gimbal angles into Q2/CL_RL:

$$Y###P###R###> Q2/CL_RL$$

[Q]_{RL_CASE} 5. Enter RGAO and RGPO into Q3/RL_CASE:

$$Y(RGAO)P(RGPO)R0 > Q3/RL_CASE$$

[Q]_{CASE_NB} 6. Enter the Nav Base to Case Matrix

(T_NBCASE I-Load) into M4/NB_CASE

7. M4 > Q4

[Q]NB_BDY 8. Enter the Nav Base to Body Matrix

(T_NBBDY I-Load) into M5/NB_BDY

9. M5 > Q5

10. CONJQ5 > Q5

Perform the Quaternion multiplication:

11. Q1 * Q2 > Q12

12. Q12 * Q3 > Q23

13. Q23 * Q4 > Q34

14. Q34 * Q5 > Q45

Extract the Orbiter attitude from Q/M50_BDY:

15. Q45 > PYR

NOTE: If a high degree of accuracy is not required some of the quaternions may be substituted with the following defaults:

Q_RL_CASE = ENTER Q3/RL_CASE 1,0,0,0

Q_CASE_NB = ENTERQ4/CASE_NB 1,0,0,0

Q_NB_BDY = P10.6Y0R0>Q5/NB_BDY

It is also important to note that this is not the exact equation that the PASS uses to determine the Orbiter attitude. The software also takes into account that there is a pitch gimbal non-orthogonality correction. However, since this error is so small, it was not accounted for in this analysis.

REFERENCE

GNC Off-line Program MQEUT Documentation Folder.

TITLE

HEX TO DECIMAL CONVERSION

PURPOSE

The purpose of this SCP is to describe the operation of GNC PC off-line program HTOD which converts between decimal and hexadecimal floating point numbers. A manual procedure is included to provide a backup capability in case the program is not available and also as a description of the program's internal operation.

BACKGROUND

The GPC Flight Software uses a hexadecimal floating point format for storing numbers. The GMEM Read/Write function requires that we be able to convert between these numbers and a more human friendly decimal floating point format. The HTOD off-line program performs these conversions.

PROGRAM DESCRIPTION

For the purposes of this application, decimal numbers will be expressed in scientific notation ($\pm X.XXXXXX E_{\pm XX}$), while hex numbers will be expressed as either single precision (XXXX XXXX) or double precision (XXXX XXXX XXXX XXXX).

The program performs the conversions with unlimited decimal precision. A hexadecimal number will be converted to the exact decimal equivalent regardless of the number of places needed (the maximum number of places ever needed is 236). The program will accept a decimal input of up to 240 decimal digits and it will find the hexadecimal number that is closest to the input decimal number. Spaces may be used to group numbers, both decimal and hexadecimal, for the user's convenience; they are ignored by the internal processing of the program. Results will always be formatted with a space between groups of four hexadecimal characters and between groups of 5 decimal digits.

In addition to the unlimited precision output of hexadecimal to decimal conversion, there is an output rounded to the approximate precision of the hexadecimal input.

For decimal to hexadecimal conversion there are three outputs: a double precision output with one additional hexadecimal character to show the proper roundoff, a rounded double precision number, and a rounded single precision number.

For reference, the decimal/hex/binary equivalents are included here.

TABLE 10.6-I. - DECIMAL, HEX, AND BINARY EQUIVALENTS

Decimal	Hex	Binary	Decimal	Hex	Binary
0	0	0000	10	A	1010
1	1	0001	11	B	1011
2	2	0010	12	C	1100
3	3	0011	13	D	1101
4	4	0100	14	E	1110
5	5	0101	15	F	1111
6	6	0110			
7	7	0111			
8	8	1000			
9	9	1001			

PROCEDURES

The following sections provide procedures for converting between hex and decimal representations of numbers using both the workstation program HTOD, and a manual method.

A. PERSONAL COMPUTER (PC) PROGRAM HTOD

Execute the program

The program is located on the MCC GNC Restricted Applications menu, and also on the DF S: drive and the MCC U: drive.

Prompt: ENTER HEXADECIMAL OR DECIMAL> -- OR -- TYPE (P)RINT, (T)UTORIAL, or (Q)UIT.

If hexadecimal to decimal, enter the hexadecimal number (exactly 8 characters for single precision or exactly 16 characters for double precision). If dec to hex, enter scientific format decimal number (+/-X.XXX- - - E+/-XX). For either hex or decimal input, spaces may be used for any convenient grouping; they are ignored by the program. The user may print (P) the last case, view a program tutorial (T), or quit the program (Q) at any prompt.

B. MANUAL PROCEDURE

1. Hex to decimal conversion

The following steps outline the procedure for converting a hex number to decimal. The individual hex characters will be identified by C followed by the number of the character

starting with 1 as the leftmost character. Single precision numbers consist of two four character half words (8 characters denoted C1 – C8) and double precision numbers consist of four, four character halfwords (16 characters denoted C1 – C16).

Step 1: Sign of the number

The first bit of the first character (C1) determines the sign of the number. If it is 0 (C1 is in the range 0-7) the number is positive; if it is 1 (C1 is in the range 8-F) the number is negative. The sign bit is removed from the character by subtracting 8 (hex) if the character is greater than or equal to 8. Alternatively the first character may be converted to binary (4 bits) using the above table, removing the first bit, and then converting the remaining binary number back to hex. If the first bit is a one the number is negative; if it is 0 the number is positive.

Example: Hex number is AD41 000C. C1 is A (1010 in binary), the sign of the number is negative, and C1, after the sign bit has been removed, is 2 (0010 in binary).

Step 2: Exponent

The first two hex characters C1 and C2 (after the sign bit has been removed) determine the exponent of 16. There is no specific sign associated with the exponent. Instead, it is coded so that the range of 00 to 7F (hex) corresponds to an actual range of –40 to +3F. The true exponent is found by subtracting 40 (hex) from the exponent characters (after the sign bit has been removed). The decimal equivalent of the exponent part of the hexadecimal number is then found by converting the true exponent to decimal (C1 X 16 plus C2) and raising 16 to the power of the decimal number.

Example: Hex number is AD41 000C. C1 and C2 (the coded exponent after the sign bit has been removed – see step 1) are 2D. Subtracting 40 (hex) the decoded (true) exponent is –13 (hex). Converting to decimal, $-(1 \times 16 + 3) = -19$. Raising 16 to the –19th power the exponent part of the hex floating point number is 1.32348898 - - - - E-23.

Step 3: Fraction

The decimal equivalent of the fraction part of the hexadecimal number (single precision) is calculated as follows:

$$\text{fraction} = \frac{C3}{16} + \frac{C4}{16^2} + \frac{C5}{16^3} + \frac{C6}{16^4} + \frac{C7}{16^5} + \frac{C8}{16^6}$$

Example: Hex number is AD41 000C. Fraction part of hex number is

$$\begin{aligned} & 4/16 + 1/16^2 + 0/16^3 + 0/16^4 + 0/16^5 + 12/16^6 \\ & = .25 + .00390625 + 0 + 0 + 0 + .0000007152557 - - - \end{aligned}$$

$$= 0.253906965 \dots$$

NOTE: For double precision numbers the above series continues through $C_{16}/16^{14}$

Step 4: Decimal number

The decimal number is calculated as follows:

$$\text{decimal number} = (\text{sign}) * (\text{fraction}) * (16)^{\text{exponent}}$$

or step 1 * step 3 * step 2

$$(-1) * (0.253906965 \dots) * (1.32348898 \dots \text{E-23})$$

$$= -3.36043070 \dots \text{E-24}$$

2. Decimal to hex conversion

The following steps outline the procedure for converting a decimal number to hex. The procedure is essentially the same as that used by the program; it is much more computationally intense than the hex to dec procedure.

Step 1: Determine the sign

Note the sign of the input decimal number
The following steps use the absolute value of the input number

Step 2: Determine the power of 16

Find the power of 16 that is just larger than the input decimal number (this decimal value will be multiplied by the decimal equivalent of the fraction (less than 1) part of the hexadecimal number to get the final decimal equivalent of the hexadecimal value that is to be compared to the input decimal value). Using the example given in the hexadecimal to decimal conversion the power of 16 is -19 or $1.32348898 \dots \text{E-23}$. This value is just larger (absolute value) than the input decimal number of $-3.3604022027 \dots \text{E-24}$. An exponent of 16 value of -20 at $8.2718 \dots \text{E-25}$ is smaller than the input decimal value.

Step 3: Determine the fraction

$$\text{fraction} = \frac{C3}{16} + \frac{C4}{16^2} + \frac{C5}{16^3} + \frac{C6}{16^4} + \frac{C7}{16^5} + \frac{C8}{16^6}$$

Repeat (iterate) this step for each of characters CN where N is 3 – 8 (3 – 16 for double precision).

Find the value of CN such that the product of the value of the exponent of 16 part of the number from step 2 and the sum of the iterations of $CN/16^{N-2}$ is just smaller than (or equal to) the input decimal number (that is the next higher value

of CN would make the product larger than the input decimal number). Repeat until the last CN has been done. The final CN may be rounded to the value that results in the product exceeding the input value if the input number is closer to the higher value than to the lower value. The program HTOD performs this rounding by looking at the next hexadecimal character (an extra character is calculated beyond the double precision 14th fraction character for this purpose).

Step 4: Hex Number

Convert the exponent of 16 from step 2 to hex by dividing by 16 and converting the quotient and the remainder to hex using table 10.6-I. The quotient is C1 (without the sign of the number) and the remainder is C2. At this point C1 and C2 are still a true (signed) exponent. Convert to the coded format by adding hex 40. If the input decimal number is negative add hex 8 to C1. Next convert each of the CN values from step 3 to hex using table 10.6-I. Assemble C1 through C8 (C1 – C16 for double precision) to complete the conversion.

C. EXAMPLES

The following examples are provided to exercise the procedures for using the program and performing the conversions manually.

<u>Example</u>	<u>Conversion</u>	<u>Given</u>	<u>Find</u>
1	HEX TO DECIMAL	B12C 87FD	DECIMAL
2	HEX TO DECIMAL	426E 0041 0000 4BC6	DECIMAL
3	DECIMAL TO HEX	5.0	HEX
4	DECIMAL TO HEX	-7.92	HEX
5	DECIMAL TO HEX	0.002618	HEX

EXAMPLE 1 - Hex to decimal conversion

Convert B12C 87FD from hex to decimal.

PC procedure:

Enter hex number: B12C 87FD RETURN
The result is: -1.5087 75886 - - - E-19

Manual procedure:

1. Sign of the number

First character = B (1011 in binary)

Since the first bit of the binary number is a 1, the number is negative.

Once the sign bit is removed C1 becomes 3 (hex) (or 0011 in binary).

The number is positive when the first character is between 0 and 7 (the first bit is 0).

The number is negative when the first character is between 8 and F (the first bit is 1).

2. Exponent

$$C1 = 11 - 8 = 3$$

$$C2 = 1$$

$$\text{Exponent} = 31 - 40 = -F \text{ (-15 decimal)}$$

Alternatively, 31 and 40 hex may be converted to decimal before performing the subtraction:

$$31 \text{ hex} = 3 \cdot 16 + 1 = 49 \text{ decimal}$$

$$40 \text{ hex} = 4 \cdot 16 + 0 = 64 \text{ decimal}$$

then

$$\text{Exponent} = 49 - 64 = -15$$

$$\text{Exponent part of the number} = 16^{-15} = 8.6736173\text{---} \text{ E-19}$$

3. Fraction

$$C3 = 2$$

$$C6 = 7$$

$$C4 = C = 12$$

$$C7 = F = 15$$

$$C5 = 8$$

$$C8 = D = 13$$

$$\text{mantissa} = \frac{C3}{16} + \frac{C4}{16^2} + \frac{C5}{16^3} + \frac{C6}{16^4} + \frac{C7}{16^5} + \frac{C8}{16^6}$$

$$\text{mantissa} = \frac{2}{16} + \frac{12}{16^2} + \frac{8}{16^3} + \frac{7}{16^4} + \frac{15}{16^5} + \frac{13}{16^6} = 0.1739500$$

4. Decimal number

$$\text{Number} = \text{Sign} * \text{Fraction} * 16^{\text{exponent}}$$

$$= -0.17395002 * (16)^{-15} = -1.50878\text{---} \text{ E-19}$$

EXAMPLE 2 - Hex to decimal conversion

Convert 426E 0041 0000 4BC6 from hex to decimal.

PC procedure:

Enter hex number: 426E0041 00004BC6 RETURN
The result is: 1.10000991821357978 - - - E + 02

Manual procedure:

NOTE: The following manual calculation uses only the single precision hex characters (the first eight hex characters). At the cost of some very tedious manual math, the last eight hex characters can be included to provide greater accuracy (double precision); in this case all calculations must be carried out to at least 18 places of accuracy.

1. Sign of the number

The number is positive when the first character is between 0 and 7.
First hex character = 4 (positive number)

2. Exponent

C1 = 4
C2 = 2
Exponent = 42-40 = 2 (2 decimal)

Alternatively, 42 and 40 hex may be converted to decimal before performing the subtraction:

42 hex = 4*16 +2 = 66 decimal

40 hex = 4*16 +0 = 64 decimal

then

Exponent = 66-64 = 2

Exponent part of the number = 16² = 256

3. Fraction

C3 = 6 C6 = 0
C4 = E = 14 C7 = 4
C5 = 0 C8 = 1

$$\text{fraction} = \frac{C3}{16} + \frac{C4}{16^2} + \frac{C5}{16^3} + \frac{C6}{16^4} + \frac{C7}{16^5} + \frac{C8}{16^6}$$

$$\text{fraction} = \frac{6}{16} + \frac{14}{16^2} + \frac{0}{16^3} + \frac{0}{16^4} + \frac{4}{16^5} + \frac{1}{16^6} = 0.429691374$$

4. Decimal number

$$\begin{aligned} \text{Number} &= \text{Sign} * \text{Fraction} * 16^{\text{exponent}} \\ &= 0.429691374\text{---} * (16)^2 = 1.100009918\text{---} \times 10^2 \end{aligned}$$

EXAMPLE 3 - Decimal to hex conversion

Convert 5.0 from decimal to hex.

PC procedure:

Enter number: 5.0 E+0

The result is: 4150 0000 0000 0000 0 with extra hex digit for roundoff
4150 0000 0000 0000 rounded to hex double precision
4150 0000 rounded to hex single precision

Manual procedure:

1. Determine sign

Positive number means C1 will be 0 – 7 (will not need to add 8 to C1).

2. Determine exponent of 16

Find the power of 16 that is just larger than the input decimal number.
Start with 0 and work down through negatives if necessary.

$$16^0 = 1$$

$$16^1 = 16$$

Therefore an exponent of 1 is just larger than the number.

Convert 1 to hex (1) and add hex 40. Since the number is positive add 0 to C1. C1 and C2 are 41.

3. Find C3 – C8

Start by making C3 = 1 (the format precludes C3 = 0) and increment until the product of the value of exponent part * C3/16 is just smaller than the input decimal number (absolute value).

When C3 = 5, C3/16 = .3125 and the product = .3125 * 16 = 5.

Since C3 gives an exact conversion the remaining CNs will all be 0.

4. Hex number

The hex number is 4150 0000

EXAMPLE 4 - Decimal to hex conversion

Convert -7.92 from decimal to HEX

Workstation procedure:

Enter number: -7.92 E+0

The result is: C17E B851 EB85 1EB8 5 with extra hex digit for roundoff
C17E B851 EB85 1EB8 rounded to hex double precision
C17E B852 rounded to hex single precision

Manual procedure:

NOTE: The following manual calculation uses only the single precision hex characters (the first eight hex characters). At the cost of some very tedious manual math, the last eight hex characters can be included to provide greater accuracy (double precision); in this case all calculations must be carried out to at least 18 places of accuracy.

1. Determine sign

Negative number means C1 will be 8 -F (will need to add 8 to C1).

2. Determine exponent

Find the power of 16 that is just larger than the input decimal number.
Start with 1 and work down through negatives if necessary.

$$16^0 = 1$$

$$16^1 = 16$$

Therefore an exponent of 1 is just larger than the number.

Convert 1 to hex (1) and add hex 40. Since the number is negative add 8 to C1. C1 and C2 are C1.

3. Determine C3 through C8

Start by making C3 = 1 and C4 through C8 = 0 (the format precludes C3 = 0). Increment C3 until the product of the value of the exponent part and the sum of the fraction part ($C3/16 + 0/16^2 + \dots$) is just smaller than (or equal to) the number (absolute value). C3 = 7 produces a product of $16*(7/16 + 0/16^2 + \dots) = 16*0.4375 = 7$ which is just smaller than 7.92. C3 of 8 produces a product of 8 which is larger than 7.92.

Next increment C4 starting with 0 until the product of the value of the exponent part and the sum of the CN terms is just smaller than (or equal to) the number.

C4 = 14 (E) produces a product of $16*(7/16 + 14/16^2 + 0/16^3 + \dots) = 7.895$ which is just smaller than 7.92. C4 = 15 produces a product of 7.935, which is larger than 7.92.

C5 = 11 (B) produces a product of 7.91796875

C6 = 8 produces a product of 7.919921875 - - -

C7 = 5 produces a product of 7.919998169 - - -

C8 = 1 produces a product of 7.919999123 - - -. C8 = 2 produces a product of 7.920000076 - - - which is slightly too large, but since this is the last digit for single precision we choose the C8 value that produces a product that is closer to the number (roundoff). The roundoff could also have been determined by continuing the CN iteration to the next character and rounding up if that character is 8 or larger.

4. Hex number

The hex number is C17E B852

EXAMPLE 5 - Decimal to hex conversion

Convert 0.002618 (2.618×10^{-3}) from decimal to hex.

PC procedure:

Convert the number to scientific format 2.618 E-3

Enter number: 2.618 E-3

The result is: 3EAB 92C0 6184 7F56 2 with extra digit for roundoff
 3EAB 92C0 6184 7F56 rounded to hex double precision
 3EAB 92C0 rounded to hex single precision

Manual procedure:

NOTE: The following example will be carried through single precision only because the math becomes extremely tedious and calculators generally do not carry enough precision to do the conversion accurately.

1. Determine sign bit

Positive number means C1 will be 0 -7 (will not need to add 8 to C1)

2. Determine exponent

Find the power of 16 that is just larger than the input decimal number.
Start with 1 and work down through negatives if necessary.

$$16^{-1} = .0625$$

$$16^{-2} = .00390625$$

$$16^{-3} = .000244140625$$

Therefore exponent of -2 is just larger than the number.

Convert -2 to hex and add 40 (hex) $-2 + 40 = 3E$. Since the number is positive add 0 to C1. C1 and C2 are 3E

3. Determine C3 through C8 (the fraction)

Start by making C3 = 1 and C4 through C8 = 0 (the format precludes C3 = 0). Increment C3 until the product of the value of exponent part and the sum of the fraction part ($C3/16 + 0/16^2 + \dots$) is just smaller than (or equal to) the number (absolute value). C3 = 10 (A) produces a product of $16^{-2} * (10/16 + 0/16^2 + \dots) = 0.00390625 * (0.625 + 0 \dots) = 0.0024140625$. C3 of 11 produces a product that is too large.

Next increment C4 starting with 0 until the product is just smaller than the number. C4 = 11 (B) produces a product of $16^{-2} * (10/16 + 11/16^2 + 0/16^3 \dots) = 0.00390625 * (0.625 + 0.04296875 + 0 \dots) = 0.00260925293 \dots$. C4 = 12 produces a product which is too large.

C5 = 9 produces a product of 0.002617835999 - - -

C6 = 2 produces a product of 0.002617955208 - - -

C7 = C produces a product of 0.002617999911 - - -

C8 = 0 produces a product of 0.002617999911 - - - . C8 = 1 produces a product which is too large and, since C8 = 0 is closer to the input decimal than C8 = 1, we do not round up.

4. Hex number

The hex number is 3EAB 92C0

REFERENCE

GNC Offline Program HTOD Documentation Folder.

TITLE

MX USER'S GUIDE

PURPOSE

This SCP serves as a user's guide for the operation of the GNC program MX.

BACKGROUND

The MX program performs various matrix operations. It can generate, rotate, multiply, transpose, orthogonalize, read, and write matrices. The operations of MX are directed by command line arguments.

MX is one of the family of programs developed by GNC to perform on matrix and quaternion operations. This family includes the MX, QX, QM, and MCHK programs. These programs read and write data in the form of human-readable ASCII text files, which can be entered and changed by any text editor. They use routines in the "libqm.a" library to do most of the work. The MX program is available as a stand-alone application, but is also used as a subroutine of NREF. The MX program is available on the MCC workstations in the following directory location:

/mcc/cert_apps/common/gnc/bin_xxyy or

/mcc/uncert_apps/common/gnc/bin_xxyy

where:

cert_apps or uncert_apps is determined by whether the activity joined during the workstation logon was in the certified or uncertified mode.

xxyy in the bin_xxyy directory is the 4 character alphanumeric identifier of the operating system baseline currently being used in the MCC, i.e., EP02 = Eyepatch, Release 2.

PROCEDURE

The MX program reads a list of user-supplied arguments and then performs one of the following operations:

Pitch, yaw, roll through any number of degrees

Multiplies two matrices

Transposes a matrix

Orthogonalizes a matrix

Read and write a matrix*

To execute the MX program, you only need to open an X-Windows Terminal (XTERM). The XTERM is opened from the GNC DNAV menu, under the XTOOLS option. Once the XTERM is open, MX is executed by typing "mx" on the command line followed by the necessary command line arguments, which are defined below.

Note: MX is executed from the XTERM command line regardless of the directory that the user is in (i.e., it is not necessary for the user to go to the directory containing MX, to execute it).

*The ENTREF program (SCP 10.12) provides a much easier method of entering matrices.

First character of argument	Rest of argument	Action
p or P	"number"	pitch up through "number" degrees
y or Y	"number"	yaw right through "number" degrees
r or R	"number"	roll right through "number" degrees
+	"filename"	multiply by matrix in "filename"
-	"filename"	multiply by transpose of matrix in "filename"
=	"filename"	write current matrix to "filename"
#	"filename"	orthogonalize and write to "filename"

The result of the operation will be displayed on the screen. If the first argument is a '+' or a '-' followed by "filename", then the program will read the matrix in the file "filename". If no filename is specified, the program will wait for the user to input the matrix. If a '-' is entered, the matrix will be transposed first. Otherwise, the desired operation will be performed on the identity matrix (diagonal ones). MX performs operations on 3 by 3 matrices only.

To print the matrices, select the line print option on the GNC menu and specify the filename as shown below:

lp "filename"

EXAMPLES

- A. Perform the operation Pitch 190, Yaw 160, Roll 210 degrees and output the results to the file named m1.

COMMAND: mx p190 y160 r210 =m1

RESULT: ###
This file contains a matrix.
The name of this file is

m1

#Matrix:
0.925416578 -0.204874129 0.318795778
0.342020143 0.813797681 -0.469846310
-0.163175911 0.543838142 0.823172945

- B. Transpose matrix m1 and assign it to m2.

COMMAND: mx -m1 =m2

RESULT: ###
This file contains a matrix.
The name of this file is

m2

#Matrix:
0.925436578 0.342020143 -0.163175911
-0.204874129 0.813797681 0.543838142
0.318795778 -0.469846310 0.823172945

- C. Multiply m1 * m2 and put the result into m3

COMMAND: mx +m1 +m2 =m3

RESULT: ###
This file contains a matrix.
The name of this file is

m3

#Matrix:
1.00000000 0.00000000 0.00000000
0.00000000 1.00000000 0.00000000
0.00000000 0.00000000 1.00000000

D. Orthogonalize m1 and assign it to m4

COMMAND: mx +m1 #m4

```
RESULT: ###
        ### This file contains a matrix.
        ### The name of this file is
        ###
        ###           m4
        ###
                # Matrix:
        0.925416578   -0.204874129   0.318795778
        0.342020144   0.813797681   -0.469846310
        -0.163175911  0.543838142   0.823172945
```

E. Read a matrix and write it to file "launch.ref1"

COMMAND: mx + =launch.ref1

```
INPUT:  1 <return>
        2 <return>
        3 <return>
        4 <return>
        5 <return>
        6 <return>
        7 <return>
        8 <return>
        9 <return>

RESULT: ###
        ### This file contains a matrix.
        ### The name of this file is
        ###
        ###           launch.ref1m2
        ###
                # Matrix:
        1.000000000   2.000000000   3.000000000
        4.000000000   5.000000000   6.000000000
        7.000000000   8.000000000   9.000000000
```

REFERENCE

GNC Off-line Program MX Documentation Folder.

TITLE

STAR TABLE USER'S GUIDE

PURPOSE

To provide star table data that is missing during GNC low data rate telemetry periods.

BACKGROUND

On some missions such as STS-107 the orbit phase requires use of a low GNC data rate telemetry format to support payload objectives. Many GNC parameters are not available in this low data rate format including the star table data. This makes it difficult to monitor the performance of the star trackers and IMUs. The Star Table computation was built using ADCO's Advanced Tool of Math (ATOM) to provide the star table data using a minimum number of variable parameter slots. The computation assumes that the star IDs for the three star table slots are in the variable parameter (VP) downlist slots 5 through 7. Along with this computation, a MSKview display (STAR TABLE) was built to display the published outputs from DPS of the VP downlist in engineering units and the outputs from the star table computation.

PROCEDURE

INITIALIZATION

To support the Star Table computation and MSKview display, the following parameters must be in the appropriate VP slots.

<u>VP Slot #</u>	<u>MSID</u>	<u>Nomenclature</u>
5	V95U4942C	STAR 1 ID FROM SIGHTING TABLE
6	V95U4943C	STAR 2 ID FROM SIGHTING TABLE
7	V95U4944C	STAR 3 ID FROM SIGHTING TABLE
8	V95U4952C	STAR 1 ANGULAR ERROR
9	V95U4953C	STAR 2 ANGULAR ERROR
10	V95U4954C	STAR 3 ANGULAR ERROR

RUNNING STAR TABLE

The Star Table computation using ATOM should be started on only one workstation since it is publishing parameters. As an example, a script was placed in the STS-107 flight directory to start the computation. Open a XTERM window in the flight directory and run the script named 'table'. The XTERM window should not be closed because the easiest way to quit the ATOM computation is to type 'Ctrl C' in the XTERM window. If the computation is run in the background or the XTERM window disappears while the computation is running, the computation must be exited by using the Unix kill command.

DISPLAY

The figure below is a representation of the MSKview display Star Table which is built to show the special outputs of the Star Table computation and the associated VP slots.

F/V	109 / 102	MM 201	STAR TABLE v1.0	
OGMT	000/00:00:00	OMET	000:00:00:00	OI 179 GN 22 SM 24
STAR TBL	1	2	3	<input type="button" value="PRINT"/>
TRK ID	110	50	41	
HOURS	0.10	0.45	0.47	
ANG DIF	134.2	85.0	68.2	
ANG ERR	0.029	0.001	0.006	
SEL		X	X	
TIME	005/13:07:33	005/12:46:42	005/12:45:28	
	X	Y	Z	
TRQ	1 0.026	-0.146	0.036	
ANG	2 -0.122	0.201	-0.002	
	3 -3.937	-107.448	-16.392	

Figure 10.8-1 Star Table Display

TRK ID

GNC_VP_EU_5
GNC_VP_EU_6
GNC_VP_EU_7

These are the star IDs from the VP slots 5, 6, and 7.

HOURS

ST_HOURS1
ST_HOURS2
ST_HOURS3

These are the length of time that each star is in the table in units of hours. It is calculated by subtracting the time the star ID was put in the table (**TIME** on the display) from the present MET and converted to hours.

CAUTION: These can be in error due to errors explained in section about **TIME**.

ANG DIF

ST_DIFF1
ST_DIFF2
ST_DIFF3

These are the true angular differences between the stars in the star table in units of degrees. It is calculated using the known star vectors from the star catalog.

CAUTION: This is different than the on-board star table which displays the measured angular difference. There could be a small error between the on-board and the computation, if there is a long period of time between stars in the table and there is a significant IMU drift.

ANG ERR

GNC_VP_EU_8
GNC_VP_EU_9
GNC_VP_EU_10

These are the angular errors between the measured star angular separation and the known star angular separation. This is the downlisted parameters using VP slots 8, 9, and 10. These values are the first half word of each parameter and therefore have a precision of +/- 0.01 degrees.

SEL

ST_SEL1
ST_SEL2
ST_SEL3

These are flags indicating the selected star pair used for calculating the IMU torquing angles. This is a Star Table computation output picking the two stars with a separation angle closest to 90 degrees and larger than 35 degrees.

CAUTION: There may be rare occasions where the two pairs of stars in the star table have nearly the same angular difference. In such a case, it possible for the Star Table computation to select a different pair than the onboard logic due to the measured verse actual angular differences used as explained in **ANG DIF**.

TIME

ST_TIME1
ST_TIME2
ST_TIME3

These are the times each star ID was determined to be placed in the star table.

CAUTION: This can be in error if the star is placed in the star table during a period of loss of telemetry. The time also can be wrong after a period of ratty data where the star ID was

corrupted temporarily causing the computation to think the star had just been placed in the star table. The time for star table slots 2 and 3 can be zero for a similar ratty data problem.

TRQ ANG

These are the IMU torquing angles which are in the low data rate telemetry format.

TITLE

MCHK USER'S GUIDE

PURPOSE

To aid the flight controller in the operation of the GNC off-line program MCHK.

BACKGROUND

The MCHK program prints a report showing the orthogonality of a given matrix. The report contains the length of each vector in the matrix and the angles between each pair of vectors.

MCHK is one of the family of programs developed by GNC to operate on matrices and quaternions. This family includes the MX, QX, QM and MCHK programs. These programs read and write data in the form of human-readable ASCII text files, which can be entered and changed by any text editor. They use routines in the "libqm.a" library to do most of the work. This library was written by GNC to perform quaternion and matrix operations in a standard and easy-to-use manner. The MCHK program is available as a stand-alone application, but is also used as a subroutine of NREF (See IMU REFSMMAT NORMALIZATION SCP 2.10). The MCHK program is available on the MCC workstations in the following directory:

/mcc/cert_apps/common/gnc/bin_xxyy or

/mcc/uncert_apps/common/gnc/bin_xxyy

where:

cert_apps or uncert_apps is governed by whether the activity joined during the workstation logon was in the certified or uncertified mode.

xxyy in the bin_xxyy directory is the 4 character alphanumeric identifier of the operating system baseline currently being used in the MCC, i.e., EP02 = Eyepatch, Release 2.

PROCEDURE

A. EXECUTING PROGRAM

To execute the MCHK program, you only need to open an X-Windows Terminal (XTERM). The XTERM is opened from the GNC DNAV menu, under the XTOOLS option. Once the XTERM is open, MCHK is executed by typing "mchk" on the command line, followed by the necessary command line arguments, which are defined below. The command line arguments are necessary for the program to execute, and the program does not prompt the user for inputs.

Note: MCHK is executed from the XTERM command line regardless of the directory that the user is in (i.e., it is not necessary for the user to go to the directory containing MCHK, to execute it).

MCHK reads its list of arguments and interprets them as directions for manipulating matrices as follows:

General Form: **mchk {mi} ...**

(where mi is a matrix file)

ARGUMENT	ACTION
mi (a filename)	perform orthogonality test on (filename), print results to standard output (screen)

EXAMPLES OF OUTPUT:

Example 1:

Orthogonality analysis of matrix 'matrix1' **A**

B			C	D
0.699533332	-0.698597058	0.150383733 :	1.000000000	90.000
0.663413948	0.556670399	-0.500000000 :	1.000000000	90.000
0.265584256	0.449533332	0.852868532 :	1.000000000	90.000
<hr/>				
1.000000000	1.000000000	1.000000000	C	
90.000	90.000	90.000	D	

Example 2:

Orthogonality analysis of matrix 'matrix2'

0.699000000	-0.698597058	0.150383733 :	0.999626989	90.017
0.663413940	0.556600000	-0.500000000 :	0.999960812	89.977
0.265584356	0.449533332	0.852000000 :	0.999259359	90.016
<hr/>				
0.999626989	0.999960812	0.999259359		
89.981	90.020	90.010		

Example 3:

Orthogonality analysis of matrix 'matrix3'

0.699533332	-0.698597058	0.150000000 :	0.999942364	92.640
0.600000000	0.556670399	-0.500000000 :	0.959104756	92.712
0.265584356	0.400000000	0.852868532 :	0.978733765	87.993
<hr/>				
0.959104756	0.978733765	0.999942364	+	
92.959	92.458	88.121		

Example 4:

Orthogonality analysis of matrix 'matrix4'

0.000000000	0.000000000	0.000000000 :	0.000000000	0.000
0.663413948	0.556670399	-0.500000000 :	1.000000000	90.000
0.265584356	0.449533332	0.852868532 :	1.000000000	0.000
<hr/>				
0.714599970	0.715515304	0.988627702	+	
17.105	81.459	98.564		

There are 2 angles shown as '0.000'. **E**

These angles involve vectors of zero magnitude. **E**

Example 5:

Orthogonality analysis of matrix 'matrix5'

0.699533332	0.000000000	0.150383733 :	0.715515304	49.137
0.663413948	0.000000000	-0.500000000 :	0.830733451	109.708
0.265584356	0.000000000	0.852868532 :	0.893263557	60.571
<hr/>				
1.000000000	0.000000000	1.000000000	+	
0.000	0.000	90.000		

There are 2 angles shown as '0.000'.

These angles involve vectors of zero magnitude.

Example 6:

Orthogonality analysis of matrix 'matrix6'

0.600000000	-0.600000000	0.100000000 :	0.854400375	89.277
0.600000000	0.500000000	-0.500000000 :	0.927361850	95.401
0.200000000	0.400000000	0.800000000 :	0.916515139	92.928
<hr/>				
0.871779789	0.877496439	0.948683298	+	
88.502	89.312	95.5451		

The report contains the name of the vector (**A**), the matrix elements (**B**), the length of each vector (**C**) and angle between each angle pair (**D**). For example, the angle difference between row 1 and row 2 is in row 1, column 1, this logic applies to all angle differences. It also contains, if applicable, a statement to the user indicating that there are pairs of vectors with zero angle difference, as well as a statement indicating that there are vectors with zero magnitude being involved (see Example 4, **E**).

MCHK can only display the output on the screen, it does not have the ability to direct this data to a file; however, the user can use the ">" function (a function of the UNIX shell) to redirect this data to a file. To execute MCHK and redirect the output to an output file the user should type:

```
mchk {filename} > {output filename}
```

This would redirect the data to an output file specified by the user. The data will not automatically be displayed on the screen. To view this data on the screen the user should execute the "more" command from GNC Menu (refer to SCP 10.1). The user should type:

```
more {output filename}
```

or, to print the output file on the line printer the user should type:

```
lp {output filename}
```

B. ANALYZING ORTHOGONALITY REPORT

To analyze the results of the orthogonality test the user examines the row vector lengths (column 4) and column vector lengths (row 4). All of these magnitudes should be approximately equal to 1.0 ($\pm .0001$). The user then examines the angles between each pair of vectors in the rows and columns (column 5 and row 5, respectively). All of these angle differences should be approximately equal to 90.0 ($\pm .001$) degrees. If both of these conditions are met, then the matrix is said to be orthogonal.

REFERENCE

GNC Off-line Program MCHK Documentation Folder.

TITLE

REFSMMAT LOADING PROGRAM (REFSLOAD)

PURPOSE

This SCP describes how to run the REFSLOAD program on the workstation. The REFSLOAD program reads three files containing Reference to Stable Member Matrices (REFSMMAT's) for the three inertial measurement units (IMU's), and writes out a file containing the three REFSMMAT's, vehicle ID, and a DSM number. The file is formatted to be retrieved by the REFSMMAT Command Display to create a REFSMMAT uplink load.

This SCP also describes the command procedure for checking and uplinking the new REFSMMAT's, as well as methods for creating REFSMMAT files from scratch.

If you are using REFSLOAD in the process of normalizing the launch REFSMMAT's, please refer to the NREF SCP 2.10 for the appropriate procedures.

GENERAL

WARNING: This procedure is governed by FCOH SOP 3.1, COMMAND POLICY FOR MOD, and cannot be modified without prior approval of the FOIG or the Flight Director (during real-time operations). Safety critical steps are marked by a box.

Restrictions:

OI Load: all

OPS Mode: PASS (OPS 2 and MM 301 of OPS 3) BFS (MM 301 of OPS 3)

Major Function: GNC

Vehicles: all

Crew/MCC coordination: information only

Time Constraints: none

Hazardous: This load replaces the values of $|T|_{M50}^{DC}$, the transpose of desired REFSMMAT for each IMU (V96U7185C - V96U7211C) with the appropriate uplinked values if an IMU alignment is not in progress. If IMU alignment is in progress, the uplink is ignored. If the uplink causes erroneous desired REFSMMAT values, the IMUs may be skewed to an undesired location during a subsequent IMU alignment.

Require safing: no

If new REFSMMAT's are uplinked to the PASS in OPS 2, no action will be required for the BFS, since the BFS gets a one shot transfer of the REFSMMAT's from the PASS during its activation sequence. However, if new REFSMMAT's are uplinked to the PASS while the BFS is already activated and in OPS 301, the same new REFSMMAT's must be uplinked to the BFS (in MM 301).

BACKGROUND

Each IMU is associated with a REFSMMAT, a matrix in software which describes the orientation of the IMU stable platform with respect to the M50 inertial coordinate system. We occasionally change these REFSMMAT's because of failures or mission requirements. The REFSLOAD program automates the process of entering changed REFSMMAT's into the Command Server for uplink.

It takes three REFSMMAT's to make a load (one for each IMU). Each REFSMMAT is a separate matrix and is stored in a separate file, but the names of the files are related. For a REFSMMAT load named final, the filenames will be final.ref1, final.ref2, and final.ref3. The REFSLOAD program deals with load names (such as final) and not filenames.

The convention is that REFSMMAT files on the workstation will be stored in a subdirectory named "refs" under the flight directory. REFSLOAD does not enforce this convention. You should ensure that you are in the "refs" subdirectory before activating REFSLOAD.

REFSMMAT files are usually generated automatically by programs such as NREF. If you need to enter REFSMMAT's manually, see the BACKUP PROCEDURES section of this SCP.

PROCEDURE

This procedure reads the three REFSMMAT files that REFSLOAD will use in a subdirectory named "refs". REFSLOAD will retrieve these files, convert the numbers to Command Server format, and write them out again. It then prompts the user for a DSM number and a vehicle ID, and formats this data in command display form. Finally, it writes out the command file and the expected display of the Command Server feedback on the command display once the load is stored in the Command Server.

A. BUILDING THE COMMAND

To begin this procedure, you need three things: input name, output name, and DSM number.

The input name is the name of the REFSMMAT's you intend to uplink. These REFSMMAT's must already be in the proper file format (see BACKGROUND). Generally, you will obtain these REFSMMAT's from another program, which will tell you their name and will ensure that they are correct. If you need to enter REFSMMAT's manually, see BACKUP PROCEDURES.

The output name is another REFSMMAT name, one which is not currently in use. As part of the load process, REFSLOAD converts the input REFSMMAT's to the shuttle floating point format. This should be an insignificant change, but REFSLOAD writes out the converted matrices to this output name so you can check them. The output name is also used for the "load" and "display" files.

The DSM number is the Command Server load tracking number which will be assigned to this load. DSM numbers for REFSMMAT loads range from 43001 to 43050. You will only need to type in a number from 1 to 50.

You are now ready to run REFSLOAD. In this example, the input name is "input", the output name is "output", and the load number is "y"8. Replace these names in the example with the names you intend to use.

You need to be in the command-line mode to run REFSLOAD. Select the new window option from the DNAV pull-down menu, and follow this script:

```
command> cd /users/gnc/Data/SSPxxx/refs<RETURN>
          (utilize the current flight number in xxx)
command> refsload input output <RETURN>
```

Enter the DSM sequence number in place of "y" for this REFSMMAT load (1 to 50):

```
y <RETURN>
```

Under rare conditions, REFSLOAD will ask you for the vehicle number and flight number for this load. Simply type the vehicle number (such as "103") and hit RETURN. For the flight number use the numeric number only (such as 91 or 091).

REFSLOAD will create several output files:

```
output.comp
output.gcs

output.ref1
output.ref2
output.ref3
```

The "output.ref" files contain copies of the input REFSMMAT's which have been slightly adjusted to fit the Shuttle floating point format. The file "output.gcs" contains the converted REFSMMAT's in a format that can be retrieved to send the new REFSMMAT load to the Command Server via REFSMMAT command display. The file "output.comp" contains the same data in the format of the server feedback on the REFSMMAT command display. This file is used to verify that the data was correctly sent to the Command Server.

You should also print a copy of the "output.comp" file, which you will use to check the load in the Command Server. From an X-Term window type the following at the command line:

```
lp <SPACE> refs/output.comp <RETURN>.
```

B. LOADING THE COMMAND INTO THE COMMAND SERVER

1. Verify a Command Manager is running on the workstation being used to submit the load to the Command Server. If required, start a Command Manager from the Master DNAV, Global Apps, Command Server menu.
2. You now have a command display file containing the (adjusted) REFSMMAT's. Now, generate the REFSMMAT uplink command by retrieving the file with the REFSMMAT command display and selecting STORE.

NOTE: Command Display inputs are not allowed when the Command Server is in checkpoint.

3. Obtain a hardcopy of the new load.

C. VERIFICATION OF COMMAND SERVER LOAD

Once you have stored the REFSMMAT load in the Command Server, the server feedback of the load is shown on the REFSMMAT command display. Verify this load by comparing it with the printout generated in step A.

Exception: When the decimal number is small (less than 0.07), the one or two least significant bits of the second hex halfword may vary between the Command Server and the NREF printout. NREF converts the decimal numbers to hex at full precision, but the command display input only provides for eight decimal digits of precision. This loss of full precision has no impact, since the decimal numbers (the "meaning" of the hex words) are still identical to eight digits.

Once you have verified that the load on REFSMMAT command display is identical to the load on the printout (subject to the above exception), you should perform an end-to-end check. Find a document (log, printout, hardcopy) which lists the REFSMMAT's you intended to load. Confirm that the sign and first six digits of each matrix element are identical between the REFSMMAT command display and the source document. This check confirms that the general orientation of the new uplink REFSMMAT load has not changed from the desired orientation (on your source document).

D. NOTIFICATION AND APPROVAL

1. Advise the GNC FCR by DSM number that the load has been built, verified, and ready for uplink.
2. The GNC FCR will verify that the load is correct.
3. The GNC FCR will receive Flight Director approval to perform the uplink. The GNC FCR request to INCO for the uplink command will include a confirmation of Flight Director approval for uplink, the GPC major function destination, and the DSM number of the command.
4. The GNC FCR will monitor the loop until all command actions are completed. INCO will notify the GNC FCR when the actions are completed. The GNC FCR will monitor the Command Tracking display to verify that the correct commands have been executed.

E. VERIFICATION OF UPLINK ONBOARD

1. Record the load number and the time of uplink in the console log. Although the new REFSMMAT's are now onboard, they will not actually be used until an IMU alignment is performed. A star alignment or IMU-to-IMU alignment will incorporate the REFSMMAT's.
2. If the uplink was unsuccessful and erroneous data was received in the desired REFSMMAT slot, the IMU torquing angles generated by a subsequent acceptable star pair would have unusually high values. The GNC should not align the IMUs to such torquing angles and the original REFSMMAT load should be uplinked. If an alignment was performed to erroneous desired REFSMMAT values, the IMU skewing would be undesired and a successful uplink followed by an alignment would be required to achieve the desired entry skewing.
3. After the IMU alignment has been made to update the REFSMMAT's, verify the transition to the new REFSMMAT's on the REFS/ROLLS/QUATS display. Record the time of the transition in the console log and the IMU update log. Save the REFS/ROLLS/QUATS display printout in the IMU update log.

F. TRACKING OF LOADS BUILT

1. REFSMMAT loads are recorded and tracked by GNC. There is no need to save REFSMMAT loads in the Command Server. At present, the initial launch $\sqrt{6}$ load and the normalized REFSMMAT load are the only loads planned for each flight.
2. The final uplinked PASS load, must be uplinked to the BFS in MM 301 prior to entry, if the PASS uplink occurred while the BFS was already in MM 301.

BACKUP PROCEDURES

We generally use offline programs to generate REFSMMAT's for uplink. However, you may have a need to type in a REFSMMAT load from some other source. This procedure describes how to do that.

You will be creating three matrix files, one for each REFSMMAT. For this example, the load you build will be named input (you can pick any name you want). The files you create will be named input.ref1, input.ref2, and input.ref3, and they will contain the REFSMMAT's for IMUs 1, 2, and 3, respectively.

When you enter the elements for a particular matrix, type them in the natural (row, col) order. When you complete each matrix, it will be printed to the screen. (In the following script, these outputs will be shown inside boxes.) Compare the screen output with the matrix you intended to input. If you made an error, simply repeat the procedure for that matrix.

You need to be in the command-line mode to run this procedure. Select the new window option from the DNAV pull down menu, select that window, and follow this script:

```
command> cd /users/gnc/Data/SSPxxx/refs<RETURN>
(utilize the current flight number in xxx, example: 057)
command> mx + =input.ref1 <RETURN>

-.31517798      <RETURN>
.68764865      <RETURN>
.65406513      <RETURN>
.47859961      <RETURN>
-.47996712     <RETURN>          REFSMMAT #1
.73523676      <RETURN>
.81951517      <RETURN>
.54476595      <RETURN>
-.17783326     <RETURN>
```

# Matrix		
-.31517798	.68764865	.65406513
.47859961	-.47996712	.73523676
.81951517	.54476595	-.17783326


```
command> mx + =input.ref2          RETURN>

.78200394      <RETURN>
.14553577      <RETURN>
.60604346      <RETURN>
-.61858183     <RETURN>
.06214468      <RETURN>          REFSMMAT #2
.78325850      <RETURN>
.07632965      <RETURN>
-.98739880     <RETURN>
.13862318      <RETURN>
```

# Matrix		
.78200394	.14553577	.60604346
-.61858183	-.06214468	.78325850
.07632965	-.98739880	.13862318

```
command> mx + =input.ref3<RETURN>

-.22169298     <RETURN>
-.52166295     <RETURN>
.82384408      <RETURN>
.38511485      <RETURN>
.72934437      <RETURN>          REFSMMAT #3
.56545782      <RETURN>
-.89584523     <RETURN>
.44263250      <RETURN>
.03920961      <RETURN>
```

# Matrix		
-.22169298	-.52166295	.82384408
.38511485	.72934437	.56545782
-.89584523	.44263250	.03920961

Once you have checked the data on these screen printouts against your input data, you are ready to begin the nominal REFSLOAD procedure.

For more information on exactly how this backup procedure works, see the documentation on the MX program (SCP 10.7).

REFERENCE

GNC Offline Program REFSLOAD Documentation Folder.

TITLE

ENTREF USER'S GUIDE

PURPOSE

To describe the use of the ENTREF program in creating, editing, viewing, deleting, and printing inertial measurement unit (IMU) reference to stable member matrices (REFSMMAT) files.

BACKGROUND

An easy-to-use tool for manipulating the REFSMMAT files was desired since there are many GNC programs which require the IMU REFSMMAT's as input. ENTREF was created to perform all necessary REFSMMAT operations from one program. ENTREF will allow the flight controller to retrieve, create, edit, view, delete, and print REFSMMAT files.

All REFSMMAT files in the workstation are stored in the "refs" subdirectory of the current flight directory. All GNC programs know to look in this directory to find the files. The REFSMMAT's are stored in separate files, one for each IMU. For example, if the IMU REFSMMAT's at launch are to be stored, the user might wish to give them the name "launch". The actual files would then be created in the "refs" directory as "launch.ref1" for IMU 1, "launch.ref2" for IMU 2, and "launch.ref3" for IMU 3. Throughout the program, you will be prompted to enter a REFSMMAT filename. At these prompts, you should only enter the name of the set of REFSMMATs; i.e., enter "launch" not "launch.ref1".

PROCEDURE

Execute ENTREF from the GNC DNAV MENU, under "Apps". ENTREF will first look for the "refs" subdirectory. It will notify the flight controller and then create one if the "refs" directory is not found. ENTREF will then read the contents of the "refs" directory and display it and the options menu on the screen. The following options are available:

1. Retrieve from telemetry
2. Create a REFSMMAT file
3. View a REFSMMAT file
4. Edit a REFSMMAT file
5. Delete a REFSMMAT file
6. Print a REFSMMAT file
7. Exit

The program now waits for you to select an option.

OPTION 1 - RETRIEVE A REFSMMAT FILE

The program asks you to name the REFSMMAT file it will retrieve from telemetry. Use REFS/Rolls/Quats display to view the REFSMMAT data the program will retrieve. Use Option 3 to see the file after it is retrieved.

OPTION 2- CREATE A REFSMMAT FILE

The program asks for the name of a REFSMMAT file to create. If the file already exists, ENTREF will ask if you wish to overwrite it. If you answer "y", the old file will be deleted and you will be prompted for the new REFSMMATs. If you answer "n", the options menu will be displayed.

When entering the REFSMMAT's, use the following format:

```
element 1,1 <return>
element 1,2 <return>
element 1,3 <return>
element 2,1 <return>
element 2,2 <return>
element 2,3 <return>
element 3,1 <return>
element 3,2 <return>
element 3,3 <return>
```

OPTION 3- VIEW A REFSMMAT FILE

Enter the name of the REFSMMAT file to view and ENTREF will display each REFSMMAT one at a time. Hit return to view the next REFSMMAT.

OPTION 4- EDIT A REFSMMAT FILE

Enter the name of the REFSMMAT's and the IMU number of the one you wish to edit. A warning will be printed cautioning you to not continue unless you are familiar with the VED editor. The following is a list of some useful commands in the VED editor.

position the cursor	Use the four arrow keys.
insert character(s)	Position the cursor where you want to insert the character(s) and type (e.g., to change 124 to 1234, position the cursor over the 4 and type 3).
backspace delete	Press the del key
delete character(s)	Position the cursor on the character you wish to delete and press the delete key followed by the char key (these key are found to the right of the alphanumeric keypad). All characters to the right of the cursor will be moved one space to the left. Repeated depressions of the char key will delete more characters.

exit the editor	Press PF7. You will be prompted with "Write back changes in the file xxxx? (y or n)". This gives you a chance to exit without saving the changes you made.
-----------------	--

Note: A more detailed discussion of the VED editor is covered in the VED Text Editor Reference Manual.

OPTION 5 - DELETE A REFSMMAT FILE

Enter the name of the REFSMMAT files you wish to delete. You will be asked to confirm the deletion before it takes place.

OPTION 6 - PRINT A REFSMMAT FILE

Enter the name of the REFSMMAT file you wish to print. The files will be sent to the laser printer.

OPTION 7 - EXIT

The program will terminate. If ENTREF was started from the GNC MENU, the program will terminate and return to the GNC MENU.

RELATIVE MOC EDTE DISPLAYS

<u>EDTE</u>	<u>TITLE</u>
1602	IMU REFSMMAT

REFERENCES

GNC Off-line Program ENTREF Documentation Folder.

TITLE

GETREFS USER'S GUIDE

PURPOSE

To describe the use of the GETREFS program in copying the IMU REFSMMAT's from telemetry into workstation data files.

BACKGROUND

The IMU Reference to Stable Member Matrices (REFSMMAT's) are used by certain GNC off-line programs to perform IMU operations. In order to facilitate the transfer of the IMU REFSMMAT's (one REFSMMAT per IMU, nine elements per REFSMMAT) from the downlisted telemetry stream to the workstation, the GETREFS program was written. Upon user command, this program will read each REFSMMAT from Data Acquisition (telemetry data) and store it in a user defined file. The three REFSMMAT files are stored in the flight "refs" directory under the names "filename".ref1, "filename".ref2, and "filename".ref3, where "filename" was specified by the user. Along with the REFSMMAT values, a header is written into each file indicating the flight number and the GMT and MET at which the REFSMMAT's were read from telemetry. If valid telemetry data is not available from Data Acquisition, the program will indicate such and terminate execution without creating any files.

PROCEDURE

1. In all current applications, the GETREFS program is called directly by the originating program (such as NREF). Therefore, the user is not required to interface directly with GETREFS and there are no procedures to be followed.
2. If for some reason it is desirable to execute GETREFS manually, the user should open a UNIX shell window and type

```
getrefs "filename"
```

where "filename" is the name of the file in which to store the REFSMMAT's. Program execution will continue without further user interface. Following completion (UNIX prompt returned), the user can locate the REFSMMAT files in the flight "refs" directory.

TITLE

OFF-LINE PROGRAM DOCUMENTATION AND CERTIFICATION GUIDELINES

PURPOSE

To provide guidelines for the GNC flight controller in the documentation and certification of GNC related off-line programs. The GNC flight controller will use these guidelines to "certify for flight use" workstation and PC programs.

BACKGROUND

The GNC flight controller has at his/her disposal many tools to assist in making critical real-time decisions. One tool that has been developed by the GNC flight controller is the off-line program(s). These off-line programs do not reside in the Mission Operations Computer (MOC), rather they are executed on either the workstation or PC's in the office, thus the designation "off-line".

Off-line programs have been developed by the GNC section to perform time-critical and/or time-consuming tasks. The results of these off-line programs are used by the GNC flight controller in making the correct decision or in supplying data pertinent to a particular mission phase (such as OMS engine trim values or orthogonalized REFSMMAT's for uplink). Because of the criticality attached to the off-line programs their results must be correct. If a GNC flight controller uses results that are incorrect, the effect on the Shuttle could be catastrophic. To eliminate the possibility of output error, each off-line program is rigorously tested by the GNC flight controllers. A detailed line by line description of the program is also documented ensuring that a thorough and complete understanding of the program logic is available to the GNC flight controller.

PROCEDURE

A. *WORKSTATION OFF-LINE PROGRAMS*

1. To certify a new off-line program or to modify an existing program a proposal must be submitted to the Software Management Board (SMB). The SMB will either approve or disapprove the proposal. If the proposal is disapproved the SMB will provide to the presenter a written justification for the rejection. The presenter can then:
 - a. Modify the program to remedy the objections and resubmit it,
 - b. Appeal the decision to the Group Lead, or
 - c. Drop the proposal.

If, however, the proposal is approved the SMB will recommend the program and an application programmer (in most cases this programmer would be the program initiator) to the Section Head. The Section Head would then approve the proposal and assign a programmer. This programmer would produce the program or modify it.

2. Once the program has been developed or modified, the application programmer provides to the SMB sample test cases and results sufficient to exercise all branches of the code. The application programmer is also responsible for documenting the program (the extent of the documentation will be discussed later in this SCP). The SMB then assigns to the program two independent testers, individuals who have had no previous contact with the code, and two independent folder reviewers.

These two independent testers use the sample test cases provided to do verification and validation tests on the code. Verification testing entails the assurance and confirmation that the algorithm on which the program is based is technically sound in both substance and application, while validation is described as the assurance that the program fulfills the intent of the requirements for which it was designed. Results can be verified by hand calculation or by comparison to a previously "flight certified" program. The reports of the tests performed and the test results are added to the program folder. If errors are found in testing, the application programmer corrects the problems. The program or modification then starts the certification process over.

3. Once a modification, no matter how minor, is made to a program that has been previously certified, the program must be recertified. Recertification is also required if the program is recompiled on a different operating system or compiler. For operating system upgrades, the SMB is responsible for determining whether recertification is required based on an assessment of upward compatibility.
4. Once the program documentation and certification has been completed, the two independent folder reviewers (normally the testers) inspect the folder. This review is done to ensure that the proper testing has been done and that the documentation is up to the standards specified by the decision. If a documentation discrepancy is found, the folder is returned to the independent tester responsible for the discrepancy.
5. Once the folder has passed the review by the independent reviewers it is presented to the SMB, Section Head, and Branch Chief for their signatures. It is then routed to the Division Software Control Authority (DSCA) for approval.

B. PC OFF-LINE PROGRAMS

The important difference is that the PC programs will only be certified at the Branch level. Once the program has passed the review by the independent testers it is presented to the SMB chairman and the Section Head for their signatures. It is then routed to the Branch Chief for approval.

C. PROGRAM FOLDER

The contents of the program folder will be similar for both workstation and PC programs (except where noted). The program folder will contain a detailed and updated description of all aspects of the program.

There are two folder configurations that are defined. First is the current recommended configuration which is defined in the following outline. The other is the original program folder configuration which has been "grandfathered" (no old program certification folders are required to be updated) which follows the new template.

Either program certification folder template is acceptable. These are suggested templates only. Items required for data files are indicated by a "*" in the new template.

New program folder template:

*1.0 General

- * 1.1 Certification
- * 1.2 Title (include title, author, release data and version number)
- 1.3 Purpose
- * 1.4 Abstract
- 1.5 Background (basis for development)

*2.0 User Interfaces

- 2.1 Hardware Requirements (mouse, floppy, hardcopy, etc.)
- 2.2 Inputs (variables, files, prompts)
- 2.3 Outputs
- 2.4 Special Restrictions

*3.0 User's Guide

4.0 Logic Description

- 4.1 Computational Formulas
- 4.2 Assumption/Constraints
- 4.3 Structural Flow

5.0 Error Handling

- 5.1 Error Presentation and Action or Results
- 5.2 Error Cases

*6.0 Program Interfaces

- 6.1 Inputs
- 6.2 Outputs
- 6.3 Support Functions
- 6.4 Support Libraries
- 6.5 External Programs References
- 6.6 WEX Interfaces
- 6.7 LAN Interfaces

7.0 Source Code

- 7.1 Date, Version Number and Abstract of Each Modification
- 7.2 Compilation and Linking Instructions (makefile)
- * 7.3 Source File Name List and Descriptions
- 7.4 Subroutine/Function Tree (if required)
- 7.5 Variable Definitions
- 7.6 Design Flow Chart (if required)
- * 7.7 Difference Listing Between Previous Version and Current Version of Program's Source Code (if feasible)
- * 7.8 Source Code Listing-(electronic media is acceptable if its storage location is clearly identified)

*8.0 Certification Testing

- 8.1 Example Test Specifications
- 8.2 Individual Test Case #1
- 8.3 Individual Test Case #2
- 8.4 Individual Test Case #3
- 8.5 Individual Test Case #4

8.n Individual Test Case #X

*9.0 Change Record

D. SOURCE CODE COMMENTS

1. Comments in the source code must be included to describe what is being done. There must be enough in-line comments to easily follow the programs execution. In addition, there must also be a header of information at the beginning of the program and all subroutines.
2. The program/subroutine header must include the following information:
 - a. Program/subroutine name
 - b. Abstract of what the routine does (Algorithm)
 - c. External file/variables necessary for execution
 - d. Description of input value(s)
 - e. Description of returned value(s)
 - f. Description of error codes (if any)
 - g. Description of any global variables referenced

The program header must also include the following information:

- a. Compile instructions (if applicable)
- b. Name of original programmer(s)
- c. Current revision level
- d. Date of last revision
- e. Names of programmers who have made modifications

REFERENCE

Mission Operations Directorate Software Management Plan for Workstation Applications, JSC-22766, Jan. 1988.

TITLE

GNC CALLS TO OTHER FCR DISCIPLINES

PURPOSE

The purpose of this SCP is to outline some of the nominal and off-nominal calls which the flight control room (FCR) GNC officer makes to other FCR disciplines during console operations.

GENERAL

During console operations, the FCR GNC officer has the need to communicate with other FCR disciplines during all phases of flight. Communication with other FCR operators is essential to assure a good understanding of the status of different vehicle systems which affect our GNC systems and the way we monitor such systems. This SCP outlines those calls which are considered important when performing nominal procedures or in response to system failures. The calls within this SCP should not be construed as the only calls that should be made since interdiscipline communication is important for a safe flight. It must be pointed out that, in some cases, some nominal calls as well as all off-nominal system performance calls should be made to the Flight Director (FD).

NOMINAL CALLS

The nominal FCR GNC calls are described according to the FCR discipline to which they pertain.

A. *INCO*

GNC will coordinate with the Instrumentation Communication Officer (INCO) any IMU gyro or accelerometer uplinks to the PASS and BFS systems. The INCO officer is responsible for the uplinks once approval from the FD is obtained by GNC.

B. *FDO/TRAJ*

GNC is required to coordinate with FDO concerning the requirement to perform the OMS TVC gimbal checks after any MM-202 OMS burns. The system (primary or secondary) to be tested will be specified on the OMS burn pads.

C. FAO

During Orbit Ops the FAO coordinates all crew activities. For IMU alignments, GNC can obtain from FAO/pointing the stars which will be used for the alignments. Coordination with FAO is required in the event that off-nominal scheduling of the GNC OPS-8 checkout (time permitting) is required by system failures, as well as for any Flight Data File changes required to be made to the D/O Prep and Entry C/L's. Any unplanned attitude maneuvers should be reviewed with FAO to ensure that other disciplines constraints are not violated and to allow them to generate the "as flown" attitude timeline.

OFF-NOMINAL CALLS

The off-nominal FCR GNC calls are described according to the FCR discipline to which they pertain.

A. DPS

GNC will coordinate with DPS the required review of all G-MEM paperwork prior to submittal to the MOIR. This coordination is essential to ensure successful completion of the G-MEM to be implemented by DPS. During all phases of flight, GNC is required to coordinate with the DPS officer any requirement to restring in order to optimize GNC systems or to regain critical LRU redundancy while protecting for the next failure.

B. GPO

During ascent and entry, the guidance and procedures officer (GPO) is responsible for the health of the onboard state vector in both the PASS and BFS system. The onboard state vector is highly dependent on the IMU system. GPO can provide insight into the performance of the IMU's by comparing the onboard state vector to a ground state vector computed based on radar tracking of the Orbiter. GPO should also be informed of any TACAN (or GPS, as applicable) LRU failures during entry.

C. RNDZ

GNC is required to notify the rendezvous officer of failures in the star trackers and COAS systems which may affect rendezvous target tracking.

D. MMACS

During ascent and entry, GNC coordination with MMACS is required for any APU failures or HYD pressure transducers failures which may cause priority rate limiting (PRL) software to take action. Depending on the failure of the system, GNC may be required to take some action in order for the DAP to know exactly the number of good hydraulic systems available.

E. PROP

During all phases of flight, GNC coordination with PROP is necessary to maintain awareness of the jet availability status due to system failures. The PROP officer will manage the PRCS and vernier jet availability; however, GNC is required to ensure that the necessary jets are available to maintain vehicle control.

F. PDRS

Coordination with PDRS is required during RMS operations to ensure that any control system failures do not violate the RMS constraints. For this case, DAP mode changes may be required for vehicle control during RMS operation.

TITLE

INTEGRATED LOAD CHECKOUT TEST PROCEDURE

PURPOSE

Provides a procedure to be used during Integrated Load Checkout (ILC's) of new training loads.

BACKGROUND

Due to the increased frequency of missions, ILC's have become the primary means of detecting and reporting Trajectory Server, Data Acquisition, Front End Processor (FEP), Local Area Network (LAN), Information Sharing Protocol (ISP) and Shuttle Mission Simulator (SMS) problems. Recent experience has shown that unless problems are reported during the ILC, the probability of getting the anomaly corrected is near zero. The following procedure is designed to aid the console operator and help ensure that any problems are identified.

General things for all positions to watch for:

- Nominal data look reasonable
- Displays, CRANS, ELOG, and RTPLOT formats that have been modified
- Any parameters that have changed for possible effects
- Be aware of any console hardware effects on operations
- Document any problems

PROCEDURES

GNC CONSOLE

A. PRELAUNCH

1. Set up the console for prelaunch.
2. Monitor the Control Ascent, Sensors Prelaunch, and Sensors Ascent/Entry displays.
3. Do the IMU comps start? Can limit sets be changed? Verify comm loops.
4. Cycle through the displays to ensure they are in the system and data are properly displayed.
5. Verify all ascent comps are running.

B. ASCENT

1. Monitor the Control Ascent and Sensors Ascent/Entry displays, checking for reasonable values.
2. Start the IMU radar comps from the PBI_MOC_COMP application at lift-off.
3. At SRB sep, again, check for reasonable values on the displays.
4. If the Sensors and Control RTPLOTS are loaded, start the plots and ensure the plots work correctly.
5. At MECO check the displayed burn attitude for accuracy and pay particular attention to the OMS data.

C. ORBIT

1. Set up the console for orbit operations.
2. Monitor the GNC Orbit Display.
3. Verify that all orbit comps are running.
4. Start the IMU comps.
5. Start Sensors and Control plots (if loaded).
6. Check the comm panel thoroughly to insure talk ability on all assigned loops. Make sure they are balanced (e.g., one loop doesn't drown out the rest).
7. Before SIM, ask the Flight Director for an IMU alignment. Check the star table for good data and check the star tracker data for reasonable values.
8. Before SIM, ask the Flight Director for an OMS burn. Check the OMS data, including burn attitude, TIG, TGO, etc.
9. During OPS 201, monitor universal pointing maneuvers, tracks, etc., and DAP performance for reasonableness.
10. Cycle through the displays to verify they are there and data are correctly displayed.

D. ENTRY

1. Set up the console for entry operations.
2. Check that the TACAN timetag is correct in the Trajectory Server via the Sensors Prelaunch display or ISP UDD.
3. Verify that all entry comps are running.
4. Monitor the Control Entry and Sensors Ascent/Entry displays.

5. Start the IMU comps.
6. At M = 7, check for good TACAN data. (Typically, TACAN 1 locks on late at about M = 6.)
7. Probes deploy at M = 5. Check for SPEC 51 and good data. Plots okay?
8. MLS data at 18,000 ft. Good data? Plots?
9. Radar altimeters at 5,000 ft. Good data? Plots?
10. Good radar data on all comps?

CONTROL CONSOLE

A. PRELAUNCH

1. Set up the console for prelaunch
2. Verify all ascent comps are running.
3. Monitor the Control Ascent display. Check for reasonable data. Main engines, SRB's, OMS, and aerosurfaces in proper configuration? Hydraulics okay?

B. ASCENT

1. Configure the console for ascent.
2. Monitor displays for reasonable data throughout ascent.
3. Good maneuver to the proper burn attitude?
4. Did the gimbals look good?

C. ORBIT

1. Configure console for orbit operations.
2. Monitor the GNC Orbit display for reasonable data (universal pointing, ADI, DAP, controllers, variable parameters, OMSTVC, and guidance values during OPS 202).
3. Pay close attention to any parts that have been changed.
4. Cycle through the history tabs and RTPLOT as well as any special displays (i.e., any displays built specifically for that flight).

D. ENTRY

1. Configure the console for entry.
2. Verify that all entry comps are running.
3. Check the Control Entry display for reasonable values.

4. Watch for any Orbiter software funnies.
5. Watch postlanding for correct behavior.
6. Document any problems.

SENSORS CONSOLE

A. ASCENT

1. Configure the console for ascent.
2. Verify that all ascent comps are running.
3. Call up the Sensors Prelaunch, Sensors Ascent/Entry and IMU Summary displays and verify reasonable values.
4. Check the REFSMMAT's (roll to rolls, etc.).
5. Check the ground reference data (radar plots).
6. Verify the TACAN timetag in the Trajectory Server via the Sensors Prelaunch display or ISP UDD.

B. ENTRY

1. Verify that all entry comps are running.
2. Configure console for entry.
3. Check TACAN timetag in the Trajectory Server via the Sensors Prelaunch display or ISP UDD.
4. Monitor for nominal entry activities (e.g., probes deploy at M = 5).
5. Check displays and RTPLOT for reasonable data.

TITLE

Pre-Flight Orbit DAP Table Build Process

PURPOSE

To define the process by which the flight specific orbit DAP tables shall be built for submittal to the appropriate book manager.

PROCEDURE

The flight specific DAP tables are normally a combination of I-load and crew modified values to meet specific mission requirements. First, the I-loads are acquired and then manually edited to support the specific mission objectives. Multiple sources of DAP parameters are available and generally include, but are not limited to; Draper Laboratory, payload customer(s), and G&C or other flight control discipline requirements.

A. ACQUIRE DAP TABLE I-LOAD VALUES FROM FLIGHT SOFTWARE CD

1. Retrieve the appropriate Flight Software CD from the DF3/Data Systems Branch office. This will require a sign-out to remove the CD.
2. Open the I-load report on the CD.
 - a. Start > MOD Server Menu > MOD-Wide Applications > DXR
 - b. File > Open > {CD volume ID} > PASS > ILDMPRPT.DAT
3. Perform four searches and Export each of the search results to a text file, appending each subsequent search to the same text file.

Perform four searches with the MSID ranges identified below in this step.

Search > Index Search F4
MSID >= {desired MSID start value}
MSID <= {desired MSID end value}

In the Search results window select:

Export > "General" tab > provide {desired path}\{filename.txt}
Note: It is helpful for Excel to use '.txt' extension
Example filename: {CD volume ID}_i-load.txt
Export Type: select "Text"
Pages to Export: select "Search Results"

For the 2nd, 3rd, and 4th search:

"Text" Tab > select "Append to file"

A sample of the text file is shown in Figure 11.3-1.

The four search ranges are:

Note: Ignore the following error message you may get each time you execute the Export: 'Unable to load '.jtb.'

- a. Msid >= V98U7275C
Msid <= V98U7364C
- b. Msid >= V98U7388C
Msid <= V98U7432C
- c. Msid >= V98U7435C
Msid <= V98U7629C
- d. Msid >= V98U7670C
Msid <= V98U7909C

4. Save selected text to Excel file

- a. Start Excel and Open the text file generated in the previous step. Expect the "Text Import Wizard" window to be displayed.
- b. For "Original data type" select the "Fixed width" option. Then proceed with the "Next >" button.
- c. In the "Data preview" window, scroll down to the 8th & 9th lines of text and place (move, add, delete) the column delimiters in the I-load header at the points indicated in figure 11.3-2. Then proceed with the "Next >" button.
- d. In the "Column data format" window, configure the columns as indicated:
Column 1: select "General"
Column 2: select "General"
Column 3: select "Do not import column (skip)"
Column 4: select "General"
Column 5: select "General"
Column 6 (and any subsequent columns): select "Do not import column (skip)"
Then proceed with the "Finish >" button.
- e. Increase the widths of column A & B to see the MSID and FSSR Name.
Note: The file will still contain several rows of extraneous data that will be removed in the next step. See figure 11.3-3 for sample of imported Excel data.
- f. Save the file (File > Save As) as an Excel file type extension (.xls).

B. PROCESS I-LOAD DATA WITH MACROS AND CONFIGURE TEMPLATE FILE

1. Configure excel file to run macro.

- a. Copy the DAP I-LOAD template Excel file
"S:\Divisions\DF\Private\DF62\SCP_11-3_DAP_Table\dapiload_Template.xls" to your local hard drive.

Recommendation: Rename with STS flight ID, ex. "dapiload_Template_114.xls"

- b. Open the local DAP I-LOAD template Excel file and "Enable Macros".
- c. Place markers in datafile for macro usage.
 - i. Open (or select) the datafile saved in step A.4.f above.
 - ii. In cell A1, enter the text "V98U".
 - iii. In cell B1, enter the text "STOP".
 - iv. At the end of the data for the last MSID, in the column A cell, enter the text "STOP". (Perform a search on V98U7909C to simplify this task, it will get within a few lines of the end of the data.)

Note: The macro you will run uses this information to select to appropriate data and stop running at the end of the data.

2. Run macro

- a. Place cursor at cell A2.
- b. Run macro via:
 - Tools > Macro > Macros...
 - Select: 'dapiload_Template.xls!config_dap_iloads'
 - Select: "Run"

Figure 11.3-4 shows an example of the datafile after running the macro.

3. Perform final editing of duplicate and extraneous records in the datafile.

Note: This is because each group of MSIDs in the searches did not start at the top or stop at the bottom of a page in the I-Load report.

- a. Leaving the first row (A1= V98U, B1=STOP), delete all rows of MSIDs prior to the first DAP I-Load MSID V98U7275C in column A.
- b. Delete the duplicate records between the following MSIDs:

Note: It is possible that there are no records to delete. This would be due to a random chance of MSIDs ending at the bottom and/or top of a page when the text file was generated from the search function in step A.3.

Note: There should be less than 10 records (rows) to delete for each of the following.

- i. first record of V98U7364C and the second record of V98U7388C
- ii. first record of V98U7432C and the second record of V98U7435C

- iii. first record of V98U7629C and the second record of V98U7670C
 - c. This should leave records with V98U7275C in row 2 and V98U7909C in row 571.
4. Mark data to copy from datafile.
 - a. Copy data from cell range7 A2:F571
 - i. Place cursor in A2
 - ii. Select: Edit > GoTo... (Ctrl + G)
In "Reference" field, enter 'F571'
While holding down Shift key:
select "OK"
 - iii. Copy: Edit > Copy (Ctrl + C)
 5. Copy data to template file.
 - a. Open (or select) the Template file
 - b. Place cursor in cell A2 of "iload_input" sheet
 - c. Paste: Edit > Paste (Ctrl + V)

Note: The file "dapiload_Template.xls" should now have all sheets populated with I-load values for all A & B DAPs. (View sheets: A1-A8, A9-A15, B1-B8, B9-B15)

6. Update cell B1 of sheets A1-A8, A9-A15, B1-B8 & B9-B15 with the STS flight number.
Figure 11.3-5 shows an example of DAPs A1-A8 after pasting the edited I-load data.
7. Save the file

C. UPDATE DAP I-LOAD DATA WITH FLIGHT SPECIFIC EDITS

1. Copy DAP I-LOAD file (ex. "dapiload_Template_114.xls") to a new FDF DAP Table file for submission to the appropriate book manager (ex. "FDF_DAP_table_114.xls").
2. Open the FDF DAP Table file just created.
3. From the flight specific resources and requirements (Draper Laboratory, payload customer(s), and G&C or other flight control discipline requirements, etc.) update the DAP parameters as required. I-load parameters that are updated shall be changed to bold & italic font.
4. At the bottom of each DAP column, update the purpose for each DAP as required. Do not change to bold & italic font,
5. At the top of each DAP page, update the title with the flight specific ID and delete the reference to "I-LOAD" at the end of the title.

6. Copy the DAP overview Excel file
“S:\Divisions\DF\Private\DF62\SCP_11-3_DAP_Table\DAP_overview.xls” to your local hard drive. Example: Name the file with the STS flight ID: DAP_overview_xxx.xls
7. Edit the DAP overview section as required for mission specific DAP nomenclature. The UNIV PTG section should not require updating.

Figure 11.3-6 shows an example of the DAP and UNIV PTG overview page.

8. Save the DAP overview file.

D. SUBMIT DAP TABLES

1. Protect the DAP overview and DAP tables.

Excel: Tools > Protection > Protect Workbook, Select “Structure” and provide a password.

Note: Record the password in a safe place, or leave an additional unprotected copy on your hard drive in addition to the protected copy.

2. Submit the completed DAP & UNIV PTG overview and FDF DAP Table protected files to the Orb Ops FS book manger via normal channels based on flight planning phase and configuration control (email, DN, or 482).

NOTE: For STS-114, submit to the Lead FAO for incorporation into the Flight Plan.

3. >>

1109

*** MSID MAPPING - OF030201 *** REPORT #1
MSID DATA BASE NUMBER IS 0003 MSID DATA BASE TITLE IS
HAL DATA BASE NUMBER IS HAL DATA BASE TITLE IS

MSID	FSW NAME	FF	UOC	MSVAL-HEX	MC	VALUE	UUNITS	DT	FR
MSID	FSW NAME	FF	UOC	MSVAL-HEX	MC	VALUE	UUNITS	DT	FR
UC ONQ	DER EQ						CVSL-HEX		

09807162C	MSMF_DILEM_FAS33_CNT_LT	>C4.91>DC000825			00	+6	NO	I	3
	CGRS_DILEMMA_CTR_LIMIT			6E8_FC3_FH_6H			NO	I	3
4	23 3423	562A1 3E1 39173 3				+6	0006		
5	26 4841	52108 305 38B45 3				+6	0006		
6	27 3203	57513 131 39097 3				+6	0006		
7	24 739	50630 227 386F7 3				+6	0006		

09807275C	TABLE_ALT_DELAY_TIME(1,1)	>C5.8>DC004402			00	+0.0E+00	SEC	F	3
	CCV_DAP_TBL_FPM_CFC3_ALT_DELAY_TIMES(01)	CFC_MF_REMOTE				0.0	00000000		
3	10 32	33621 32 3034E 0.0					00000000		

09807276C	TABLE_ALT_DELAY_TIME(2,1)	>C5.8>DC004402			00	+0.0E+00	SEC	F	3
	CCV_DAP_TBL_FPM_CFC3_ALT_DELAY_TIMES(02)	CFC_MF_REMOTE				0.0	00000000		
3	10 66	33621 66 30364 0.0					00000000		

09807277C	TABLE_ALT_DELAY_TIME(3,1)	>C5.8>DC004402			00	+0.0E+00	SEC	F	3
	CCV_DAP_TBL_FPM_CFC3_ALT_DELAY_TIMES(03)	CFC_MF_REMOTE				0.0	00000000		
3	10 100	33621 100 30386 0.0					00000000		

09807278C	TABLE_ALT_DELAY_TIME(4,1)	>C5.8>DC004402			00	+0.0E+00	SEC	F	3
	CCV_DAP_TBL_FPM_CFC3_ALT_DELAY_TIMES(04)	CFC_MF_REMOTE				0.0	00000000		
3	10 134	33621 134 30386 0.0					00000000		

09807279C	TABLE_ALT_DELAY_TIME(5,1)	>C5.8>DC004402			00	+0.0E+00	SEC	F	3
	CCV_DAP_TBL_FPM_CFC3_ALT_DELAY_TIMES(05)	CFC_MF_REMOTE				0.0	00000000		
3	10 168	33621 168 303CA 0.0					00000000		

09807280C	TABLE_ALT_DELAY_TIME(6,1)	>C5.8>DC004402			00	+0.0E+00	SEC	F	3
	CCV_DAP_TBL_FPM_CFC3_ALT_DELAY_TIMES(06)	CFC_MF_REMOTE				0.0	00000000		
3	10 202	33621 202 303EC 0.0					00000000		

Figure 11.3-1, Sample portion of text file after MSID search from FSW CD (step A.3)

Column 1 Import	Column 2 import	Column 3 do not import	Column 4 import	Column 5 import	Column 6 do not import
MS ID	FSR NAME	EF	MC	ITEM UNITS	DT PR
REL NAME		UOC	VALUE		DT PR
			ELOCK		

↓ leave 3 spaces

Figure 11.3-2, Column formatting of text DAP I-load data for Excel import (step A.4.c)

Row	Column A	Column B	Column C	Column D	Column E	Column F	Column G	Column H	Column I	Column J	Column K
1											
2											
3											
4			*** REPORT #								
5		MSID	SID DATA BASE TITLE IS								
6		HAL DATA BASE N	TITLE IS								
7		FSSR NAME	VALUE UNITS								
8		HAL NAME	BLOCK IBM UNITS								
9		PH LB OFFSE	CVAL HEX								
10											
11											
12											
13											
14											
15		MANIF_DILEM_PASS_COUNT_LT	6 ND								
16		A_CTR_LIMIT	ND								
17		56911 361 39173 3	6								
18		52108 306 39146 3	6								
19		57613 131 39097 3	6								
20		50630 227 39677 3	6								
21											
22											
23											
24		TABLE_ALT_DELAY_TIME(1)	0.00E+00 SEC								
25		L_PRIM_CGGS_ALT_DELAY_TIMES	SEC								
26		33631 32 30342 0 0	0								
27											
28											
29											
30		TABLE_ALT_DELAY_TIME(2)	0.00E+00 SEC								
31		L_PRIM_CGGS_ALT_DELAY_TIMES	SEC								
32		33631 66 30364 0 0	0								

Figure 11.3-3, Sample of imported Excel data (step A.4.e)

A	B	C	D	E	F	G	H	I	J	K
1	V68U	STOP								
2	V68U7162C	MANF_DILEM_PASS_COUNT	6 ND	6	6					
3	V68U7275C	TABLE_ALT_DELAY_TIME(1,1)	0.00E+00 SEC	0	0					
4	V68U7276C	TABLE_ALT_DELAY_TIME(2,1)	0.00E+00 SEC	0	0					
5	V68U7277C	TABLE_ALT_DELAY_TIME(3,1)	0.00E+00 SEC	0	0					
6	V68U7278C	TABLE_ALT_DELAY_TIME(4,1)	0.00E+00 SEC	0	0					
7	V68U7279C	TABLE_ALT_DELAY_TIME(5,1)	0.00E+00 SEC	0	0					
8	V68U7280C	TABLE_ALT_DELAY_TIME(6,1)	0.00E+00 SEC	0	0					
9	V68U7281C	TABLE_ALT_DELAY_TIME(7,1)	0.00E+00 SEC	0	0					
10	V68U7282C	TABLE_ALT_DELAY_TIME(8,1)	0.00E+00 SEC	0	0					
11	V68U7283C	TABLE_ALT_DELAY_TIME(9,1)	0.00E+00 SEC	0	0					
12	V68U7284C	TABLE_ALT_DELAY_TIME(10,1)	0.00E+00 SEC	0	0					
13	V68U7285C	TABLE_ALT_DELAY_TIME(11,1)	0.00E+00 SEC	0	0					
14	V68U7286C	TABLE_ALT_DELAY_TIME(12,1)	0.00E+00 SEC	0	0					
15	V68U7287C	TABLE_ALT_DELAY_TIME(13,1)	0.00E+00 SEC	0	0					
16	V68U7288C	TABLE_ALT_DELAY_TIME(14,1)	0.00E+00 SEC	0	0					
17	V68U7289C	TABLE_ALT_DELAY_TIME(15,1)	0.00E+00 SEC	0	0					
18	V68U7290C	TABLE_ALT_DELAY_TIME(1,2)	0.00E+00 SEC	0	0					
19	V68U7291C	TABLE_ALT_DELAY_TIME(2,2)	0.00E+00 SEC	0	0					
20	V68U7292C	TABLE_ALT_DELAY_TIME(3,2)	0.00E+00 SEC	0	0					
21	V68U7293C	TABLE_ALT_DELAY_TIME(4,2)	0.00E+00 SEC	0	0					
22	V68U7294C	TABLE_ALT_DELAY_TIME(5,2)	0.00E+00 SEC	0	0					
23	V68U7295C	TABLE_ALT_DELAY_TIME(6,2)	0.00E+00 SEC	0	0					
24	V68U7296C	TABLE_ALT_DELAY_TIME(7,2)	0.00E+00 SEC	0	0					
25	V68U7297C	TABLE_ALT_DELAY_TIME(8,2)	0.00E+00 SEC	0	0					
26	V68U7298C	TABLE_ALT_DELAY_TIME(9,2)	0.00E+00 SEC	0	0					
27	V68U7299C	TABLE_ALT_DELAY_TIME(10,2)	0.00E+00 SEC	0	0					
28	V68U7300C	TABLE_ALT_DELAY_TIME(11,2)	0.00E+00 SEC	0	0					
29	V68U7301C	TABLE_ALT_DELAY_TIME(12,2)	0.00E+00 SEC	0	0					
30	V68U7302C	TABLE_ALT_DELAY_TIME(13,2)	0.00E+00 SEC	0	0					
31	V68U7303C	TABLE_ALT_DELAY_TIME(14,2)	0.00E+00 SEC	0	0					
32	V68U7304C	TABLE_ALT_DELAY_TIME(15,2)	0.00E+00 SEC	0	0					

Figure 11.3-4, Example of the datafile after running the macro (step B.2.b)

	A1	A2	A3	A4	A5	A6	A7	A8
1	STS-114 DAP A1-A8 CONFIGURATIONS I-LOADS							
2	ITEM#							
3								
4	PRI							
5	ROTRATE	0.4000	0.2000	0.5000	0.2000	0.2000	0.2000	0.0500
6	ATT DB	1.00	0.30	3.00	5.00	5.00	2.00	2.00
7	RATEDB	0.20	0.20	0.20	0.20	0.20	0.20	0.20
8	ROTPLS	0.100	0.100	0.100	0.100	0.100	0.100	0.100
9	COMP	.000	.000	.000	.000	.000	.000	.000
10	POPTION	ALL	ALL	ALL	ALL	ALL	ALL	ALL
11	YOPTION	ALL	TAIL	ALL	ALL	TAIL	ALL	ALL
12	TRANPLS	0.100	0.100	0.100	0.100	0.100	0.100	0.100
13	ALT							
14	RATE DB	0.200	0.070	0.200	0.070	0.070	0.100	0.100
15	JETOPT	ALL	ALL	ALL	ALL	TAIL	ALL	ALL
16	# JETS	2	2	2	1	1	2	2
17	DN TIME	0.08	0.08	0.08	0.08	0.08	0.08	0.08
18	DELAY	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	VERN							
20	ROTRATE	0.2000	0.4000	0.0080	0.2000	0.0500	0.0180	0.0500
21	ATT DB	1.000	1.000	0.070	1.000	1.000	1.000	1.000
22	RATEDB	.020	.020	.010	.020	.020	.020	.020
23	ROTPLS	0.010	0.010	0.010	0.010	0.010	0.010	0.050
24	COMP	.000	.000	.000	.000	.000	.000	.000
25	DN TLACC	0	0	0	0	0	0	0
26	PURPOSE	NOMINAL	FTC	GG	PRE/POST DEPLOY	LOSS OF VERN (ALL)	LOSS OF VERN (TAIL ONLY)	TERMINAL PHASE
27								
28								
29								
30								
31								
32								

Figure 11.3-5, Example of DAPs A1-A8 after pasting the edited I-load data.

D. BACKUP DATA

MSID	FSSR Name	Corresponding DAP Table Parameter			
		A/B	#	Mode	Nomenclature
V98U7275C	TABLE_ALT_DELAY_TIME(1,1)	A	1	ALT	Delay
V98U7276C	TABLE_ALT_DELAY_TIME(2,1)	A	2	ALT	Delay
V98U7277C	TABLE_ALT_DELAY_TIME(3,1)	A	3	ALT	Delay
V98U7278C	TABLE_ALT_DELAY_TIME(4,1)	A	4	ALT	Delay
V98U7279C	TABLE_ALT_DELAY_TIME(5,1)	A	5	ALT	Delay
V98U7280C	TABLE_ALT_DELAY_TIME(6,1)	A	6	ALT	Delay
V98U7281C	TABLE_ALT_DELAY_TIME(7,1)	A	7	ALT	Delay
V98U7282C	TABLE_ALT_DELAY_TIME(8,1)	A	8	ALT	Delay
V98U7283C	TABLE_ALT_DELAY_TIME(9,1)	A	9	ALT	Delay
V98U7284C	TABLE_ALT_DELAY_TIME(10,1)	A	10	ALT	Delay
V98U7285C	TABLE_ALT_DELAY_TIME(11,1)	A	11	ALT	Delay
V98U7286C	TABLE_ALT_DELAY_TIME(12,1)	A	12	ALT	Delay
V98U7287C	TABLE_ALT_DELAY_TIME(13,1)	A	13	ALT	Delay
V98U7288C	TABLE_ALT_DELAY_TIME(14,1)	A	14	ALT	Delay
V98U7289C	TABLE_ALT_DELAY_TIME(15,1)	A	15	ALT	Delay
V98U7290C	TABLE_ALT_DELAY_TIME(1,2)	B	1	ALT	Delay
V98U7291C	TABLE_ALT_DELAY_TIME(2,2)	B	2	ALT	Delay
V98U7292C	TABLE_ALT_DELAY_TIME(3,2)	B	3	ALT	Delay
V98U7293C	TABLE_ALT_DELAY_TIME(4,2)	B	4	ALT	Delay
V98U7294C	TABLE_ALT_DELAY_TIME(5,2)	B	5	ALT	Delay
V98U7295C	TABLE_ALT_DELAY_TIME(6,2)	B	6	ALT	Delay
V98U7296C	TABLE_ALT_DELAY_TIME(7,2)	B	7	ALT	Delay
V98U7297C	TABLE_ALT_DELAY_TIME(8,2)	B	8	ALT	Delay
V98U7298C	TABLE_ALT_DELAY_TIME(9,2)	B	9	ALT	Delay
V98U7299C	TABLE_ALT_DELAY_TIME(10,2)	B	10	ALT	Delay
V98U7300C	TABLE_ALT_DELAY_TIME(11,2)	B	11	ALT	Delay
V98U7301C	TABLE_ALT_DELAY_TIME(12,2)	B	12	ALT	Delay
V98U7302C	TABLE_ALT_DELAY_TIME(13,2)	B	13	ALT	Delay
V98U7303C	TABLE_ALT_DELAY_TIME(14,2)	B	14	ALT	Delay
V98U7304C	TABLE_ALT_DELAY_TIME(15,2)	B	15	ALT	Delay
V98U7305C	TABLE_ALT_JET_OPTION(1,1)	A	1	ALT	Jet Option
V98U7306C	TABLE_ALT_JET_OPTION(2,1)	A	2	ALT	Jet Option
V98U7307C	TABLE_ALT_JET_OPTION(3,1)	A	3	ALT	Jet Option
V98U7308C	TABLE_ALT_JET_OPTION(4,1)	A	4	ALT	Jet Option
V98U7309C	TABLE_ALT_JET_OPTION(5,1)	A	5	ALT	Jet Option
V98U7310C	TABLE_ALT_JET_OPTION(6,1)	A	6	ALT	Jet Option
V98U7311C	TABLE_ALT_JET_OPTION(7,1)	A	7	ALT	Jet Option
V98U7312C	TABLE_ALT_JET_OPTION(8,1)	A	8	ALT	Jet Option
V98U7313C	TABLE_ALT_JET_OPTION(9,1)	A	9	ALT	Jet Option
V98U7314C	TABLE_ALT_JET_OPTION(10,1)	A	10	ALT	Jet Option
V98U7315C	TABLE_ALT_JET_OPTION(11,1)	A	11	ALT	Jet Option
V98U7316C	TABLE_ALT_JET_OPTION(12,1)	A	12	ALT	Jet Option
V98U7317C	TABLE_ALT_JET_OPTION(13,1)	A	13	ALT	Jet Option
V98U7318C	TABLE_ALT_JET_OPTION(14,1)	A	14	ALT	Jet Option
V98U7319C	TABLE_ALT_JET_OPTION(15,1)	A	15	ALT	Jet Option

MSID	FSSR Name	Corresponding DAP Table Parameter			
		A/B	#	Mode	Nomenclature
V98U7320C	TABLE_ALT_JET_OPTION(1,2)	B	1	ALT	Jet Option
V98U7321C	TABLE_ALT_JET_OPTION(2,2)	B	2	ALT	Jet Option
V98U7322C	TABLE_ALT_JET_OPTION(3,2)	B	3	ALT	Jet Option
V98U7323C	TABLE_ALT_JET_OPTION(4,2)	B	4	ALT	Jet Option
V98U7324C	TABLE_ALT_JET_OPTION(5,2)	B	5	ALT	Jet Option
V98U7325C	TABLE_ALT_JET_OPTION(6,2)	B	6	ALT	Jet Option
V98U7326C	TABLE_ALT_JET_OPTION(7,2)	B	7	ALT	Jet Option
V98U7327C	TABLE_ALT_JET_OPTION(8,2)	B	8	ALT	Jet Option
V98U7328C	TABLE_ALT_JET_OPTION(9,2)	B	9	ALT	Jet Option
V98U7329C	TABLE_ALT_JET_OPTION(10,2)	B	10	ALT	Jet Option
V98U7330C	TABLE_ALT_JET_OPTION(11,2)	B	11	ALT	Jet Option
V98U7331C	TABLE_ALT_JET_OPTION(12,2)	B	12	ALT	Jet Option
V98U7332C	TABLE_ALT_JET_OPTION(13,2)	B	13	ALT	Jet Option
V98U7333C	TABLE_ALT_JET_OPTION(14,2)	B	14	ALT	Jet Option
V98U7334C	TABLE_ALT_JET_OPTION(15,2)	B	15	ALT	Jet Option
V98U7335C	TABLE_ALT_MAX_JETS(1,1)	A	1	ALT	# Jets
V98U7336C	TABLE_ALT_MAX_JETS(2,1)	A	2	ALT	# Jets
V98U7337C	TABLE_ALT_MAX_JETS(3,1)	A	3	ALT	# Jets
V98U7338C	TABLE_ALT_MAX_JETS(4,1)	A	4	ALT	# Jets
V98U7339C	TABLE_ALT_MAX_JETS(5,1)	A	5	ALT	# Jets
V98U7340C	TABLE_ALT_MAX_JETS(6,1)	A	6	ALT	# Jets
V98U7341C	TABLE_ALT_MAX_JETS(7,1)	A	7	ALT	# Jets
V98U7342C	TABLE_ALT_MAX_JETS(8,1)	A	8	ALT	# Jets
V98U7343C	TABLE_ALT_MAX_JETS(9,1)	A	9	ALT	# Jets
V98U7344C	TABLE_ALT_MAX_JETS(10,1)	A	10	ALT	# Jets
V98U7345C	TABLE_ALT_MAX_JETS(11,1)	A	11	ALT	# Jets
V98U7346C	TABLE_ALT_MAX_JETS(12,1)	A	12	ALT	# Jets
V98U7347C	TABLE_ALT_MAX_JETS(13,1)	A	13	ALT	# Jets
V98U7348C	TABLE_ALT_MAX_JETS(14,1)	A	14	ALT	# Jets
V98U7349C	TABLE_ALT_MAX_JETS(15,1)	A	15	ALT	# Jets
V98U7350C	TABLE_ALT_MAX_JETS(1,2)	B	1	ALT	# Jets
V98U7351C	TABLE_ALT_MAX_JETS(2,2)	B	2	ALT	# Jets
V98U7352C	TABLE_ALT_MAX_JETS(3,2)	B	3	ALT	# Jets
V98U7353C	TABLE_ALT_MAX_JETS(4,2)	B	4	ALT	# Jets
V98U7354C	TABLE_ALT_MAX_JETS(5,2)	B	5	ALT	# Jets
V98U7355C	TABLE_ALT_MAX_JETS(6,2)	B	6	ALT	# Jets
V98U7356C	TABLE_ALT_MAX_JETS(7,2)	B	7	ALT	# Jets
V98U7357C	TABLE_ALT_MAX_JETS(8,2)	B	8	ALT	# Jets
V98U7358C	TABLE_ALT_MAX_JETS(9,2)	B	9	ALT	# Jets
V98U7359C	TABLE_ALT_MAX_JETS(10,2)	B	10	ALT	# Jets
V98U7360C	TABLE_ALT_MAX_JETS(11,2)	B	11	ALT	# Jets
V98U7361C	TABLE_ALT_MAX_JETS(12,2)	B	12	ALT	# Jets
V98U7362C	TABLE_ALT_MAX_JETS(13,2)	B	13	ALT	# Jets
V98U7363C	TABLE_ALT_MAX_JETS(14,2)	B	14	ALT	# Jets
V98U7364C	TABLE_ALT_MAX_JETS(15,2)	B	15	ALT	# Jets

MSID	FSSR Name	Corresponding DAP Table Parameter			
		A/B	#	Mode	Nomenclature
V98U7388C	TABLE_ALT_ON_TIME(1,1)	A	1	ALT	On Time
V98U7389C	TABLE_ALT_ON_TIME(2,1)	A	2	ALT	On Time
V98U7390C	TABLE_ALT_ON_TIME(3,1)	A	3	ALT	On Time
V98U7391C	TABLE_ALT_ON_TIME(4,1)	A	4	ALT	On Time
V98U7392C	TABLE_ALT_ON_TIME(5,1)	A	5	ALT	On Time
V98U7393C	TABLE_ALT_ON_TIME(6,1)	A	6	ALT	On Time
V98U7394C	TABLE_ALT_ON_TIME(7,1)	A	7	ALT	On Time
V98U7395C	TABLE_ALT_ON_TIME(8,1)	A	8	ALT	On Time
V98U7396C	TABLE_ALT_ON_TIME(9,1)	A	9	ALT	On Time
V98U7397C	TABLE_ALT_ON_TIME(10,1)	A	10	ALT	On Time
V98U7398C	TABLE_ALT_ON_TIME(11,1)	A	11	ALT	On Time
V98U7399C	TABLE_ALT_ON_TIME(12,1)	A	12	ALT	On Time
V98U7400C	TABLE_ALT_ON_TIME(13,1)	A	13	ALT	On Time
V98U7401C	TABLE_ALT_ON_TIME(14,1)	A	14	ALT	On Time
V98U7402C	TABLE_ALT_ON_TIME(15,1)	A	15	ALT	On Time
V98U7403C	TABLE_ALT_ON_TIME(1,2)	B	1	ALT	On Time
V98U7404C	TABLE_ALT_ON_TIME(2,2)	B	2	ALT	On Time
V98U7405C	TABLE_ALT_ON_TIME(3,2)	B	3	ALT	On Time
V98U7406C	TABLE_ALT_ON_TIME(4,2)	B	4	ALT	On Time
V98U7407C	TABLE_ALT_ON_TIME(5,2)	B	5	ALT	On Time
V98U7408C	TABLE_ALT_ON_TIME(6,2)	B	6	ALT	On Time
V98U7409C	TABLE_ALT_ON_TIME(7,2)	B	7	ALT	On Time
V98U7410C	TABLE_ALT_ON_TIME(8,2)	B	8	ALT	On Time
V98U7411C	TABLE_ALT_ON_TIME(9,2)	B	9	ALT	On Time
V98U7412C	TABLE_ALT_ON_TIME(10,2)	B	10	ALT	On Time
V98U7413C	TABLE_ALT_ON_TIME(11,2)	B	11	ALT	On Time
V98U7414C	TABLE_ALT_ON_TIME(12,2)	B	12	ALT	On Time
V98U7415C	TABLE_ALT_ON_TIME(13,2)	B	13	ALT	On Time
V98U7416C	TABLE_ALT_ON_TIME(14,2)	B	14	ALT	On Time
V98U7417C	TABLE_ALT_ON_TIME(15,2)	B	15	ALT	On Time
V98U7418C	TABLE_ALT_RATE_LIMIT(1,1)	A	1	ALT	Rate Deadband
V98U7419C	TABLE_ALT_RATE_LIMIT(2,1)	A	2	ALT	Rate Deadband
V98U7420C	TABLE_ALT_RATE_LIMIT(3,1)	A	3	ALT	Rate Deadband
V98U7421C	TABLE_ALT_RATE_LIMIT(4,1)	A	4	ALT	Rate Deadband
V98U7422C	TABLE_ALT_RATE_LIMIT(5,1)	A	5	ALT	Rate Deadband
V98U7423C	TABLE_ALT_RATE_LIMIT(6,1)	A	6	ALT	Rate Deadband
V98U7424C	TABLE_ALT_RATE_LIMIT(7,1)	A	7	ALT	Rate Deadband
V98U7425C	TABLE_ALT_RATE_LIMIT(8,1)	A	8	ALT	Rate Deadband
V98U7426C	TABLE_ALT_RATE_LIMIT(9,1)	A	9	ALT	Rate Deadband
V98U7427C	TABLE_ALT_RATE_LIMIT(10,1)	A	10	ALT	Rate Deadband
V98U7428C	TABLE_ALT_RATE_LIMIT(11,1)	A	11	ALT	Rate Deadband
V98U7429C	TABLE_ALT_RATE_LIMIT(12,1)	A	12	ALT	Rate Deadband
V98U7430C	TABLE_ALT_RATE_LIMIT(13,1)	A	13	ALT	Rate Deadband
V98U7431C	TABLE_ALT_RATE_LIMIT(14,1)	A	14	ALT	Rate Deadband
V98U7432C	TABLE_ALT_RATE_LIMIT(15,1)	A	15	ALT	Rate Deadband

MSID	FSSR Name	Corresponding DAP Table Parameter			
		A/B	#	Mode	Nomenclature
V98U7435C	TABLE_COMP_THRESHOLD(1,1,1)	A	1	PRI	Compensation
V98U7436C	TABLE_COMP_THRESHOLD(2,1,1)	A	2	PRI	Compensation
V98U7437C	TABLE_COMP_THRESHOLD(3,1,1)	A	3	PRI	Compensation
V98U7438C	TABLE_COMP_THRESHOLD(4,1,1)	A	4	PRI	Compensation
V98U7439C	TABLE_COMP_THRESHOLD(5,1,1)	A	5	PRI	Compensation
V98U7440C	TABLE_COMP_THRESHOLD(6,1,1)	A	6	PRI	Compensation
V98U7441C	TABLE_COMP_THRESHOLD(7,1,1)	A	7	PRI	Compensation
V98U7442C	TABLE_COMP_THRESHOLD(8,1,1)	A	8	PRI	Compensation
V98U7443C	TABLE_COMP_THRESHOLD(9,1,1)	A	9	PRI	Compensation
V98U7444C	TABLE_COMP_THRESHOLD(10,1,1)	A	10	PRI	Compensation
V98U7445C	TABLE_COMP_THRESHOLD(11,1,1)	A	11	PRI	Compensation
V98U7446C	TABLE_COMP_THRESHOLD(12,1,1)	A	12	PRI	Compensation
V98U7447C	TABLE_COMP_THRESHOLD(13,1,1)	A	13	PRI	Compensation
V98U7448C	TABLE_COMP_THRESHOLD(14,1,1)	A	14	PRI	Compensation
V98U7449C	TABLE_COMP_THRESHOLD(15,1,1)	A	15	PRI	Compensation
V98U7450C	TABLE_COMP_THRESHOLD(1,1,2)	A	1	VERN	Compensation
V98U7451C	TABLE_COMP_THRESHOLD(2,1,2)	A	2	VERN	Compensation
V98U7452C	TABLE_COMP_THRESHOLD(3,1,2)	A	3	VERN	Compensation
V98U7453C	TABLE_COMP_THRESHOLD(4,1,2)	A	4	VERN	Compensation
V98U7454C	TABLE_COMP_THRESHOLD(5,1,2)	A	5	VERN	Compensation
V98U7455C	TABLE_COMP_THRESHOLD(6,1,2)	A	6	VERN	Compensation
V98U7456C	TABLE_COMP_THRESHOLD(7,1,2)	A	7	VERN	Compensation
V98U7457C	TABLE_COMP_THRESHOLD(8,1,2)	A	8	VERN	Compensation
V98U7458C	TABLE_COMP_THRESHOLD(9,1,2)	A	9	VERN	Compensation
V98U7459C	TABLE_COMP_THRESHOLD(10,1,2)	A	10	VERN	Compensation
V98U7460C	TABLE_COMP_THRESHOLD(11,1,2)	A	11	VERN	Compensation
V98U7461C	TABLE_COMP_THRESHOLD(12,1,2)	A	12	VERN	Compensation
V98U7462C	TABLE_COMP_THRESHOLD(13,1,2)	A	13	VERN	Compensation
V98U7463C	TABLE_COMP_THRESHOLD(14,1,2)	A	14	VERN	Compensation
V98U7464C	TABLE_COMP_THRESHOLD(15,1,2)	A	15	VERN	Compensation
V98U7465C	TABLE_COMP_THRESHOLD(1,2,1)	B	1	PRI	Compensation
V98U7466C	TABLE_COMP_THRESHOLD(2,2,1)	B	2	PRI	Compensation
V98U7467C	TABLE_COMP_THRESHOLD(3,2,1)	B	3	PRI	Compensation
V98U7468C	TABLE_COMP_THRESHOLD(4,2,1)	B	4	PRI	Compensation
V98U7469C	TABLE_COMP_THRESHOLD(5,2,1)	B	5	PRI	Compensation
V98U7470C	TABLE_COMP_THRESHOLD(6,2,1)	B	6	PRI	Compensation
V98U7471C	TABLE_COMP_THRESHOLD(7,2,1)	B	7	PRI	Compensation
V98U7472C	TABLE_COMP_THRESHOLD(8,2,1)	B	8	PRI	Compensation
V98U7473C	TABLE_COMP_THRESHOLD(9,2,1)	B	9	PRI	Compensation
V98U7474C	TABLE_COMP_THRESHOLD(10,2,1)	B	10	PRI	Compensation
V98U7475C	TABLE_COMP_THRESHOLD(11,2,1)	B	11	PRI	Compensation
V98U7476C	TABLE_COMP_THRESHOLD(12,2,1)	B	12	PRI	Compensation
V98U7477C	TABLE_COMP_THRESHOLD(13,2,1)	B	13	PRI	Compensation
V98U7478C	TABLE_COMP_THRESHOLD(14,2,1)	B	14	PRI	Compensation
V98U7479C	TABLE_COMP_THRESHOLD(15,2,1)	B	15	PRI	Compensation

MSID	FSSR Name	Corresponding DAP Table Parameter			
		A/B	#	Mode	Nomenclature
V98U7480C	TABLE_COMP_THRESHOLD(1,2,2)	B	1	VERN	Compensation
V98U7481C	TABLE_COMP_THRESHOLD(2,2,2)	B	2	VERN	Compensation
V98U7482C	TABLE_COMP_THRESHOLD(3,2,2)	B	3	VERN	Compensation
V98U7483C	TABLE_COMP_THRESHOLD(4,2,2)	B	4	VERN	Compensation
V98U7484C	TABLE_COMP_THRESHOLD(5,2,2)	B	5	VERN	Compensation
V98U7485C	TABLE_COMP_THRESHOLD(6,2,2)	B	6	VERN	Compensation
V98U7486C	TABLE_COMP_THRESHOLD(7,2,2)	B	7	VERN	Compensation
V98U7487C	TABLE_COMP_THRESHOLD(8,2,2)	B	8	VERN	Compensation
V98U7488C	TABLE_COMP_THRESHOLD(9,2,2)	B	9	VERN	Compensation
V98U7489C	TABLE_COMP_THRESHOLD(10,2,2)	B	10	VERN	Compensation
V98U7490C	TABLE_COMP_THRESHOLD(11,2,2)	B	11	VERN	Compensation
V98U7491C	TABLE_COMP_THRESHOLD(12,2,2)	B	12	VERN	Compensation
V98U7492C	TABLE_COMP_THRESHOLD(13,2,2)	B	13	VERN	Compensation
V98U7493C	TABLE_COMP_THRESHOLD(14,2,2)	B	14	VERN	Compensation
V98U7494C	TABLE_COMP_THRESHOLD(15,2,2)	B	15	VERN	Compensation
V98U7495C	TABLE_DB(1,1,1)	A	1	PRI	Attitude Deadband
V98U7496C	TABLE_DB(2,1,1)	A	2	PRI	Attitude Deadband
V98U7497C	TABLE_DB(3,1,1)	A	3	PRI	Attitude Deadband
V98U7498C	TABLE_DB(4,1,1)	A	4	PRI	Attitude Deadband
V98U7499C	TABLE_DB(5,1,1)	A	5	PRI	Attitude Deadband
V98U7500C	TABLE_DB(6,1,1)	A	6	PRI	Attitude Deadband
V98U7501C	TABLE_DB(7,1,1)	A	7	PRI	Attitude Deadband
V98U7502C	TABLE_DB(8,1,1)	A	8	PRI	Attitude Deadband
V98U7503C	TABLE_DB(9,1,1)	A	9	PRI	Attitude Deadband
V98U7504C	TABLE_DB(10,1,1)	A	10	PRI	Attitude Deadband
V98U7505C	TABLE_DB(11,1,1)	A	11	PRI	Attitude Deadband
V98U7506C	TABLE_DB(12,1,1)	A	12	PRI	Attitude Deadband
V98U7507C	TABLE_DB(13,1,1)	A	13	PRI	Attitude Deadband
V98U7508C	TABLE_DB(14,1,1)	A	14	PRI	Attitude Deadband
V98U7509C	TABLE_DB(15,1,1)	A	15	PRI	Attitude Deadband
V98U7510C	TABLE_DB(1,1,2)	A	1	VERN	Attitude Deadband
V98U7511C	TABLE_DB(2,1,2)	A	2	VERN	Attitude Deadband
V98U7512C	TABLE_DB(3,1,2)	A	3	VERN	Attitude Deadband
V98U7513C	TABLE_DB(4,1,2)	A	4	VERN	Attitude Deadband
V98U7514C	TABLE_DB(5,1,2)	A	5	VERN	Attitude Deadband
V98U7515C	TABLE_DB(6,1,2)	A	6	VERN	Attitude Deadband
V98U7516C	TABLE_DB(7,1,2)	A	7	VERN	Attitude Deadband
V98U7517C	TABLE_DB(8,1,2)	A	8	VERN	Attitude Deadband
V98U7518C	TABLE_DB(9,1,2)	A	9	VERN	Attitude Deadband
V98U7519C	TABLE_DB(10,1,2)	A	10	VERN	Attitude Deadband
V98U7520C	TABLE_DB(11,1,2)	A	11	VERN	Attitude Deadband
V98U7521C	TABLE_DB(12,1,2)	A	12	VERN	Attitude Deadband
V98U7522C	TABLE_DB(13,1,2)	A	13	VERN	Attitude Deadband
V98U7523C	TABLE_DB(14,1,2)	A	14	VERN	Attitude Deadband
V98U7524C	TABLE_DB(15,1,2)	A	15	VERN	Attitude Deadband

MSID	FSSR Name	Corresponding DAP Table Parameter			
		A/B	#	Mode	Nomenclature
V98U7525C	TABLE_DB(1,2,1)	B	1	PRI	Attitude Deadband
V98U7526C	TABLE_DB(2,2,1)	B	2	PRI	Attitude Deadband
V98U7527C	TABLE_DB(3,2,1)	B	3	PRI	Attitude Deadband
V98U7528C	TABLE_DB(4,2,1)	B	4	PRI	Attitude Deadband
V98U7529C	TABLE_DB(5,2,1)	B	5	PRI	Attitude Deadband
V98U7530C	TABLE_DB(6,2,1)	B	6	PRI	Attitude Deadband
V98U7531C	TABLE_DB(7,2,1)	B	7	PRI	Attitude Deadband
V98U7532C	TABLE_DB(8,2,1)	B	8	PRI	Attitude Deadband
V98U7533C	TABLE_DB(9,2,1)	B	9	PRI	Attitude Deadband
V98U7534C	TABLE_DB(10,2,1)	B	10	PRI	Attitude Deadband
V98U7535C	TABLE_DB(11,2,1)	B	11	PRI	Attitude Deadband
V98U7536C	TABLE_DB(12,2,1)	B	12	PRI	Attitude Deadband
V98U7537C	TABLE_DB(13,2,1)	B	13	PRI	Attitude Deadband
V98U7538C	TABLE_DB(14,2,1)	B	14	PRI	Attitude Deadband
V98U7539C	TABLE_DB(15,2,1)	B	15	PRI	Attitude Deadband
V98U7540C	TABLE_DB(1,2,2)	B	1	VERN	Attitude Deadband
V98U7541C	TABLE_DB(2,2,2)	B	2	VERN	Attitude Deadband
V98U7542C	TABLE_DB(3,2,2)	B	3	VERN	Attitude Deadband
V98U7543C	TABLE_DB(4,2,2)	B	4	VERN	Attitude Deadband
V98U7544C	TABLE_DB(5,2,2)	B	5	VERN	Attitude Deadband
V98U7545C	TABLE_DB(6,2,2)	B	6	VERN	Attitude Deadband
V98U7546C	TABLE_DB(7,2,2)	B	7	VERN	Attitude Deadband
V98U7547C	TABLE_DB(8,2,2)	B	8	VERN	Attitude Deadband
V98U7548C	TABLE_DB(9,2,2)	B	9	VERN	Attitude Deadband
V98U7549C	TABLE_DB(10,2,2)	B	10	VERN	Attitude Deadband
V98U7550C	TABLE_DB(11,2,2)	B	11	VERN	Attitude Deadband
V98U7551C	TABLE_DB(12,2,2)	B	12	VERN	Attitude Deadband
V98U7552C	TABLE_DB(13,2,2)	B	13	VERN	Attitude Deadband
V98U7553C	TABLE_DB(14,2,2)	B	14	VERN	Attitude Deadband
V98U7554C	TABLE_DB(15,2,2)	B	15	VERN	Attitude Deadband
V98U7555C	TABLE_MNVR_RATE(1,1,1)	A	1	PRI	Rotation Rate
V98U7556C	TABLE_MNVR_RATE(2,1,1)	A	2	PRI	Rotation Rate
V98U7557C	TABLE_MNVR_RATE(3,1,1)	A	3	PRI	Rotation Rate
V98U7558C	TABLE_MNVR_RATE(4,1,1)	A	4	PRI	Rotation Rate
V98U7559C	TABLE_MNVR_RATE(5,1,1)	A	5	PRI	Rotation Rate
V98U7560C	TABLE_MNVR_RATE(6,1,1)	A	6	PRI	Rotation Rate
V98U7561C	TABLE_MNVR_RATE(7,1,1)	A	7	PRI	Rotation Rate
V98U7562C	TABLE_MNVR_RATE(8,1,1)	A	8	PRI	Rotation Rate
V98U7563C	TABLE_MNVR_RATE(9,1,1)	A	9	PRI	Rotation Rate
V98U7564C	TABLE_MNVR_RATE(10,1,1)	A	10	PRI	Rotation Rate
V98U7565C	TABLE_MNVR_RATE(11,1,1)	A	11	PRI	Rotation Rate
V98U7566C	TABLE_MNVR_RATE(12,1,1)	A	12	PRI	Rotation Rate
V98U7567C	TABLE_MNVR_RATE(13,1,1)	A	13	PRI	Rotation Rate
V98U7568C	TABLE_MNVR_RATE(14,1,1)	A	14	PRI	Rotation Rate
V98U7569C	TABLE_MNVR_RATE(15,1,1)	A	15	PRI	Rotation Rate

MSID	FSSR Name	Corresponding DAP Table Parameter			
		A/B	#	Mode	Nomenclature
V98U7570C	TABLE_MNVR_RATE(1,1,2)	A	1	VERN	Rotation Rate
V98U7571C	TABLE_MNVR_RATE(2,1,2)	A	2	VERN	Rotation Rate
V98U7572C	TABLE_MNVR_RATE(3,1,2)	A	3	VERN	Rotation Rate
V98U7573C	TABLE_MNVR_RATE(4,1,2)	A	4	VERN	Rotation Rate
V98U7574C	TABLE_MNVR_RATE(5,1,2)	A	5	VERN	Rotation Rate
V98U7575C	TABLE_MNVR_RATE(6,1,2)	A	6	VERN	Rotation Rate
V98U7576C	TABLE_MNVR_RATE(7,1,2)	A	7	VERN	Rotation Rate
V98U7577C	TABLE_MNVR_RATE(8,1,2)	A	8	VERN	Rotation Rate
V98U7578C	TABLE_MNVR_RATE(9,1,2)	A	9	VERN	Rotation Rate
V98U7579C	TABLE_MNVR_RATE(10,1,2)	A	10	VERN	Rotation Rate
V98U7580C	TABLE_MNVR_RATE(11,1,2)	A	11	VERN	Rotation Rate
V98U7581C	TABLE_MNVR_RATE(12,1,2)	A	12	VERN	Rotation Rate
V98U7582C	TABLE_MNVR_RATE(13,1,2)	A	13	VERN	Rotation Rate
V98U7583C	TABLE_MNVR_RATE(14,1,2)	A	14	VERN	Rotation Rate
V98U7584C	TABLE_MNVR_RATE(15,1,2)	A	15	VERN	Rotation Rate
V98U7585C	TABLE_MNVR_RATE(1,2,1)	B	1	PRI	Rotation Rate
V98U7586C	TABLE_MNVR_RATE(2,2,1)	B	2	PRI	Rotation Rate
V98U7587C	TABLE_MNVR_RATE(3,2,1)	B	3	PRI	Rotation Rate
V98U7588C	TABLE_MNVR_RATE(4,2,1)	B	4	PRI	Rotation Rate
V98U7589C	TABLE_MNVR_RATE(5,2,1)	B	5	PRI	Rotation Rate
V98U7590C	TABLE_MNVR_RATE(6,2,1)	B	6	PRI	Rotation Rate
V98U7591C	TABLE_MNVR_RATE(7,2,1)	B	7	PRI	Rotation Rate
V98U7592C	TABLE_MNVR_RATE(8,2,1)	B	8	PRI	Rotation Rate
V98U7593C	TABLE_MNVR_RATE(9,2,1)	B	9	PRI	Rotation Rate
V98U7594C	TABLE_MNVR_RATE(10,2,1)	B	10	PRI	Rotation Rate
V98U7595C	TABLE_MNVR_RATE(11,2,1)	B	11	PRI	Rotation Rate
V98U7596C	TABLE_MNVR_RATE(12,2,1)	B	12	PRI	Rotation Rate
V98U7597C	TABLE_MNVR_RATE(13,2,1)	B	13	PRI	Rotation Rate
V98U7598C	TABLE_MNVR_RATE(14,2,1)	B	14	PRI	Rotation Rate
V98U7599C	TABLE_MNVR_RATE(15,2,1)	B	15	PRI	Rotation Rate
V98U7600C	TABLE_MNVR_RATE(1,2,2)	B	1	VERN	Rotation Rate
V98U7601C	TABLE_MNVR_RATE(2,2,2)	B	2	VERN	Rotation Rate
V98U7602C	TABLE_MNVR_RATE(3,2,2)	B	3	VERN	Rotation Rate
V98U7603C	TABLE_MNVR_RATE(4,2,2)	B	4	VERN	Rotation Rate
V98U7604C	TABLE_MNVR_RATE(5,2,2)	B	5	VERN	Rotation Rate
V98U7605C	TABLE_MNVR_RATE(6,2,2)	B	6	VERN	Rotation Rate
V98U7606C	TABLE_MNVR_RATE(7,2,2)	B	7	VERN	Rotation Rate
V98U7607C	TABLE_MNVR_RATE(8,2,2)	B	8	VERN	Rotation Rate
V98U7608C	TABLE_MNVR_RATE(9,2,2)	B	9	VERN	Rotation Rate
V98U7609C	TABLE_MNVR_RATE(10,2,2)	B	10	VERN	Rotation Rate
V98U7610C	TABLE_MNVR_RATE(11,2,2)	B	11	VERN	Rotation Rate
V98U7611C	TABLE_MNVR_RATE(12,2,2)	B	12	VERN	Rotation Rate
V98U7612C	TABLE_MNVR_RATE(13,2,2)	B	13	VERN	Rotation Rate
V98U7613C	TABLE_MNVR_RATE(14,2,2)	B	14	VERN	Rotation Rate
V98U7614C	TABLE_MNVR_RATE(15,2,2)	B	15	VERN	Rotation Rate

MSID	FSSR Name	Corresponding DAP Table Parameter			
		A/B	#	Mode	Nomenclature
V98U7615C	TABLE_ALT_RATE_LIMIT(1,2)	B	1	ALT	Rate Deadband
V98U7616C	TABLE_ALT_RATE_LIMIT(2,2)	B	2	ALT	Rate Deadband
V98U7617C	TABLE_ALT_RATE_LIMIT(3,2)	B	3	ALT	Rate Deadband
V98U7618C	TABLE_ALT_RATE_LIMIT(4,2)	B	4	ALT	Rate Deadband
V98U7619C	TABLE_ALT_RATE_LIMIT(5,2)	B	5	ALT	Rate Deadband
V98U7620C	TABLE_ALT_RATE_LIMIT(6,2)	B	6	ALT	Rate Deadband
V98U7621C	TABLE_ALT_RATE_LIMIT(7,2)	B	7	ALT	Rate Deadband
V98U7622C	TABLE_ALT_RATE_LIMIT(8,2)	B	8	ALT	Rate Deadband
V98U7623C	TABLE_ALT_RATE_LIMIT(9,2)	B	9	ALT	Rate Deadband
V98U7624C	TABLE_ALT_RATE_LIMIT(10,2)	B	10	ALT	Rate Deadband
V98U7625C	TABLE_ALT_RATE_LIMIT(11,2)	B	11	ALT	Rate Deadband
V98U7626C	TABLE_ALT_RATE_LIMIT(12,2)	B	12	ALT	Rate Deadband
V98U7627C	TABLE_ALT_RATE_LIMIT(13,2)	B	13	ALT	Rate Deadband
V98U7628C	TABLE_ALT_RATE_LIMIT(14,2)	B	14	ALT	Rate Deadband
V98U7629C	TABLE_ALT_RATE_LIMIT(15,2)	B	15	ALT	Rate Deadband
V98U7670C	TABLE_NOM_NOSE_TAIL_PITCH(1,1)	A	1	PRI	Pitch Option
V98U7671C	TABLE_NOM_NOSE_TAIL_PITCH(2,1)	A	2	PRI	Pitch Option
V98U7672C	TABLE_NOM_NOSE_TAIL_PITCH(3,1)	A	3	PRI	Pitch Option
V98U7673C	TABLE_NOM_NOSE_TAIL_PITCH(4,1)	A	4	PRI	Pitch Option
V98U7674C	TABLE_NOM_NOSE_TAIL_PITCH(5,1)	A	5	PRI	Pitch Option
V98U7675C	TABLE_NOM_NOSE_TAIL_PITCH(6,1)	A	6	PRI	Pitch Option
V98U7676C	TABLE_NOM_NOSE_TAIL_PITCH(7,1)	A	7	PRI	Pitch Option
V98U7677C	TABLE_NOM_NOSE_TAIL_PITCH(8,1)	A	8	PRI	Pitch Option
V98U7678C	TABLE_NOM_NOSE_TAIL_PITCH(9,1)	A	9	PRI	Pitch Option
V98U7679C	TABLE_NOM_NOSE_TAIL_PITCH(10,1)	A	10	PRI	Pitch Option
V98U7680C	TABLE_NOM_NOSE_TAIL_PITCH(11,1)	A	11	PRI	Pitch Option
V98U7681C	TABLE_NOM_NOSE_TAIL_PITCH(12,1)	A	12	PRI	Pitch Option
V98U7682C	TABLE_NOM_NOSE_TAIL_PITCH(13,1)	A	13	PRI	Pitch Option
V98U7683C	TABLE_NOM_NOSE_TAIL_PITCH(14,1)	A	14	PRI	Pitch Option
V98U7684C	TABLE_NOM_NOSE_TAIL_PITCH(15,1)	A	15	PRI	Pitch Option
V98U7685C	TABLE_NOM_NOSE_TAIL_PITCH(1,2)	B	1	PRI	Pitch Option
V98U7686C	TABLE_NOM_NOSE_TAIL_PITCH(2,2)	B	2	PRI	Pitch Option
V98U7687C	TABLE_NOM_NOSE_TAIL_PITCH(3,2)	B	3	PRI	Pitch Option
V98U7688C	TABLE_NOM_NOSE_TAIL_PITCH(4,2)	B	4	PRI	Pitch Option
V98U7689C	TABLE_NOM_NOSE_TAIL_PITCH(5,2)	B	5	PRI	Pitch Option
V98U7690C	TABLE_NOM_NOSE_TAIL_PITCH(6,2)	B	6	PRI	Pitch Option
V98U7691C	TABLE_NOM_NOSE_TAIL_PITCH(7,2)	B	7	PRI	Pitch Option
V98U7692C	TABLE_NOM_NOSE_TAIL_PITCH(8,2)	B	8	PRI	Pitch Option
V98U7693C	TABLE_NOM_NOSE_TAIL_PITCH(9,2)	B	9	PRI	Pitch Option
V98U7694C	TABLE_NOM_NOSE_TAIL_PITCH(10,2)	B	10	PRI	Pitch Option
V98U7695C	TABLE_NOM_NOSE_TAIL_PITCH(11,2)	B	11	PRI	Pitch Option
V98U7696C	TABLE_NOM_NOSE_TAIL_PITCH(12,2)	B	12	PRI	Pitch Option
V98U7697C	TABLE_NOM_NOSE_TAIL_PITCH(13,2)	B	13	PRI	Pitch Option
V98U7698C	TABLE_NOM_NOSE_TAIL_PITCH(14,2)	B	14	PRI	Pitch Option
V98U7699C	TABLE_NOM_NOSE_TAIL_PITCH(15,2)	B	15	PRI	Pitch Option

MSID	FSSR Name	Corresponding DAP Table Parameter			
		A/B	#	Mode	Nomenclature
V98U7700C	TABLE_NOM_NOSE_TAIL_YAW(1,1)	A	1	PRI	Yaw Option
V98U7701C	TABLE_NOM_NOSE_TAIL_YAW(2,1)	A	2	PRI	Yaw Option
V98U7702C	TABLE_NOM_NOSE_TAIL_YAW(3,1)	A	3	PRI	Yaw Option
V98U7703C	TABLE_NOM_NOSE_TAIL_YAW(4,1)	A	4	PRI	Yaw Option
V98U7704C	TABLE_NOM_NOSE_TAIL_YAW(5,1)	A	5	PRI	Yaw Option
V98U7705C	TABLE_NOM_NOSE_TAIL_YAW(6,1)	A	6	PRI	Yaw Option
V98U7706C	TABLE_NOM_NOSE_TAIL_YAW(7,1)	A	7	PRI	Yaw Option
V98U7707C	TABLE_NOM_NOSE_TAIL_YAW(8,1)	A	8	PRI	Yaw Option
V98U7708C	TABLE_NOM_NOSE_TAIL_YAW(9,1)	A	9	PRI	Yaw Option
V98U7709C	TABLE_NOM_NOSE_TAIL_YAW(10,1)	A	10	PRI	Yaw Option
V98U7710C	TABLE_NOM_NOSE_TAIL_YAW(11,1)	A	11	PRI	Yaw Option
V98U7711C	TABLE_NOM_NOSE_TAIL_YAW(12,1)	A	12	PRI	Yaw Option
V98U7712C	TABLE_NOM_NOSE_TAIL_YAW(13,1)	A	13	PRI	Yaw Option
V98U7713C	TABLE_NOM_NOSE_TAIL_YAW(14,1)	A	14	PRI	Yaw Option
V98U7714C	TABLE_NOM_NOSE_TAIL_YAW(15,1)	A	15	PRI	Yaw Option
V98U7715C	TABLE_NOM_NOSE_TAIL_YAW(1,2)	B	1	PRI	Yaw Option
V98U7716C	TABLE_NOM_NOSE_TAIL_YAW(2,2)	B	2	PRI	Yaw Option
V98U7717C	TABLE_NOM_NOSE_TAIL_YAW(3,2)	B	3	PRI	Yaw Option
V98U7718C	TABLE_NOM_NOSE_TAIL_YAW(4,2)	B	4	PRI	Yaw Option
V98U7719C	TABLE_NOM_NOSE_TAIL_YAW(5,2)	B	5	PRI	Yaw Option
V98U7720C	TABLE_NOM_NOSE_TAIL_YAW(6,2)	B	6	PRI	Yaw Option
V98U7721C	TABLE_NOM_NOSE_TAIL_YAW(7,2)	B	7	PRI	Yaw Option
V98U7722C	TABLE_NOM_NOSE_TAIL_YAW(8,2)	B	8	PRI	Yaw Option
V98U7723C	TABLE_NOM_NOSE_TAIL_YAW(9,2)	B	9	PRI	Yaw Option
V98U7724C	TABLE_NOM_NOSE_TAIL_YAW(10,2)	B	10	PRI	Yaw Option
V98U7725C	TABLE_NOM_NOSE_TAIL_YAW(11,2)	B	11	PRI	Yaw Option
V98U7726C	TABLE_NOM_NOSE_TAIL_YAW(12,2)	B	12	PRI	Yaw Option
V98U7727C	TABLE_NOM_NOSE_TAIL_YAW(13,2)	B	13	PRI	Yaw Option
V98U7728C	TABLE_NOM_NOSE_TAIL_YAW(14,2)	B	14	PRI	Yaw Option
V98U7729C	TABLE_NOM_NOSE_TAIL_YAW(15,2)	B	15	PRI	Yaw Option
V98U7730C	TABLE_PAYLOAD_EXTENDED(1,1)	A	1	-	Control Accleration
V98U7731C	TABLE_PAYLOAD_EXTENDED(2,1)	A	2	-	Control Accleration
V98U7732C	TABLE_PAYLOAD_EXTENDED(3,1)	A	3	-	Control Accleration
V98U7733C	TABLE_PAYLOAD_EXTENDED(4,1)	A	4	-	Control Accleration
V98U7734C	TABLE_PAYLOAD_EXTENDED(5,1)	A	5	-	Control Accleration
V98U7735C	TABLE_PAYLOAD_EXTENDED(6,1)	A	6	-	Control Accleration
V98U7736C	TABLE_PAYLOAD_EXTENDED(7,1)	A	7	-	Control Accleration
V98U7737C	TABLE_PAYLOAD_EXTENDED(8,1)	A	8	-	Control Accleration
V98U7738C	TABLE_PAYLOAD_EXTENDED(9,1)	A	9	-	Control Accleration
V98U7739C	TABLE_PAYLOAD_EXTENDED(10,1)	A	10	-	Control Accleration
V98U7740C	TABLE_PAYLOAD_EXTENDED(11,1)	A	11	-	Control Accleration
V98U7741C	TABLE_PAYLOAD_EXTENDED(12,1)	A	12	-	Control Accleration
V98U7742C	TABLE_PAYLOAD_EXTENDED(13,1)	A	13	-	Control Accleration
V98U7743C	TABLE_PAYLOAD_EXTENDED(14,1)	A	14	-	Control Accleration
V98U7744C	TABLE_PAYLOAD_EXTENDED(15,1)	A	15	-	Control Accleration

MSID	FSSR Name	Corresponding DAP Table Parameter		
		A/B #	Mode	Nomenclature
V98U7745C	TABLE_PAYLOAD_EXTENDED(1,2)	B 1	-	Control Accleration
V98U7746C	TABLE_PAYLOAD_EXTENDED(2,2)	B 2	-	Control Accleration
V98U7747C	TABLE_PAYLOAD_EXTENDED(3,2)	B 3	-	Control Accleration
V98U7748C	TABLE_PAYLOAD_EXTENDED(4,2)	B 4	-	Control Accleration
V98U7749C	TABLE_PAYLOAD_EXTENDED(5,2)	B 5	-	Control Accleration
V98U7750C	TABLE_PAYLOAD_EXTENDED(6,2)	B 6	-	Control Accleration
V98U7751C	TABLE_PAYLOAD_EXTENDED(7,2)	B 7	-	Control Accleration
V98U7752C	TABLE_PAYLOAD_EXTENDED(8,2)	B 8	-	Control Accleration
V98U7753C	TABLE_PAYLOAD_EXTENDED(9,2)	B 9	-	Control Accleration
V98U7754C	TABLE_PAYLOAD_EXTENDED(10,2)	B 10	-	Control Accleration
V98U7755C	TABLE_PAYLOAD_EXTENDED(11,2)	B 11	-	Control Accleration
V98U7756C	TABLE_PAYLOAD_EXTENDED(12,2)	B 12	-	Control Accleration
V98U7757C	TABLE_PAYLOAD_EXTENDED(13,2)	B 13	-	Control Accleration
V98U7758C	TABLE_PAYLOAD_EXTENDED(14,2)	B 14	-	Control Accleration
V98U7759C	TABLE_PAYLOAD_EXTENDED(15,2)	B 15	-	Control Accleration
V98U7760C	TABLE_RATE_LIMIT(1,1,1)	A 1	PRI	Rate Deadband
V98U7761C	TABLE_RATE_LIMIT(2,1,1)	A 2	PRI	Rate Deadband
V98U7762C	TABLE_RATE_LIMIT(3,1,1)	A 3	PRI	Rate Deadband
V98U7763C	TABLE_RATE_LIMIT(4,1,1)	A 4	PRI	Rate Deadband
V98U7764C	TABLE_RATE_LIMIT(5,1,1)	A 5	PRI	Rate Deadband
V98U7765C	TABLE_RATE_LIMIT(6,1,1)	A 6	PRI	Rate Deadband
V98U7766C	TABLE_RATE_LIMIT(7,1,1)	A 7	PRI	Rate Deadband
V98U7767C	TABLE_RATE_LIMIT(8,1,1)	A 8	PRI	Rate Deadband
V98U7768C	TABLE_RATE_LIMIT(9,1,1)	A 9	PRI	Rate Deadband
V98U7769C	TABLE_RATE_LIMIT(10,1,1)	A 10	PRI	Rate Deadband
V98U7770C	TABLE_RATE_LIMIT(11,1,1)	A 11	PRI	Rate Deadband
V98U7771C	TABLE_RATE_LIMIT(12,1,1)	A 12	PRI	Rate Deadband
V98U7772C	TABLE_RATE_LIMIT(13,1,1)	A 13	PRI	Rate Deadband
V98U7773C	TABLE_RATE_LIMIT(14,1,1)	A 14	PRI	Rate Deadband
V98U7774C	TABLE_RATE_LIMIT(15,1,1)	A 15	PRI	Rate Deadband
V98U7775C	TABLE_RATE_LIMIT(1,1,2)	A 1	VERN	Rate Deadband
V98U7776C	TABLE_RATE_LIMIT(2,1,2)	A 2	VERN	Rate Deadband
V98U7777C	TABLE_RATE_LIMIT(3,1,2)	A 3	VERN	Rate Deadband
V98U7778C	TABLE_RATE_LIMIT(4,1,2)	A 4	VERN	Rate Deadband
V98U7779C	TABLE_RATE_LIMIT(5,1,2)	A 5	VERN	Rate Deadband
V98U7780C	TABLE_RATE_LIMIT(6,1,2)	A 6	VERN	Rate Deadband
V98U7781C	TABLE_RATE_LIMIT(7,1,2)	A 7	VERN	Rate Deadband
V98U7782C	TABLE_RATE_LIMIT(8,1,2)	A 8	VERN	Rate Deadband
V98U7783C	TABLE_RATE_LIMIT(9,1,2)	A 9	VERN	Rate Deadband
V98U7784C	TABLE_RATE_LIMIT(10,1,2)	A 10	VERN	Rate Deadband
V98U7785C	TABLE_RATE_LIMIT(11,1,2)	A 11	VERN	Rate Deadband
V98U7786C	TABLE_RATE_LIMIT(12,1,2)	A 12	VERN	Rate Deadband
V98U7787C	TABLE_RATE_LIMIT(13,1,2)	A 13	VERN	Rate Deadband
V98U7788C	TABLE_RATE_LIMIT(14,1,2)	A 14	VERN	Rate Deadband
V98U7789C	TABLE_RATE_LIMIT(15,1,2)	A 15	VERN	Rate Deadband

MSID	FSSR Name	Corresponding DAP Table Parameter			
		A/B	#	Mode	Nomenclature
V98U7790C	TABLE_RATE_LIMIT(1,2,1)	B	1	PRI	Rate Deadband
V98U7791C	TABLE_RATE_LIMIT(2,2,1)	B	2	PRI	Rate Deadband
V98U7792C	TABLE_RATE_LIMIT(3,2,1)	B	3	PRI	Rate Deadband
V98U7793C	TABLE_RATE_LIMIT(4,2,1)	B	4	PRI	Rate Deadband
V98U7794C	TABLE_RATE_LIMIT(5,2,1)	B	5	PRI	Rate Deadband
V98U7795C	TABLE_RATE_LIMIT(6,2,1)	B	6	PRI	Rate Deadband
V98U7796C	TABLE_RATE_LIMIT(7,2,1)	B	7	PRI	Rate Deadband
V98U7797C	TABLE_RATE_LIMIT(8,2,1)	B	8	PRI	Rate Deadband
V98U7798C	TABLE_RATE_LIMIT(9,2,1)	B	9	PRI	Rate Deadband
V98U7799C	TABLE_RATE_LIMIT(10,2,1)	B	10	PRI	Rate Deadband
V98U7800C	TABLE_RATE_LIMIT(11,2,1)	B	11	PRI	Rate Deadband
V98U7801C	TABLE_RATE_LIMIT(12,2,1)	B	12	PRI	Rate Deadband
V98U7802C	TABLE_RATE_LIMIT(13,2,1)	B	13	PRI	Rate Deadband
V98U7803C	TABLE_RATE_LIMIT(14,2,1)	B	14	PRI	Rate Deadband
V98U7804C	TABLE_RATE_LIMIT(15,2,1)	B	15	PRI	Rate Deadband
V98U7805C	TABLE_RATE_LIMIT(1,2,2)	B	1	VERN	Rate Deadband
V98U7806C	TABLE_RATE_LIMIT(2,2,2)	B	2	VERN	Rate Deadband
V98U7807C	TABLE_RATE_LIMIT(3,2,2)	B	3	VERN	Rate Deadband
V98U7808C	TABLE_RATE_LIMIT(4,2,2)	B	4	VERN	Rate Deadband
V98U7809C	TABLE_RATE_LIMIT(5,2,2)	B	5	VERN	Rate Deadband
V98U7810C	TABLE_RATE_LIMIT(6,2,2)	B	6	VERN	Rate Deadband
V98U7811C	TABLE_RATE_LIMIT(7,2,2)	B	7	VERN	Rate Deadband
V98U7812C	TABLE_RATE_LIMIT(8,2,2)	B	8	VERN	Rate Deadband
V98U7813C	TABLE_RATE_LIMIT(9,2,2)	B	9	VERN	Rate Deadband
V98U7814C	TABLE_RATE_LIMIT(10,2,2)	B	10	VERN	Rate Deadband
V98U7815C	TABLE_RATE_LIMIT(11,2,2)	B	11	VERN	Rate Deadband
V98U7816C	TABLE_RATE_LIMIT(12,2,2)	B	12	VERN	Rate Deadband
V98U7817C	TABLE_RATE_LIMIT(13,2,2)	B	13	VERN	Rate Deadband
V98U7818C	TABLE_RATE_LIMIT(14,2,2)	B	14	VERN	Rate Deadband
V98U7819C	TABLE_RATE_LIMIT(15,2,2)	B	15	VERN	Rate Deadband
V98U7820C	TABLE_ROT_PULSE(1,1,1)	A	1	PRI	Rotation Pulse
V98U7821C	TABLE_ROT_PULSE(2,1,1)	A	2	PRI	Rotation Pulse
V98U7822C	TABLE_ROT_PULSE(3,1,1)	A	3	PRI	Rotation Pulse
V98U7823C	TABLE_ROT_PULSE(4,1,1)	A	4	PRI	Rotation Pulse
V98U7824C	TABLE_ROT_PULSE(5,1,1)	A	5	PRI	Rotation Pulse
V98U7825C	TABLE_ROT_PULSE(6,1,1)	A	6	PRI	Rotation Pulse
V98U7826C	TABLE_ROT_PULSE(7,1,1)	A	7	PRI	Rotation Pulse
V98U7827C	TABLE_ROT_PULSE(8,1,1)	A	8	PRI	Rotation Pulse
V98U7828C	TABLE_ROT_PULSE(9,1,1)	A	9	PRI	Rotation Pulse
V98U7829C	TABLE_ROT_PULSE(10,1,1)	A	10	PRI	Rotation Pulse
V98U7830C	TABLE_ROT_PULSE(11,1,1)	A	11	PRI	Rotation Pulse
V98U7831C	TABLE_ROT_PULSE(12,1,1)	A	12	PRI	Rotation Pulse
V98U7832C	TABLE_ROT_PULSE(13,1,1)	A	13	PRI	Rotation Pulse
V98U7833C	TABLE_ROT_PULSE(14,1,1)	A	14	PRI	Rotation Pulse
V98U7834C	TABLE_ROT_PULSE(15,1,1)	A	15	PRI	Rotation Pulse

MSID	FSSR Name	Corresponding DAP Table Parameter			
		A/B	#	Mode	Nomenclature
V98U7835C	TABLE_ROT_PULSE(1,1,2)	A	1	VERN	Rotation Pulse
V98U7836C	TABLE_ROT_PULSE(2,1,2)	A	2	VERN	Rotation Pulse
V98U7837C	TABLE_ROT_PULSE(3,1,2)	A	3	VERN	Rotation Pulse
V98U7838C	TABLE_ROT_PULSE(4,1,2)	A	4	VERN	Rotation Pulse
V98U7839C	TABLE_ROT_PULSE(5,1,2)	A	5	VERN	Rotation Pulse
V98U7840C	TABLE_ROT_PULSE(6,1,2)	A	6	VERN	Rotation Pulse
V98U7841C	TABLE_ROT_PULSE(7,1,2)	A	7	VERN	Rotation Pulse
V98U7842C	TABLE_ROT_PULSE(8,1,2)	A	8	VERN	Rotation Pulse
V98U7843C	TABLE_ROT_PULSE(9,1,2)	A	9	VERN	Rotation Pulse
V98U7844C	TABLE_ROT_PULSE(10,1,2)	A	10	VERN	Rotation Pulse
V98U7845C	TABLE_ROT_PULSE(11,1,2)	A	11	VERN	Rotation Pulse
V98U7846C	TABLE_ROT_PULSE(12,1,2)	A	12	VERN	Rotation Pulse
V98U7847C	TABLE_ROT_PULSE(13,1,2)	A	13	VERN	Rotation Pulse
V98U7848C	TABLE_ROT_PULSE(14,1,2)	A	14	VERN	Rotation Pulse
V98U7849C	TABLE_ROT_PULSE(15,1,2)	A	15	VERN	Rotation Pulse
V98U7850C	TABLE_ROT_PULSE(1,2,1)	B	1	PRI	Rotation Pulse
V98U7851C	TABLE_ROT_PULSE(2,2,1)	B	2	PRI	Rotation Pulse
V98U7852C	TABLE_ROT_PULSE(3,2,1)	B	3	PRI	Rotation Pulse
V98U7853C	TABLE_ROT_PULSE(4,2,1)	B	4	PRI	Rotation Pulse
V98U7854C	TABLE_ROT_PULSE(5,2,1)	B	5	PRI	Rotation Pulse
V98U7855C	TABLE_ROT_PULSE(6,2,1)	B	6	PRI	Rotation Pulse
V98U7856C	TABLE_ROT_PULSE(7,2,1)	B	7	PRI	Rotation Pulse
V98U7857C	TABLE_ROT_PULSE(8,2,1)	B	8	PRI	Rotation Pulse
V98U7858C	TABLE_ROT_PULSE(9,2,1)	B	9	PRI	Rotation Pulse
V98U7859C	TABLE_ROT_PULSE(10,2,1)	B	10	PRI	Rotation Pulse
V98U7860C	TABLE_ROT_PULSE(11,2,1)	B	11	PRI	Rotation Pulse
V98U7861C	TABLE_ROT_PULSE(12,2,1)	B	12	PRI	Rotation Pulse
V98U7862C	TABLE_ROT_PULSE(13,2,1)	B	13	PRI	Rotation Pulse
V98U7863C	TABLE_ROT_PULSE(14,2,1)	B	14	PRI	Rotation Pulse
V98U7864C	TABLE_ROT_PULSE(15,2,1)	B	15	PRI	Rotation Pulse
V98U7865C	TABLE_ROT_PULSE(1,2,2)	B	1	VERN	Rotation Pulse
V98U7866C	TABLE_ROT_PULSE(2,2,2)	B	2	VERN	Rotation Pulse
V98U7867C	TABLE_ROT_PULSE(3,2,2)	B	3	VERN	Rotation Pulse
V98U7868C	TABLE_ROT_PULSE(4,2,2)	B	4	VERN	Rotation Pulse
V98U7869C	TABLE_ROT_PULSE(5,2,2)	B	5	VERN	Rotation Pulse
V98U7870C	TABLE_ROT_PULSE(6,2,2)	B	6	VERN	Rotation Pulse
V98U7871C	TABLE_ROT_PULSE(7,2,2)	B	7	VERN	Rotation Pulse
V98U7872C	TABLE_ROT_PULSE(8,2,2)	B	8	VERN	Rotation Pulse
V98U7873C	TABLE_ROT_PULSE(9,2,2)	B	9	VERN	Rotation Pulse
V98U7874C	TABLE_ROT_PULSE(10,2,2)	B	10	VERN	Rotation Pulse
V98U7875C	TABLE_ROT_PULSE(11,2,2)	B	11	VERN	Rotation Pulse
V98U7876C	TABLE_ROT_PULSE(12,2,2)	B	12	VERN	Rotation Pulse
V98U7877C	TABLE_ROT_PULSE(13,2,2)	B	13	VERN	Rotation Pulse
V98U7878C	TABLE_ROT_PULSE(14,2,2)	B	14	VERN	Rotation Pulse
V98U7879C	TABLE_ROT_PULSE(15,2,2)	B	15	VERN	Rotation Pulse

MSID	FSSR Name	Corresponding DAP Table Parameter			
		A/B	#	Mode	Nomenclature
V98U7880C	TABLE_TRANS_PULSE(1,1)	A	1	PRI	Translation Pulse
V98U7881C	TABLE_TRANS_PULSE(2,1)	A	2	PRI	Translation Pulse
V98U7882C	TABLE_TRANS_PULSE(3,1)	A	3	PRI	Translation Pulse
V98U7883C	TABLE_TRANS_PULSE(4,1)	A	4	PRI	Translation Pulse
V98U7884C	TABLE_TRANS_PULSE(5,1)	A	5	PRI	Translation Pulse
V98U7885C	TABLE_TRANS_PULSE(6,1)	A	6	PRI	Translation Pulse
V98U7886C	TABLE_TRANS_PULSE(7,1)	A	7	PRI	Translation Pulse
V98U7887C	TABLE_TRANS_PULSE(8,1)	A	8	PRI	Translation Pulse
V98U7888C	TABLE_TRANS_PULSE(9,1)	A	9	PRI	Translation Pulse
V98U7889C	TABLE_TRANS_PULSE(10,1)	A	10	PRI	Translation Pulse
V98U7890C	TABLE_TRANS_PULSE(11,1)	A	11	PRI	Translation Pulse
V98U7891C	TABLE_TRANS_PULSE(12,1)	A	12	PRI	Translation Pulse
V98U7892C	TABLE_TRANS_PULSE(13,1)	A	13	PRI	Translation Pulse
V98U7893C	TABLE_TRANS_PULSE(14,1)	A	14	PRI	Translation Pulse
V98U7894C	TABLE_TRANS_PULSE(15,1)	A	15	PRI	Translation Pulse
V98U7895C	TABLE_TRANS_PULSE(1,2)	B	1	PRI	Translation Pulse
V98U7896C	TABLE_TRANS_PULSE(2,2)	B	2	PRI	Translation Pulse
V98U7897C	TABLE_TRANS_PULSE(3,2)	B	3	PRI	Translation Pulse
V98U7898C	TABLE_TRANS_PULSE(4,2)	B	4	PRI	Translation Pulse
V98U7899C	TABLE_TRANS_PULSE(5,2)	B	5	PRI	Translation Pulse
V98U7900C	TABLE_TRANS_PULSE(6,2)	B	6	PRI	Translation Pulse
V98U7901C	TABLE_TRANS_PULSE(7,2)	B	7	PRI	Translation Pulse
V98U7902C	TABLE_TRANS_PULSE(8,2)	B	8	PRI	Translation Pulse
V98U7903C	TABLE_TRANS_PULSE(9,2)	B	9	PRI	Translation Pulse
V98U7904C	TABLE_TRANS_PULSE(10,2)	B	10	PRI	Translation Pulse
V98U7905C	TABLE_TRANS_PULSE(11,2)	B	11	PRI	Translation Pulse
V98U7906C	TABLE_TRANS_PULSE(12,2)	B	12	PRI	Translation Pulse
V98U7907C	TABLE_TRANS_PULSE(13,2)	B	13	PRI	Translation Pulse
V98U7908C	TABLE_TRANS_PULSE(14,2)	B	14	PRI	Translation Pulse
V98U7909C	TABLE_TRANS_PULSE(15,2)	B	15	PRI	Translation Pulse

TITLE

GNC PARAMETER OVERRIDE PROCESSING

PURPOSE

To override (disable) an individual telemetry parameter (analog, discrete, HEX, or ASCII) for some off-nominal condition. The parameter will be over-ridden until the parameter is reenabled.

PROCEDURE

Parameter overrides can be implemented using Telemetry Services Function found on the Master DNAV Menu under Global Apps. The users manual can be found on EDP in bookshelf REFERENCE DOCUMENTS, CCF. The document name is CCF Software User's Handbook Vol III. The paragraph is 3.6.2 Parameter Override Manager.

After performing a parameter override, notify GC on the GC CALL loop.

REFERENCES

1. FCOH, JSC-26843, SOP 4.7.4. (Not updated for FEPS)
2. CCF Software User's Handbook Vol III.

TITLE

GNC GROUP ADMINISTRATOR DUTIES

PURPOSE

The purpose of this section is to provide a guide to GNC Group Administrators (GAs) in order to support flight operations. Only GNC-specific responsibilities are covered in this document. GAs should refer to the Workstation Applications Department Software Management Plan (SFOC-FL1113) and the Group Administrator's Standards Handbook (SFOC-FL1134) for additional information.

BACKGROUND

GA duties fall into two categories as defined by the Software Management Plan for Mission Control Center Applications (JSC-27029) and GA Handbook: User GAs and Software GAs.

USER GA ROLES

The role of the user GA is to maintain the discipline-specific workstation configuration. User GAs are charged with maintaining software applications (primarily data files) within the group, as well as developing and maintaining:

- UNIX configuration files,
- Information Sharing Protocol (ISP) dictionaries,
- Display Navigation (DNAV) scripts,
- X resource files, and
- other UNIX shell scripts.

User GAs have no authorization to promote software between the Operations (OPS) environment and Consolidated Development Environment (CDE), but do have access to the `/users/gncds` directory where GNC data files are maintained for use in SIMs and flights. User GAs may also be tasked with generating documents and supervising the testing of applications in their charge.

SOFTWARE GA ROLES

The Software GA's duties include:

- promoting software between the CDE and OPS environments,
- building and updating Makefiles,
- compiling programs,
- moving files external to the Mission Control Center (MCC),
- performing general directory maintenance,
- supporting critical periods during flight and SIMs,
- supporting special testing and Integrated Load Checkouts (ILCs), and

- participating in certification testing.

GAs are also responsible for generating certification application notebooks. In many instances, the software GA may also have the role of a software developer for the group.

PROCEDURES

SETTING UP GA ACCOUNTS

To perform GA duties, the proper accounts must be set up. As a minimum, GAs require a GA account in both the OPS and CDE. GA accounts will have the login ID of gncgax, where x = 1, 2, 3... In addition, to move files external to the MCC, a Mission Support LAN (MSL) account must be set up. Setting up these accounts requires Primary GA, Group management, and USA management approval.

Forms can be obtained from the Access Control Account (ACA) group located in building 30S, room 3306. This group also supports password changes for the OPS environment.

For CDE passwords, and CDE and MSL account setup and maintenance, see the CDE manager in building 30S, room 4318.

APPLICATION CERTIFICATION

The certification and testing procedures for all software applications are discussed fully in the GA Standards Handbook (SFOC-FL1134) and the Workstation Applications Department Software Management Plan (SFOC-1113). Both documents can be found on the SFOC Electronic Library System (SELS).

After the application to be certified has been tested and is ready for approval, an audit report must be generated. The steps below should be followed to get a hard copy of the audit:

1. Change directory to /devusr/mivtds/audit
2. Type audit <path>/<filename>
3. Print the file in /devusr/mivtds/reports (long # with day and time)
4. Attach the audit report to the JET form for certification

PROMOTING FROM CDE TO OPS

The software GA is responsible for all file transfers between the CDE and OPS environments. A file transfer in any direction between these two environments requires access to the Configuration Management (CM) workstations in the MSL on the 5th floor of building 30S. The directory structure of the CDE and OPS are similar and each is divided into two partitions, the read-write partition and the read-only partition. The read-only partitions contain the latest uncertified and certified versions of compiled executable programs only. All other files including shell scripts and data files reside on the read-write

partitions. File transfer procedures are different depending on which partition the files are targeted to.

FILE TRANSFER TO READ-WRITE PARTITIONS

For file transfers to either read-write partition, UNIX commands may be used to copy or move files. When logged into the CM server, the read-write partition of the CDE or OPS environment can be accessed by using the "/cde/rw1/..." or "/ops/rw2/..." directory specification on the command line, respectively. The directory paths which correspond to the "/users/..." path are slightly different for each environment.

The CDE "/users/..." directory can be accessed using the path "/cde/rw1/df6/...". The OPS "/users/..." directory corresponds to "/ops/rw2/users/...". From then on the subdirectory names are the same. For example, to copy the file `gnc.dict` from the OPS directory "/users/gncds/rw_common/cert_apps/isp_dict" to the same path in the CDE, use the following command from an xterm window:

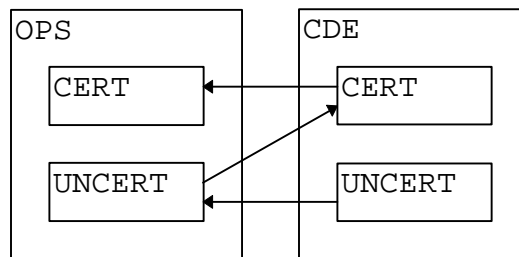
```
cp /ops/rw2/users/gncds/rw_common/cert_apps/isp_dict/gnc.dict  
/cde/rw1/df6/gncds/rw_common/cert_apps/isp_dict/gnc.dict
```

As with any file operations, be careful to use the correct directory and file names, especially due to the complexity of the file systems and similar directory naming conventions. Always check the files to confirm the copy, move, or deletion.

FILE PROMOTION OF COMPILED EXECUTABLES TO READ-ONLY PARTITIONS

A tool called "Server Sync" must be used to transfer files to the read-only partitions. The only exception is the CDE read-only partition, in which UNIX commands may also be used. Only compiled executables should be copied into the read-only partitions. A specific channel of transfer is allowed between the uncertified and certified areas of these partitions. Files must be promoted in this order:

CDE uncert -> OPS uncert -> CDE cert -> OPS cert



To run Server Sync, follow the steps below:

- Bring up the Motif Window manager (MWM) root menu from the CM workstation and select "Server Sync".

- After a few seconds, two windows, the Server Sync user interface and a message window, will appear on the screen. Select the operation desired, either “Sync”, “Merge”, “Preview”, or “Delete”.
 - ⇒ The “Sync” operation duplicates an entire directory tree exactly, adding, replacing, or deleting files to make them the same. This is potentially very dangerous so be very careful with this operation.
 - ⇒ The “Merge” operation simply copies a file.
 - ⇒ “Preview” allows non-destructive “rehearsal” of an operation.
 - ⇒ “Delete” allows deletion of files or directories.
- Click on the down arrow to the left of “Src Server” and select the server that corresponds to the environment containing the file or directory to be merged or synched. This is usually “cde-cm1” or “ops-cm1”.
- Select the source repository in a similar fashion. This is usually “u_apps_rep” for uncertified files or “c_apps_rep” for certified files.
- Select the source path which will bring up a file selection box and double click on “alpha_3.2”, then “common”, click under the scroll bar about 3 times and double click on “gnc”.
- Select the bin directory such as “bin_en05” and the file and click “OK”.
- Next, select the destination server. This is usually “cde-cm1” for CDE or “All CCC” for OPS.
- Select the destination repository. To avoid going through the file box to select the destination path, simply double click on the source path and paste it into the destination path by clicking on the middle mouse button.
- If everything looks right, select “Execute”. A dialog box will appear to confirm the operation.

NOTE: It is very important to check over the operation here before clicking on the “OK” button. Look over the messages in the other window to further confirm the operation.

EXPORTING/IMPORTING FILES IN THE MCC

Getting files in OPS or CDE onto floppy disk, tape, mail, or on the Internet requires the file to be accessed from a machine with a disk drive, tape drive, mail server, or Internet gateway, respectively. An unavoidable step in getting the file to these devices is to get the file onto the ACCT network, where machines with floppy disks and tape drives exist. If the final destination is the Internet, then the file must be put on tape and loaded onto Andromeda, an ACCT machine which can be seen by the Internet. Here are the steps for getting a file from OPS to a floppy disk:

1. Move the file from OPS to CDE. This can only be accomplished using a CM workstation on the 5th floor of Building 30S.
2. On a CDE workstation, do the following:
 - a) Locate the file to be moved and note the path name.
 - b) Switch ('su') to your GA account.
 - c) Rlogin to the cde-compile1 or cde-compile2 server.
 - d) Change the directory to /transfers.out/<ga id>. Create a sub-directory to hold the outgoing files and copy the files to the new directory.
 - e) Change the directory to your home directory and run /usr/local/bin/BuildPromotionForm.sh.
 - f) Answer the questions provided by the BuildPromotionForm.sh script.
 - g) Exit out of the cde-compile server
3. On an ACCT workstation, do the following:
 - a) Rlogin to msl-server1 or msl-server2. If the transfer was successful, you should have new mail confirming the transfer of the file.
 - b) Change the directory to /transfers.in
 - c) Look for the directory with the correct user id and date and then change into that directory
 - d) FTP to the ACCT workstation you are currently using and 'mput' the file into your home directory (be sure the FTP mode is ascii for data files and binary for graphics)
 - e) Exit out of FTP and the msl server
 - f) Locate an ACCT workstation with a floppy disk drive and ask the user of the workstation to insert the disk into their disk drive.
 - g) Rlogin to the workstation with the disk and type 'mountfd' to mount the disk directory.
 - h) Change the directory to /pcfs and copy the file to this directory.
 - i) Change the directory to the parent directory of /pcfs and type 'umountfd'.
 - j) Now you have unmounted the floppy directory. Type 'eject' to eject the disk from the drive, and quit the rlogin to the other workstation.

PRE-LAUNCH ACTIVITIES

Pre-launch activities consist of verifying that the GNC DNAV menubar works as expected, and clearing the flight specific directories. Files in the following directories should be deleted as necessary:

- /users/gnc/Data/SSP-XXX/IMUDrift,
- /users/gnc/Data/SSP-XXX/MEDS, and

- /users/gnc/Data/SSP-XXX .

After the last certified SIM for the upcoming mission, files in the directories above with the extensions .out, .med or log. should be deleted or moved to a temporary location for disposal at a later date.

MAINTAINING AND GENERATING APPLICATION NOTEBOOKS

GNC Application Notebooks reside electronically in MS Word format on the Department 4580 website. The URL is:

http://usa1.unitedspacealliance.com/usahou/orgs/45-80/prop_guid_app_nb.cfm#gnc

Physical copies of the Application Notebooks are considered the official versions. These folders are located in Bldg. 4N, Rm. 1006 and must be checked in and out of the bookshelf where they reside.

To update an existing Application Notebook, follow the steps below:

1. Copy the electronic version of the notebook to a file on your computer hard drive.
2. Edit the notebook and save when complete.
3. Print a physical copy of the notebook and place it in the Application Notebook folder. When replacing an older version, be sure to retain any old test cases and miscellaneous notes from the previous versions.
4. E-mail the new version of the Application Notebook to the Curator of the Department 4580 website. That person will save the file on the web server and update the link to the new file.

For new Application Notebooks, steps 2 through 4 should be followed.

MAINTAINING THE ISP DICTIONARY

Users will occasionally need the ISP dictionary updated. This dictionary can be found at: /users/gnc/rw_common/cert_apps/isp_dict

The dictionary is written in a certain format which must be followed. The format is as follows: symbol:switches:owner:nomenclature

where:

- symbol is a MSID, PUI, parameter name, etc.
- switches include
 - ⇒ 'c' for comp value (local data)
 - ⇒ 'h' for server value (peer-to-peer connections)
 - ⇒ 'v' for value (integer, double or boolean)
 - ⇒ 'd' for change-only (delta)
 - ⇒ 's' for store in server
- owner is the discipline or group who owns the symbol (case-sensitive)
- nomenclature is the name of the symbol written out

After the ISP dictionary has been updated, the script, CreateLocalDict needs to be run. Then, the gnc_localnull.dictnew should be copied to gnc_localnull.dict.

ON-CALL SUPPORT

In addition to supporting the ascent and entry phases of the flight, GAs must also support other critical phases of the mission. To find out when critical phases happen during the mission, the on-call GA should contact the GNC DTR or Group Lead. Software GAs are on-call for 24 hours during a mission. The GA must keep their pager on at all times and be prepared to support the mission if called. If the GA on-call cannot support the mission, then the on-call GA must find a replacement and notify the users of the change.

MISCELLANEOUS PATHS AND COMMANDS

To edit resources: editres

To edit colors: xcolors

To count the lines of a program: ws -l filename

Xe Library source code: /amd.1/cde-cm-server/sccs_db/gnc/new_devel/lib/Xe

RCS commands: check out, locked: co -l
check in, unlocked, ci -u

REFERENCES

The following references serve as control documents for GA activities:

Software Management Plan for Mission Control Center Applications, JSC-27029

Group Administrators Handbook, SFOC-FL1134

USA Software Management Plan, SFOC-FL1113

ACRONYMS

ACA	Access Control and Audit	MCC	Mission Control Center
CDE	Common Development Environment	MOD	Mission Operations Directorate
CM	Configuration Management	MSL	Mission Support LAN
DNAV	Display Navigation	MWM	Motif Window Manager
DTR	Discipline Technical Representative	OPS	Operations
GA	Group Administrator	OS	Operating System
ILD	Integrated Load Checkout	SFOC	Space Flight Operations Contract
ISP	Information Sharing Protocol	SMP	Software Management Plan
JET	Joint Evaluation Team	USA	United Space Alliance
LAN	Local Area Network		

TITLE

ISP LIMIT MANAGER

PURPOSE

The purpose of this section is to provide a guide to configure the MCC workstation ISP Limit Manager.

BACKGROUND

The ISP Limit manager provides an interface to define monitoring limits for display on MSK, CRANS, ELOG, or to generate DVIS tones. The application provides for the setting of upper and lower limits, definition of display colors, definition of critical tones, and the definition of indicator symbols such as < and > to indicate an out of limits (OOL) condition. The manager is started from the GNC DNAV Menu. Throughout this SCP, menu selections are indicated by the following convention:

MENU 1^MENU 2^...^MENU N^<Application Name>

The MCC console is typically comprised of three displays (heads) and two Central Processing Units (CPU's). The exception is the SENSORS console which only has one CPU. Each CPU is serviced by a keyboard and mouse. The left and center heads can be controlled from a common keyboard and mouse, while the right head is controlled from its own keyboard/mouse. This was done to provide redundancy for critical operations.

In order to reduce the load on CPU's, the MCC provides for multiple workstations to be grouped together and share applications. For this reason, only one copy of the limit manager needs to be running for each group. As a practice, only one limit manager should be attached to the ISP server at a time. This will avoid conflicts between different managers which could have unpredictable results.

The manager organizes sets of predefined limits into a **checkpoint**. Checkpoints can be selected from a file menu, and are recognized by a ".cp" suffix in the filename. Checkpoints are built from **limit files**, which have a ".lim" suffix in the filename. Finally, configurations can be defined in **configuration files**, and are recognized by ".lc" in the suffix. Configuration files can contain logic which is used by the **automatic** feature in the limit manager. Configurations are arranged into **groups** and **contexts**. An example of a group would be "OMS", and a context would be "ascent". Groups and contexts are displayed in the Limit Manager window after a checkpoint is loaded. Configurations can **automatically** change limit definitions according to the appropriate conditions, e.g. major mode. A **manual** control feature is also available. In order for the limits to take effect, the limit manager must be **connected** to the ISP server from the X-window menu in the upper left corner of the limit manager window frame. This menu also allows the manager to be **disconnected** from the server.

Limits can be edited using a special editor. The editor provides for definition of MSID, numerical limit, color, and type of limit. It also allows selection of groups and contexts.

Changes are made to a checkpoint by selecting a value and **uploading** that value. Conversely checkpoint groups and contexts can be retrieved by **downloading** those files. Access to the GNC dictionary is also provided in the editor. Once the desired changes are uploaded to the checkpoint currently loaded, it must be saved in order to retain the changes.

The limit Manager also provides a global snapshot feature. This feature sends a global command to any snapshot-capable application, e.g. History Tabs, which is actively running and connected to the server. This provides a way to take multiple data points with only one command.

PROCEDURE

A. STARTING THE APPLICATION

On a G&C workstation:

1. GNC^ISP^<Limit Manager>

WARNING

Only run one Limit Manager in the group to avoid conflicts between the applications.

NOTE

The menu start script will automatically load the checkpoint and connect to the server.

B. CHANGING A LIMIT

1. Call Up the Editor:
Edit^<List> or <Symbol>

<List> displays the limit parameters in a tabular format, while <Symbol> displays individual parameters.
2. Download the Group and Context:
Select a Group and Context using the buttons on the Edit window
Download^<Merge>
3. Locate the desired parameter(s) and edit as desired.
4. Select the new parameter(s) by pointing the cursor at the MSID, press Ctrl, and double click the left mouse button.
5. Upload the new value:
Upload^<Replace><Values>
6. If the changes are to be permanent, save them to the limit file:
File^Save As^<filename> <OK>
7. Close the Editor:
File^<Close>

8. If the change is to be permanent, save the checkpoint:
In the Limit Manager Window:

File^<Save>

C. CHANGING A CONFIGURATION

NOTE

This can only be done prior to recalling a Checkpoint File

In the Limit Manager Window:

1. Options^<Configuration>
2. Start the Editor:
Edit^<List>

In the Editor Window:

3. Select a Group and Context using the buttons on the Edit window
4. Save each Group and Context:
File^Open^<Limit File> <OK>
Edit^<Select All>
Upload^<Merge>
5. Close the Editor:
File^<Close>
6. Save the checkpoint:
File^<Save> or <Save As>

D. SAVING A CHECKPOINT

In the Limit Manager Window:

File^<Save> or <Save As>

E. SELECTING A NEW CHECKPOINT

In the Limit Manager Window:

1. File^<Open>
2. Select a file, then OK
3. Check that the server is connected and limits Enabled. Connect the limit manager to the ISP server by selecting the X windows menu in the upper left corner of the window:

X Windows Menu^<Connect>

F. ENABLING LIMIT SENSING

In the Limit Manager window:

Select "Enable", then connect the manager to the ISP server by selecting the X windows menu in the upper left corner of the window:

X Windows Menu^<Connect>

G. DISABLING LIMIT SENSING

In the Limit Manager window:

Select "Disable"

H. TAKING A GLOBAL SNAPSHOT

In the Limit Manager window:

Options^<Snapshot>

TITLE

MCC WORKSTATION OPERATIONS

PURPOSE

The purpose of this section is to provide a guide to configure the MCC workstation to support flight operations.

BACKGROUND

The MCC workstation requires certain applications to be active in order to effectively monitor shuttle flight operations. This SCP provides a list of recommended applications which will provide the minimum tools required to support operations. Detailed instructions on individual applications should be referenced in the appropriate SCP. Menu selections are indicated by the following convention:

MENU 1^MENU 2^...^MENU N^<Application Name>

The MCC console is typically comprised of three displays (heads) and two Central Processing Units (CPU's). The exception is the SENSORS console which only has one CPU. This was done to provide redundancy for critical operations.

The GNC workstation configuration is:

GNC console	left cpu	white-fcr2	DEC 900
GNC console	right cpu	white-fcr21	DEC 300
Control console	left cpu	white-mps11	DEC 900
Control console	right cpu	white-mps14	DEC 900
Sensors console	single cpu	white-mps12	DEC Alpha

USER CAUTIONS

1. Do not start Limit Manager or Channelization unless valid data is present (No "M" status). Doing so can lead to incomplete setting of limits, and unpredictable effects on commfault status.
2. Do not start more than one Limit Manager, Channelization, Publish CRANS, or Dracula. Doing so will lead to conflicting data and unpredictable results to display data.
3. All Publishing applications (Dracula, Published CRANS, etc.) are required to be run from the same CPU, typically these should be run on WMPSR 11.
4. Do NOT minimize channelization until the initializing process is complete. Minimizing the application during its initialization has been observed to cause it to crash 5% of the time.

A. LOGIN PROCEDURE

1. Log into the desired workstation(s).

NOTE

For FCR only operations during flight, it is required that both the left CPU's in the GNC and Control consoles be logged in under the on console personnel's userid. The left CPU on the Control console shall be paused as required for security issues.

2. Select the appropriate activity.
3. Wait for the login function to complete. When supporting a test, simulation, or a flight, either white-fcr2, white-mpsr11, or white-mpsr14 (left CPU on the GNC console, and either Control CPU's) must be logged on to automatically receive GNC ISP data to GNC ISP applications. (This includes displays, computations, elog, rtplot, etc.) If data is desired, and one of these workstations is not available see part B, NAP Operations, of this SCP to receive real-time data from the GNC ISP server.

NOTE

For FCR only operations it is highly recommended, but not required, that the ISP server be running on the Control CPU's and isplimit and ispchannel be running on the GNC CPU. If the server is running on the FCR console, it may be moved to the Control CPU by commanding the GNC CPU to leave, and then join the NAP group. See section B of this SCP for details.

4. Start a display. On the desired head:

GNC^Displays^<desired display>

5. Start Publish CRANS. GNC^RealTime^Publish to ISP server

Note: User configurable entries will need to be made at this time. These include selection of VP slots used to drive ELOG and MSKView star tracker mode.

NOTE

Only run one version of Publishing applications in the group to avoid conflicts. All Publishing applications (Dracula, Published CRANS, etc.) are required to be run from the same CPU, typically these should be run on WMPSR 11.

6. Start CRANS.
GNC^RealTime^Ascent/Entry/Orbit

Note: User configurable entries will need to be made at this time. These include star tracker VP and types, and TACAN types. Failure to do so may disable CRANS logic and result in misleading indications.

7. Start ELOG.
GNC^RealTime^<desired ELOG>

NOTE

ELOG writes to a file log, and two applications writing to a common file can create application problems. The start script for GNC and TCS ELOG writes a unique file for the GNC (WFCR 2 & 21), Control_Support (WMPSR 11 & 14), and Sensors (WMPSR 12)

positions. Do not start more than one GNC and TCS ELOG from those positions. ELOG's started from any other workstation will write a unique file based on the CPU name. Do not start more than one GNC and TCS ELOG for any one CPU.

8. Start RTPLOT.
GNC^RealTime^<desired RTPLOT>
9. Start SPECS
If a DPS is logged in and has SPECS started, select the data source from DPS. This will ensure the scratchpad entries displayed will be in synch with the rest of the FC team:

Master^Shuttle^DPS^Real-Time(data from DPS)^<SPECS>

If no DPS is available, select the data source as the local machine:

Master^Shuttle^DPS^Real-Time (data from local servers)^<SPECS>
10. Start Onboard Fault Summary (OFS). Multiple numbers of this application may be started if the BFS fault summary is desired. If a DPS is logged in and has OFS started, select the data source from DPS. This will ensure the messages displayed will be in synch with the rest of the FC team:

Master^Shuttle^DPS^Real-Time (data from DPS)^<Onboard Fault Summary(OFS)>

If no DPS is available, select the data source as the local machine:

Master^Shuttle^DPS^Real-Time(data from local servers)^<Onboard Fault Summary(OFS)>
11. Start the comp pbi.
GNC^Apps^<PBI (WS & MOC comps)>
12. After valid data is flowing, start ISP Limit Manager. This will automatically adjust display limits based on Major Mode:
GNC^ISP^<Limit Manager>

When the Limit Manger window has started, it will automatically connect to the server, load the gnc checkpoint, and select automatic.

NOTE

Only run one Limit Manager in the group to avoid conflicts between the applications.

13. After valid data is flowing, start ISP Channelization:
GNC^ISP^<Channelization>

The Channelization will be rebuilt using the Shuttle Data Tape (SDT). When the graph build is complete, select Automatic (Real Time) to enable automatic commfaulting of data.

NOTE

Only run one Channelization in the group to avoid conflicts.
Do NOT minimize channelization until the initializing process is complete. Minimizing the application during its initialization has been observed to cause it to crash 5% of the time.

14. Start Dracula.
GNC^Apps^Dracula^<Start>

NOTE

Only run one Dracula in the group to avoid conflicts between the applications. All Publishing applications (Dracula, Published CRANS, etc.) are required to be run from the same CPU, typically these should be run on WMPSR 11.

15. Send Roll-to-Roll matrices to ISP.
GNC^ISP^Value Manager

When the Value Manager window pops up, send the roll-to-roll matrices to the ISP server by performing the following actions in the Value Manager Window:

- a. Select FILE, then OPEN.
- b. From the pop-up menu, select the appropriate file, from the FILES list.
For a simulation, select sms_rollroll.val
For flight operations, select the file for the appropriate vehicle ID.
- c. Once the appropriate file is selected, click OK.
- d. Select TRANSMIT, then ALL.

When these steps are completed, the roll-to-roll matrices should be available to the ISP server. If they are not, then the "Ck RI to RI" field in the ORBITER STATUS matrix in CRANS will be yellow, indicating that the roll-to-rolls are not available to ISP. In addition, if the roll-to-rolls are not available to ISP, the IMU Comps will not be able to be displayed on MSKView and will indicate "M" for missing data. If the roll-to-rolls are available to ISP, the field in CRANS will read "RI to RI In" and will be gray, and the roll-to-rolls will be displayed on the REFS/ROLLS/QUATS MSK View display.

16. Send IMU Gyro Drift Bias and IMU Accel Bias to the GCS

Load Gyro Drift Bias and Accel Bias into GCS per SCP's 2.4a and 2.5a.

NOTE

For Flight Operations, the SENSORS operator should have already sent the loads to the GCS during the prelaunch timeframe after completion of the IMU calibration using IRAMS calibration data. The SENSORS operator should have sent the loads to the GCS per GNC SCP 1.4 PRELAUNCH CONSOLE OPS.

17. Send IMU REFSMMATS to the GCS. GNC^RealTime^Send Launch
REFSMMAT^OV xxx

Load REFSMMAT in GCS per SCP 10.11a.

NOTE

For Flight Operations, the SENSORS operator should have already sent the REFSMMAT load to the GCS during the prelaunch timeframe at T-4 minutes after the IMUs were moded to inertial navigation submode. The SENSORS operator should have sent the loads to the GCS per GNC SCP 1.4 PRELAUNCH CONSOLE OPS.

B. NETWORK AUTOPILOT (NAP) OPERATIONS

The ability to manage specific aspects of Network Autopilot (NAP) has been provided to allow the flight controller the ability to properly configure ISP servers and computations for workstation failure cases and for off nominal workstation assignments.

NOTE

Due to workstation loading, it is strongly recommended that NAP be started only a model 900 workstation. This will prevent CPU overload in most cases.

NAP is specific to a particular MCC activity. If logging into a flight following activity (example: uncert software and no MOC), there will be no data available until NAP is manually started on a flight following workstation. This assumes the standard DEC 900's are configured to support the flight. (GNC & Control left CPU's.)

Running NAP on a workstation assigns the workstation to the "GNC Processing Group". What this means is that the workstation will be assigned GNC background applications ISP servers and computations, to be used by all applications requesting GNC ISP data, whether or not the application is running a workstation that is part of the GNC processing group. This is accomplished by registering desired workstations with the Network Registration Services (NRS) server. NAP will then assign each server and computation to specific workstations in the GNC Processing Group. This will allow all workstations to have knowledge of where the GNC ISP data is available from. When an application is started that requires data from the GNC ISP server, it will check with NRS to determine where the GNC ISP server is running, and then will request the desired data directly from the GNC ISP server on the specific workstation via the LAN.

1. Viewing the NAP configuration on GNC workstations

The menu command to view the GNC processing group configuration is:

`GNC^NAP^Show NAP Configuration`

This command will open a window showing a graphical distribution of NAP managed applications. (ISP servers and computations.) Each workstation in the GNC Processing Group will be shown with the applications assigned to run on it below the workstation name and attached via a line. The workstation running the Processed Telemetry Message (PTM) ISP server will be shown in purple. The name for the PTM server is "ispdacq", and the MTM server is "ispdacqMTM".

2. Joining the NAP group

The menu command to join the GNC processing group is:

`GNC^NAP^Join NAP group`

This menu option will start NAP on the workstation. The workstation will be registered with NRS as available to run ISP servers.

If NAP is already running on a GNC workstation(s), it will redistribute applications (computations) for load sharing purposes. ISP servers will not move unless the workstation running the server is either removed from the NAP group, logged out, locks up, or crashes.

If NAP is not currently running on a GNC workstation, the ISP servers and computations will all start on the workstation and data will be available.

3. Leaving the NAP group

The menu command to leave the GNC processing group is:
GNC^NAP^Leave NAP group

4. Recovery steps if NAP moves the ISP server to a different workstation

If the PTM ISP server is moved to a different workstation, or recycles on the same workstation, the following applications must be reconfigured:

- | | |
|------------|--|
| ispvalue | Roll-to-roll matrices, and any other specific static values previously sent to the ISP server, must be resent via the normal method. |
| ispchannel | If the workstation failed (i.e., crashes, hangs, or is rebooted), ispchanel needs to be disconnected, and reconnected via the mwm menu. (Upper left corner of the window.) |

C. UNIX COMMAND UTILITIES

To make use of the documentation, the following key naming conventions will be used throughout this section:

- A key by itself will be shown in lowercase (e.g., "pf7")
- A key used in combination with the shift key will be shown in uppercase (e.g., "PF7")
- A key used in combination with another key will be shown in a hyphenated form (e.g., "ctrl-c")

The keyboard is the means by which you communicate with the system.

The following is a list of the most used commands. For a more complete list of commands and options, see the Reference Manuals listed at the end of this SCP. When executing a UNIX command, the following keys can be helpful.

<u>KEY</u>	<u>USAGE</u>
return	execute the command
ctrl-c	cancel a command
ctrl-u	cancel the command to the left of the cursor on the command line
del	delete one character to the left of the cursor

Clearing The Screen

- To clear the screen of all text:

clear

Copying Files

- To make a copy of a file:

cp filename copyfilename

Deleting Files

- To delete a file from a directory:

rm filename

Making A Directory

- To create a directory in your current directory:

mkdir directoryname

Printing Files

- To print a file, ensure the printer is online.
- To print a file:

lp filename

Renaming A File

- To rename a file:

mv oldfilename newfilename

Viewing A Directory

- To view the contents of your current directory:

ls [-lasdR]

-l	long format
-a	all entries (including ".")
-s	report size in blocks
-d	directory status
-R	show files also in subdirectories

where the above options may be concatenated.

Viewing A File

- To view a particular file (selective viewing):

more filename

or,

page filename

This will display the file on the screen. If the file is more than one page long (CRT or screen page), the display will stop at the end of the page and prompt you "-- More -- (xx%)", indicating that you have already viewed xx percent of the file. You may press the space bar to view the next page, press return to view the next line, or ctrl-c to exit viewing the file. Press the "H" key to display the options that can be used with this command.

- To view a particular file (continuous scroll):

cat filename

To stop the scrolling for viewing a particular portion of the text, press ctrl-s. To continue the scrolling, press ctrl-q.

Working Directory

- The working directory is the directory you are currently in. To return to the login directory from the working directory:

cd

- To change from the working directory to any subdirectory:

cd path

where path is the list of directories which must be traversed to get to the subdirectory where you wish to go.

D. DOCUMENTATION

If you need additional help in understanding the system, the following documentation is available.

UNIX System Administrator's Guide - This manual contains instructions to be followed by the system manager for adding new users to the system, performing system updates, administrative and other procedures.

VI Text Editor Reference Manuals - Many versions of these guides are available. These are a quick reference to the commands and keys used when this editor is invoked. On line documentation is also available via the "man vi" command.

Introducing the UNIX System - This is a general introduction to the UNIX operating system. It contains all common commands and examples. It also discusses file systems and general

operations. Online documentation of specific commands is available via the "man <command name>" command.

A User's Guide to the UNIX System by Rebecca Thomas and Jean Yates - This paperbound book provides a general introduction to the UNIX operating system commands and concepts. The book also contains tutorials for the beginner to follow.

Principles of FORTRAN 77 Programming by Jerrold L. Wagner - This paperbound book provides a reference guide to FORTRAN 77.

Introducing the UNIX System by Henry McGilton and Rachel Morgan - A good book describing the UNIX operating system. It has a lot of useful information concerning commands and system procedures.

The C Programming Language by Brian W. Kernighan and Dennis M. Ritchie - This book is meant to help the reader learn how to program in C. It contains a tutorial introduction, separate chapters on each major function of C, and a reference manual.

TITLE

Emergency Mission Control Center (EMCC) and Temporary Mission Control Center (TMCC) Operations

PURPOSE

This procedure describes the GNC related actions required to support ground operations from EMCC or TMCC. The background section describes the philosophy and current implementation of the EMCC and the TMCC. The procedures section describes considerations for the TMCC and how to prepare for and execute EMCC operations.

BACKGROUND

I. PHILOSOPHY

The TMCC and EMCC are temporary backup facilities capable of providing essential ground operations for any STS flight should the Mission Control Center (MCC) be rendered inoperable. Emergency operations may be declared and activated in the event of severe local weather, sabotage, loss of communications, or general loss of FCR/MPSR capabilities. FCOH SOP 2.7, MCC Emergency Procedures, outlines these conditions. If an MCC team is not available between the time the TMCC or EMCC activation occurs, and the time the JSC flight control team goes off station, the network manager at Goddard Space Flight Center (GSFC) assumes command of the mission. Once the JSC operators are on station and ready to resume operations, ground control is handed over to either the TMCC or EMCC.

The TMCC is designed to provide an unclassified temporary backup to the MCC for orbiter orbit/deorbit support for a period of up to 10 hours or longer if necessary (Ref. FCOH SOP 2.10, Temporary Mission Control Center). The operational requirements are based on the philosophy of continuing on-orbit support while maintaining a primary or secondary landing site safe flight termination capability. The TMCC is generally a voice only operation. However, depending on the activation circumstances, limited data may be available. Primary vehicle systems monitoring is the responsibility of the crew who will relay necessary indications to ground personnel, if required. Provisions for a TMCC capability will continue as an operational requirement until the MCC is restored to an operational state, or the EMCC has been activated.

The primary goal during EMCC operations is to plan for and execute a deorbit to the next Primary Landing Site (PLS). These activities include verification of systems configuration and monitoring of critical parameters. Secondary goals are to establish tables for deorbit opportunities, ground site acquisitions, and TDRS acquisitions, and to monitor secondary parameters. The EMCC operators will not perform payload activities other than safing, stow, or jettison.

For specifics on EMCC activation, reference the Space Program Emergency Mission Control Center Activation and Operations Procedures (450-CAP-EMCC) in the EMCC box or in the GNC library. This document is under the configuration management of the GSFC Customer

Commitment Office Configuration Control Board (CCB), Code 451, and has been placed on the Mission Operations and Data Systems Directorate (MO&DSD) Online Services (OLS).

The maximum support time for EMCC operations is 48 hours. Control will be returned to the MCC as soon as possible. If the EMCC team designated preflight is deemed insufficient by MOD then additional support may be dispatched from JSC. For GNC, additional support should be requested if known systems failures exist that complicate deorbit and entry planning operations in either the SENSORS or CONTROLS subsystems.

For operators in the MCC when an incident occurs, it may be necessary to carry out the JSC Contingency Plan (FCOH SOP 2.8) per Flight Director orders.

II. IMPLEMENTATION

The TMCC will be located on site at JSC in Building 4N, room 3025. An alternate location (activated at the discretion of the Flight Director) may be utilized in Building 5. These locations are situation specific, and are intended to provide a common location for flight control team members, primarily voice-only communication with orbiter crew, and, if possible, ready access to data source locations (Building 5 workstations). When the TMCC is activated, the on console Flight Director will determine the time and location of the TMCC.

The EMCC is located in one of the three firing rooms in the Launch Control Complex (LCC) at the Kennedy Space Center (KSC) on Merritt Island, Florida. When EMCC support is required, a designated primary flight control team and their support equipment will be flown via a government provide aircraft (likely the NASA KC-135) from Ellington Field to the Shuttle Landing Facility (SLF) at KSC. For GNC, the EMCC controller is typically the Ascent/Entry GNC assigned to that mission (determined preflight when the COFR statement is submitted and posted on the S:\ drive). Each team member will make their way to Ellington within 2 hours of EMCC activation. The JSC transportation duty officer will ensure that each team's EMCC materials are transported to Ellington. JSC security officials will handle gate access at Ellington. Ground transportation to the LCC will be provided upon arrival at the SLF. A backup flight control team may also be dispatched to KSC if the Flight Director deems multi-shift operations necessary. In addition to the primary and backup flight control teams, Mission Management Team representatives may be dispatched for support at the Huntsville Operations Control Center at Marshall Space Flight Center. A surgeon team will be dispatched to the primary landing site.

A 17-member primary EMCC flight control team consists of FD, CAPCOM, FDO, Entry Support Engineer (ESE), GPO, INCO, GC, TRAJ, FAO, EECOM, EGIL, MMACS, GNC, PROP, DPS, PAYLOADS, and PAO. Each team member is at least an orbit certified FCR operator, except for the CAPCOM and FDO, who must be entry-certified. A 17-member backup team if/when additional manning is required at the EMCC to meet extended duration operations.

The primary **EMCC facilities** consist of the existing LCC firing room consoles being supplied a telemetry stream from the NASA Ground Terminal (NGT) at White Sands, NM. The LCC facility is capable of processing all of the parameters in the telemetry stream, although all of these parameters may not be available on predefined displays. Special EMCC hardware taken to KSC from JSC includes several portable computers for flight dynamics computations. Any electronic devices (including lap-top computers, cell-phones, pagers, etc.) must be pre-approved to be brought into the LCC at KSC (due to EMI restrictions). This equipment will be

crated and moved, along with a flight control team, to KSC. The FAO will supervise the aircraft loading and unloading operations and maintain the manifest.

Upon arrival at KSC, this equipment will be set up in the designated LCC firing room and verified operational. A map of the console positions in the LCC is included here in Figure 11.11-1, and a picture of the GNC console is shown in Figure 11.11-2. KSC operators will assist the JSC flight control team with console operations, provide headsets, and help the team to identify useful displays. LCC facilities include voice keysets, clocks, telephones, facsimile machines, document reproduction machines, and communication and power connections for the JSC-provided equipment. KSC has a PC system that contains MS Office and other normal tools. These PCs do accept CDs but software and hardware compatibility should be checked before bringing any PC based applications (i.e. some CD-ROM drives do not run if certain brands of CDs are used, or certain types of software is used to burn the CD-ROM disc.) The GC will provide a flight-specific list of LCC telephone numbers to the flight control team. Two-way pagers and cell phones are not allowed in the LCC. Three copies of the Flight Data File will be made available to the EMCC team by the FAO. The FDF used by the EMCC team is a crew copy taken from one of the simulators (GNS, Motion Base SMS, or Fixed-Base SMS). This FDF is different than the FDF normally used on console. The Commander/Pilot FDF in particular is significantly different than the FDF used in the MCC because it does not contain 'cue card' procedures in the books. Instead the CDR/PLT versions of the FDF have separate bags full of individual cue cards that must be sorted and used individually, and are not located in the individual books. If possible, use a Mission Specialist (MS) copy of the FDF that does not contain separate cue cards.

Telemetry monitoring at KSC is done using two systems, GOAL and PC GOAL. The GOAL system works much like the old "green screen" displays in the old MCC. Each monitor at each position can retain up to 6 displays in memory, and the operator has to toggle between displays. Data is specific to each console, meaning that the GNC data is only available on the GOAL displays at the GNC console. This is not true for the PC GOAL system. Each console also has two or three PCs that run PC GOAL. PC GOAL makes data from all the orbiters systems available to all users. Only DPS is capable of monitoring the Onboard Fault Summary Display, meaning that DPS and the crew will have to announce all FDAs to the team. Crew keystrokes may be available on PC GOAL, but will certainly be monitored at the DPS console. Another application that may be useful is 2 stage LPS DMON (Data Monitor). This is a build able display that may be used to view the values of MSIDs, and usually takes between 5 and 20 minutes to build. Each DMON is exclusive to the LPS console at which it was built, and a user can have up to three DMONs per console. A reference guide of the LCC displays is provide here in Appendix A, arranging the displays by both system and mission activity.

Tracking data, high-speed filter, trajectory processing, groundtrack, and the ability to evaluate orbiter energy are not available in the LCC. This leads to the loss of the ability to evaluate TACAN, Air Data, MLS, GPS, and IMU dilemmas and entry performance by comparing the on-board telemetry to the ground filter. Delta state updates, landing site redesignation, landing site uplinks, and GCAs are not possible from the LCC.

It is possible to send **commands** to the PASS S/W using the two-stage buffer and manual hex word build and verification process. The commands must be uploaded as one 16-bit hex word at a time. Currently, the only commands that are thought necessary are the orbiter state vector, a target state vector, and an SPC to hand down to MILA during the entry. The GPS state vector may be used as a possible replacement for the orbiter state vector command.

GNC has no “mandatory” commands for EMCC operations. IMU Gyro, IMU Accel, and IMU REFSMMAT uplinks are considered contingency-only requirements to deal with a system failure. However, there currently is no mechanism to evaluate IMU gyro drift and accelerometer biases on an axis-by-axis basis. KSC is only able to monitor total IMU misalignment (RSS'ed) and total IMU accelerometer error, and IMU uplinks must be performed on an axis-by-axis basis. Unless KSC ground computations are updated or changed in the future, there is no way to compensate the IMU gyros and/or accelerometers from the EMCC. There is no ability to send commands to the BFS, so the entry checklist procedure to update the BFS IMU gyro/accel loads will not be performed under EMCC operations. Communication will occur using the **KSC OIS loops** in the same manner as voice loops are used here at JSC. The voice loop configuration is shown here in Figure 11.11-9. The OIS system is easy to use and reconfigure. Some LCC consoles can monitor 4 loops while others can monitor 8, and the volume of each loop is adjustable. The GNC console in the EMCC is only capable of monitoring 4 loops at a time. Loop configurations are pre-defined using function keys on the OIS panel. GNC will use OIS 171 to contact MCC-Houston once on station at the LCC for a hand-over (if MCC-Houston is available for a handover). The GNC at the EMCC will go by the call-sign “Cape GNC”, and the GNC at the MCC in Houston will go by the call sign “Houston GNC”.

Limited history tab, **plotting**, and Strip Chart Recorder capabilities are available upon request (but not predefined) at the EMCC. Playback data is available from the LPS common data buffer if the parameters are identified and recorded beforehand. Operators who wish to become more familiar with the LPS displays prior to supporting a flight in an EMCC role may visit the MER or SAIL when their LPS displays are in operation (generally near mission time). Hardcopies of the latest KSC LPS displays are available in the EMCC box for familiarization purposes.

III. Differences in GNC console ops between MCC-Houston and EMCC

- No BFS Uplink capability (cannot uplink IMU Gyro and Accel Bias comps in OPS 3)
- PASS Uplinks must be built and uplinked manually via HEX memory address and value.
- No expectation that PC tools or offline applications are available or can run on KSC PCs. KSC does not allow ‘outside’ PC applications to run on their PCs in the LCC.
- Must use MANY (12+) KSC LPS displays to do what we have on 2 or 3 displays in the MCC. Before a dynamic flight phase, such as entry, take a few minutes to preload the required displays into the background for easy call-up during the dynamic flight phase.
- KSC does not apply any cal curves, scale factors, biases, or software corrections to the downlist. All you get is raw vehicle data displayed in radians, volts, arcseconds, etc. Be sure to verify the units on the display with your KSC counterpart if the data looks ‘funny’.
- C-Band data is not available in the LCC (cannot use it to break an IMU, TACAN, MLS, or AIR DATA dilemma per the flight rules (assume it is not available).
- In an EMCC scenario, to ensure a good state vector is maintained onboard the Shuttle, GPS will be taken to AUTO on-orbit, inhibited for the D/O burn, and then taken back to AUTO for entry. This is done on FDO call based on FDO state vector management flight rules/procedures.

- Once in the LCC, you do not have a MPSR from Houston. Instead the folks from KSC serve as your MPSR (along with Pointing). Once in the LCC, Pointing sits with FAO, the Flight Director, and CAPCOM.
- There is no expectation that we will know how to run the KSC headsets, loops, or displays on the consoles. That is what the KSC folks do for us! They also know where to find all sorts of data. Just ask them where to find information on IMU RPCs, or ATVC secondary delta-p's, or MPS TVC isolation valves, etc.
- No IMU comps are available (VEL_DIFF, IMU_EIGEN_COMP, etc). KSC has no mechanism to evaluate IMU gyros or accelerometers on an individual axis-by-axis basis (only total RSS'ed errors).
- Must rely on Pointing to do attitude maneuver time calculations.
- No GPS comps (i.e., GECKO) comps are available.
- Plotting capability exists, but is very limited in the LCC. The LCC plotting capability is limited to 6 parameters at a time (i.e., you need 10 parameters to assess an OMS TVC gimbal check).

PROCEDURES

I. PREPARATION

In the event that the EMCC becomes active after transitioning to the TMCC, the documents and resources that are required for EMCC should be prepared and taken to the TMCC location. Most of the basic documentation for EMCC is stored in one box as part of the group library material, though **the EMCC box usually is stored in the group lead office** rather than the library cabinets. The contents of this box should be checked for completeness and accuracy for the current mission prior to each mission as part of the Lead GNC Checklist Responsibilities (per GNC SCP 11.13), and quickly reverified once the TMCC or EMCC activation is declared. Figure 11.11-3 provides a checklist for this review.

II. EXECUTION

If the activation of the EMCC is imminent, the checklists shown in Figures 11.11-3 and 11.11-4 should be put into work. A handover sheet, shown here as Figure 11.11-5, should be completed and put in the box, summarizing the important mission specific data as it relates to GNC and possible deorbit and entry operators. Once the box is prepared with all of the current flight data, it should be moved to the drop off point, where it will be taken to Ellington Field. The drop off point for the EMCC box will be determined in real-time by the on-console Flight Director based on the reason for the EMCC/TMCC activation. From here it will be crated and shipped to Ellington Field to be loaded on the NASA aircraft for transport to KSC. The EMCC GNC will then accompany the EMCC box to the EMCC location. Once the EMCC box is shipped to Ellington Field, the MCC-Houston flight controllers should make preparations to hand over to the EMCC from either their console positions in the MCC, or from the TMCC.

Upon activation of the TMCC, flight controllers will monitor air-to-ground communication as the crew is responsible for vehicle systems monitoring. All efforts should be made to minimize extraneous conversations due to the close proximity of personnel and logistics of the TMCC location. If possible, consideration should be given to locating additional MPSR personnel in the GNC group lead office where FDF, electronic documentation and software, and A/G squawk boxes, are available for monitoring crew activities. It may also be possible to

acquire vehicle data from KSC through various network resources available on the PC. The TMCC remains active until the MCC is cleared for operations, or the EMCC is activated.

The first task to be accomplished by the EMCC team is to establish and update the orbiter state vector. The state vector is required to maintain quiescent operations on-orbit and to begin construction of deorbit targets. The LCC has complicated albeit sufficient capability to perform uplinks. For state vector updates, FDO prefers to use GPS over the manual build, load verification, and uplink technique.

A GNC is required at EMCC to provide a GNC systems expertise to the EMCC flight control team, and to support deorbit and entry operations (as required). The EMCC GNC via the morning message may provide any updates that need to be given to the crew regarding GNC subsystem configuration changes. In addition, any problem that may arise, or questions generated by the crew involving the GNC systems, may be addressed by the EMCC GNC (similar to normal console operations from the MCC in Houston). Any GNC assigned to the EMCC can expect to receive assistance from several of their counterparts at KSC, including representatives from NASA or USA or both in the areas of Flight Control, GNC, and Comm & Track.

The document entitled "Human Spaceflight Program Emergency Mission Control Center Activation and Operations Procedures", also known as 450-CAP-EMCC, contains basic information for all flight controllers concerning the activation and operation of EMCC. The GNC items specific to this document are summed up in Figure 11.11-8 (as a ready reference).

III. Lessons Learned - EMCC Drill 10/16/03

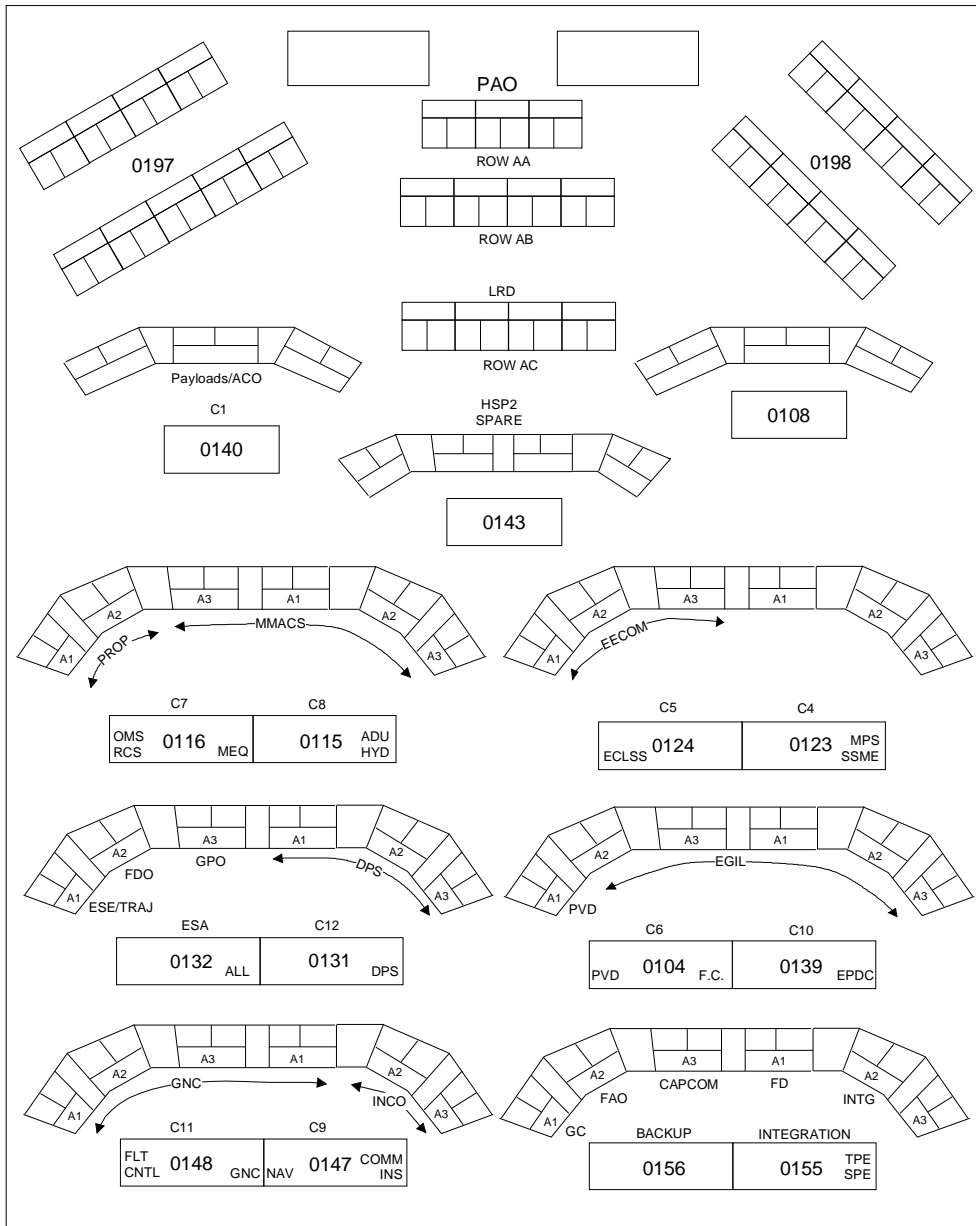
The following summary is a brief narrative of the 'full-up' EMCC Drill conducted on 10/16/03 and supported by DF62/M. Sarafin (EMCC GNC), DF62/J. Helms (Houston-GNC Support), and DF62/K. Dunn (Houston-Orbit GNC). The drill simulated a category 4 hurricane headed directly towards Galveston/Clear Lake during the STS-114 mission. At the time the EMCC activation was declared the shuttle was docked to the ISS. The drill activated an entry flight control team and deployed them to KSC on a NASA aircraft (KC-135). The EMCC team was called at home, ordered to pack a bag of personal items including a change of clothes, personal items, goodie books, etc. The EMCC team met their EMCC 'boxes' containing EMCC checklist, console handbooks, etc. at Ellington Field. The on-console team in Houston retrieved the EMCC box from the Group Lead's Office, brought it to the White-FCR per on-console Flight Director instruction, verified the contents of the EMCC box, included a quick handover sheet of recent items (see Figure 11.11-5), and placed the EMCC box in the front of the FCR for JSC transportation to pick-up and take to Ellington Field. The on-console team then proceeded to support an undock of the shuttle from ISS, followed by the deorbit IMU alignment, and start of the Deorbit Prep checklist. The EMCC boxes were loaded onto the KC-135 ('Vomit Comet') at Ellington via forklift. The EMCC team boarded the KC-135 and flew to KSC, landing at the Shuttle Landing Facility (SLF) at KSC less than 2 hours after take-off from Houston. Once at KSC, the EMCC team was transported to the Launch Control Center (LCC) via bus, and entered the LCC Firing Room #1. In the LCC, the KSC flight control counterparts had already set up the LCC consoles to monitor the on-going simulation being run from Houston. After meeting/greeting the KSC GNC counterparts (Flight Control, GNC, and Comm & Track), the EMCC GNC proceeded to determine which displays to use for the deorbit operations, configured communications loops for handover from Houston, get a headset, find the EMCC box, find a copy of the Flight Data File (FDF) brought from Houston,

and learn how to use the LPS consoles. Once settled in at the EMCC, the MCC-Houston was contacted to report that the EMCC team was 'on station'. After a brief handover with Houston, the EMCC team assumed control of the shuttle from the LCC and the Houston team 'evacuated' the MCC. The EMCC team then picked up the flight activities during the early stages of deorbit prep (Blocks 5 & 6). The EMCC then completed the deorbit burn targeting, state vector uplink, another state vector update via GPS, the deorbit burn, and entry through wheelstop. Post-landing operations were not performed. A debrief was conducted the following day.

The following is a summary of lessons learned from the 10/16/03 EMCC drill:

- The LCC Firing rooms are large, spread-out, noisy and in general not as 'user friendly' as the MCC. Each LCC console is very large and contains only 3 "in-console" monitors spaced apart by 2+ feet with a lot of dead console space in between the monitors. There are also 2 "above console" monitors that are used to run PC GOAL applications. The consoles are 4+ feet tall and are spread apart enough that it makes it difficult if not impossible to 'talk over the airwaves' to another console operator. Almost every call had to be conducted 'on the loops' because of the room configuration. The ambient noise levels in the LCC are also noticeable due to all the cooling fans and computers running in the room.
- Expect some initial anxiety and 'minor console hiccups' from being in an environment you are unfamiliar with, using new displays you are not use to using, using a different comm system, and working with a team of folks that you don't normally interact with. The KSC folks are as technically competent in GN&C systems as anyone, and know where to find data and information. Take every advantage of that fact! The KSC folks are not familiar with how we operate the hardware and software in flight, nor are they familiar with the Flight Data File (FDF).
- The LCC consoles have several noticeable limitations, when compared to the MCC consoles. Limitations include (1) only four comm loops are available at any one time (one for air-to-ground, one for the Flight Loop, one for your internal peer-to-peer MOCR loop to allow other folks to call you, and one for handover (AFD CONF) or to talk to another discipline); (2) no high-density displays are available (i.e., to perform an entry some 15+ displays must be used to scan through IMUs, Air Data, GPS, TACAN, MLS, RA, ASA, SSME Repo, etc); (3) no limit sensing is available (i.e., no Limit Manager), (4) no IMU comps are available (i.e., IMU drift, Vel_Diff, etc), and (5) no clocks are available other than GMT and countdown clocks (i.e., no TIG minus clocks, no MET clocks, etc).
- The DPS Officer and the crew are the only folks that know what onboard Fault Messages are annunciated (i.e., OFS is not available to every console). DPS is also one of the few people in the room that has good insight to crew keyboard items entries (i.e., SPECs is not available at each console). To verify that the crew completed an item entry action (i.e., ALT Body Bending Filter enabled), you must first tell DPS what to look for, then have DPS call you back to verify that those items were indeed completed. Crew reporting is also another means to verify switch settings and/or fault messages (i.e., ask the crew to verify an item entry or switch setting).
- Real-time plotting capability is limited to 6 parameters at a time - TOTAL! This includes OMS TVC gimbal checks and air data parameters.

- KSC displays have very limited status parameters. Their displays only tell you that you are/are not receiving telemetry. They do not blank specific parameters, or go static or missing if those parameters are no longer available (i.e., due to a TFL swap or OPS mode change). For example the inertial attitude displayed on the MANEUVER display is only valid in OPS 2, but looks perfectly valid in OPS 3. The only way to know that the parameter is no longer valid to see it not update, then suspect it is invalid and have KSC verify it via manual look-up-table to see if the parameters are available in the current downlist format/ops mode).
- IMU monitoring capability is very limited. At KSC only IMU torquing angles, RSS misalignment compared to the other IMUS, and total acceleration sensed by and IMU is available. You cannot see individual IMU misalignment, IMU drift, or velocity errors on an axis-by-axis basis (i.e., no VEL_DIFF, NULL_ACCELS, IMU_DRIFT, etc).
- During EMCC operations the KSC folks are the EMCC GNC's eyes and ears. They can be used to find data, check data validity, troubleshoot technical issues, monitor 'other' loops, and guide you to the correct display to view a GNC subsystem.



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Figure 11.11-1: EMCC Console Configuration in Firing Room 1



Figure 11.11-2: GNC/INCO console for EMCC activities at KSC

EMCC PRE-DEPLOY BOX CONTENT CHECKLIST (STS-)

Initials of GNC on-console during EMCC activation

- _____ Retrieve EMCC Container from 4N/105
- _____ Fill out EMCC Handover Sheet (SCP Figure 11.11-5)
- _____ Print the following
 - ___ IMUdrift log (to document IMU drift rates and times of IMU alignments)
 - ___ Current Star Uplink display (to document the Star Uplink Load)
 - ___ Current IMU Summary display (to document onboard Gyro and Accel comps)
 - ___ Current REFS/ROLLS/Quats display (to document onboard REFSMMATs)
 - ___ SSME Position Display and SSME Drift Spreadsheet
- _____ Ensure EMCC Container has the latest version of the following contents:
(Use caution not to mix MCC and EMCC items.)
 - ___ GNC Systems Briefs
 - ___ GNC Console Handbook
 - ___ SCAP Flight Critical MDM Channelization
 - ___ EMCC Activation and Operations Procedures (450-CAP-EMCC)
 - ___ CD containing off-line GNC applications
 - ___ SSSH (section 9)
 - ___ Orbiter Displays Reference Guide for the current OI
 - ___ FCR Log including GNC Pre-Flight Summary
 - ___ IMU Log/Binder
 - ___ Printed datasheets as specified above
 - ___ Hardcopies of KSC LPS Displays (EMCC Display Book)
 - ___ EMCC Handover Sheet (Figure 11.11-5)
 - ___ MRE (for emergency snack on Vomit Comet)
 - ___ EMCC Skynyrd (ready for musical deployment)
- _____ Place Container at pickup location designated by on-console Flight Director

Figure 11.11-3

EMCC GNC CONTACT CHECKLIST (STS-)

Perform only after EMCC has been activated)

Initials of GNC on-console during EMCC activation

_____ Note any specific instructions from the Flight Director for deployment.
Notes:

_____ Contact EMCC GNC and provide the following data.

_____ Notification of and reason for EMCC activation.

_____ Required time to be on station at Ellington Field.

_____ Required location to be on station at Ellington Field.

_____ Provide reminder for items to be carried.

- change of clothes
- personal items
- goodie books
- etc.

_____ Provide status of EMCC documentation transport to Ellington Field. (if known)

_____ Request full legal name and Social Security # of EMCC GNC. (KSC badging)
Legal name:

Social Security # (treat as confidential):

_____ Provide any special instructions noted above.

Figure 11.11-4

EMCC GNC Handover Sheet

Flight: **GMT:**
OV: **MET:**
Date: **Local:**

Off Going Team

Team:
Name:

On Coming Team

Team: EMCC
Name:

Orbiter Status:

Attitude: TGT:___ BV:___
P:___ Y:___ OM:___

DAP Config:
NBAT:

Last IMU Align

Time: GMT___/___:___:___ MET___/___:___:___
Type: __Star __IMU/IMU __Matrix IMUs aligned: __1 __2 __3

Current Gyro Comp (deg/hr)

	X	Y	Z
1			
2			
3			

Current Accel Comp (µg's)

	X	Y	Z
1			
2			
3			

Current Uplink Stars

101		102		103		104		105	
106		107		108		109		110	

SSME Positions

	Position	Δ Stow		Position	Δ Stow		Position	Δ Stow
	CP			LP			RP	
	CY			LY			RY	

PLB < 10,000 lbs < PLB

Notes:

Figure 11.11-5

11.11-13

HOUSTON GNC HANDOVER CHECKLIST (STS-)

Initials of Houston GNC on-console during EMCC handover

- _____ Monitor systems to give EMCC-GNC any updates to the handover information provided at EMCC activation
- _____ Monitor OIS 171 for contact from EMCC-GNC once on station
- _____ Once contact is made with EMCC-GNC, conduct a thorough handover
- _____ Ask EMCC-GNC if further support is needed or any questions remain to be answered
- _____ Provide EMCC-GNC with Houston (or alternative location) contact information
- _____ Obtain EMCC-GNC's contact information while at EMCC
- _____ Handover complete
- _____ Await release by EMCC-GNC and on-console Flight Director
- _____ Run like hell.

Figure 11.11-6

EMCC GNC ON STATION CHECKLIST (STS-)

Initials of EMCC GNC once on station

- _____ Meet KSC counterparts, introduce yourself and position
- _____ Collect all items brought to the EMCC
 - ___ Get copies of required Flight Data File (FDF) books - ORB OPS, Flight Plan, D/O Prep, Entry C/L, OPCL, EPCL, AESP, MAL, etc.
 - ___ Get GNC EMCC box.
 - ___ Get a headset (provided by KSC).
- _____ Configure Workstation (KSC should already have console logged in and running)
 - ___ Setup workstation displays for current flight phase (orbit, de-orbit prep, entry)
 - ___ Configure voice loops for handover (i.e., OIS 171 to talk to Houston-GNC)
 - ___ Activate any PC applications and offline tools as necessary
- _____ Contact Houston GNC on OIS 171 as early as possible to report "on station"
- _____ Recontact Houston GNC when "ready for handover"
- _____ Conduct handover (with Houston-GNC on OIS 171, followed by Cape Flight Director on OIS 161).
- _____ Notify Houston GNC of how to contact you at KSC (phone, fax, etc.)
- _____ Get information on how to contact Houston-GNC after MCC evacuation.
- _____ Determine if backup support will be necessary at EMCC from Houston.
- _____ Release Houston support as soon as possible

Figure 11.11-7

GNC Specific Information in 450-CAP-EMCC

- Section 1.1 - General Overview of EMCC Concept
- Section 1.4 - EMCC Ops Philosophy
- Section 2.4.8 - Flight Control Team (FCT) Responsibility Overview
- Section 2.5.1.1 - EMCC Team Members
- Table 2-1 - EMCC Firing Room Console S/W Loads for FCT disciplines
- Section 3.2 - EMCC Location
- Section 3.3 - EMCC Configuration
- Figures 3-2 to 3-4 - EMCC Firing Room Seating Chart
- Table 3-1 - EMCC Voice Loop Availability
- Section 3.5 - EMCC Telemetry Availability
- Section 4.6.1.3 - Call Signs to be used in the EMCC "i.e. EMCC GNC"
- Figure 4-10 - Deorbit Maneuver Pad (blank form)
- Figure 4-11 - Del Pad (blank form)
- Appendix A, Section A.2.4 - EMCC GNC Checklist
- Appendix A, Section A.3.3.7 - EMCC GNC Responsibilities
- Appendix A, Section A.4.2 - Required Documents
- Appendix A, Section A.4.9 - Required Hardware
- Supplement - EMCC Phone Numbers For All 3 KSC Firing Rooms

Figure 11.11-8

Appendix A

EMCC DISPLAY GUIDE

SYSTEMS DISPLAYS

<u>GNC SYSTEM</u>	<u>KSC DISPLAY</u>	<u>AVAILABLE DATA</u>
AA	RG/AA DETAIL DATA	RATES, ACCELS, SMRD, RM FL
AEROJET DAP	CONTROLLERS/SWITCHES	SBTC, FCS MODE...
ADP	AIR DATA SYSTEM	ADTA PRESSURE, ADP
		DEPLOY/STOW DISCRETES
ADTA	AIR DATA SYSTEM	ADTA PRESSURE, ADP
		DEPLOY/STOW DISCRETES
ASA	ASA DETAIL	RPC, DRIVER, POS FDBK,
		SEC DELTA-P
	HYDRAULICS DETAIL	APU PRESS, FCS CHANNELS
		ASA & ATVC DRIVER, POS FDBK
	FLIGHT CONTROL HYDRAUL	ASA & ATVC POS, FAIL
	AEROSURFACE STATUS	ASA POS, FAIL
ATVC	HYDRAULICS DETAIL	APU PRESS, FCS CHANNELS
		ASA & ATVC DRIVER, POS FDBK
	FLIGHT CONTROL HYDRAUL	ASA & ATVC POS, FAIL
	ATVC DETAIL	ATVC CMD, POS, FAIL ,APU PRESS
	GN 1ST STAGE ASCENT	SSME POSITION
DAP	CONTROLLERS/SWITCHES	DAP PBI, FCS MODE SWITCHES...
DDU	CONTROLLERS/SWITCHES	DDU, FCS MODE SWITCHES
FCS MODE SWITCH	CONTROLLERS/SWITCHES	ROLL MODE, TRIM SW, DAP PBI,
		FCS MODE SWITCH
GPS	GPS/NAV INTEGRATED	GPS RCVR STATUS, MODE, SATS,
		FOM, GDOP, TACAN & RA DATA
	GPS MONITOR	CHANNEL STATUS, RCVR STATUS,
		ENCRYPT KEY STATUS, LAT, LON
	GPS NAVIGATION	CHANNEL STATUS, RCVR STATUS,
		ENCRYPT KEY STATUS, LAT, LON
HYDRAULICS	HYDRAULICS DETAIL	APU PRESS, FCS CHANNELS
		ASA & ATVC DRIVER, POS FDBK
	NWS STATUS AND TEST	APU PRESSURE, RPTA
	BRAKES STATUS AND TEST	APU PRESS, RPTA, NWS
IMU	ST TRK/COAS IMU ALIGN	ST INFO, IMU INFO, STAR TABLE,
		TORQUING ANGLE, IMU RM
	GN ON-ORBIT SUMMARY	BITE, RM THOLD
	IMU STATUS/TEST SELECT	RX ANGLES, ACCELS, BITE, RPC,
		OPER/STBY IND, ALIGN
	IMU SUBMODE DISPLAY	TRANS WD1, WD2, ATT ERR,
		VEL ERROR
	IMU DETAIL DISPLAY	RX ANGLE, RED RATE,
		TRANS WD 1, WD 2, ACCEL
		DATA, RM FAIL, BITE, MODE
		STAT WD
	IMU/STAR TRACKER	ST INFO, IMU BITE, RX ANGLE,
		ACCEL
MLS	INTEGRATED NAV AIDS SYS	TACAN, MLS, RA DATA
	MSBLS SYSTEM MONITOR	AZ, EL, RNG, LOCK...
	COMM/NAV SOFTWARE	TACAN PWR, MLS PWR, RA PWR
	Unknown	Unknown (Talk w/MMACS)
MPS TVC ISOL VALVE	OMS/RCS MANEUVER	OMS TVC, DELTA-V, BURN ATT
OMS TVC		IMU RM, BITE, RATE

ORBIT DAP MODE	CONTROLLERS/SWITCHES	DAP MODE, THC, RHC...
PRL	Unknown	Unknown (Talk w/MMACS)
RA	INTEGRATED NAVAIDS SYS	TACAN, MLS, RA DATA
	RA SYSTEM MONITOR	RA ALT, LOCK, PWR...
	COMM/NAV SOFTWARE	TACAN PWR, MLS PWR, RA PWR
RCS	RCS DETAIL DATA DISPLAY	RCS JET CMD & PC
RGA	RGA/AA DETAIL DATA	RATES, ACCELS, SMRD, RM FL
RHC	CONTROLLERS/SWITCHES	RHC, FCS MODE...
RPTA	CONTROLLERS/SWITCHES	RPTA, FCS MODE...
	NWS STATUS AND TEST	RPTA TRANSDUCER
	BRAKES STATUS AND TEST	RPTA, APU, NWS
SBTC	CONTROLLERS/SWITCHES	SBTC, FCS MODE...
STAR TABLE	ST TRK/COAS IMU ALIGN	ST INFO, IMU INFO, STAR TABLE, TORQUING ANGLE, IMU RM
STAR TRACKER	IMU/STAR TRACKER	ST PWR, BITE, MODE, IMU INFO
SWITCHES	CONTROLLERS/SWITCHES	FCS MODE, DAP PBI
TACAN	INTEGRATED NAVAIDS SYS	TACAN, MLS, RA DATA
	TACAN SYSTEM	TACAN RNG, BRG, MODE, AGC...
	INTEGRATED COMM/NAVAID	TACAN RNG, BRG, CHANNEL, AGC
	GPS/NAV INTEGRATED	GPS RCVR STATUS, MODE, SATS, FOM, GDOP, TACAN & RA DATA
	COMM/NAV SOFTWARE	TACAN PWR, MLS PWR, RA PWR
THC	CONTROLLERS/SWITCHES	THC, FCS MODE...
TRANS DAP MODE	CONTROLLERS/SWITCHES	DAP PBI, FCS MODE
UNIV PTG	POINTING/RENDEZ NAV/ORB	UNIV PTG SETTINGS, PYOM, ATTITUDE, RATES,

NOTE: **BOLD ITALICS** indicate primary display for that subsystem or operation

OPERATIONAL DISPLAYS

<u>FLIGHT PHASE</u>	<u>KSC DISPLAY</u>	<u>AVAILABLE DATA</u>
IMU ALIGN	ST TRK/COAS IMU ALIGN	ST INFO, IMU INFO, STAR TABLE, TORQUING ANGLE, IMU RM
	IMU STATUS/TEST SELECT	IMU ALIGN SELECTION, RPC ACCEL, RX ANGLE
	IMU SUBMODE DISPLAY	TRANS WD1, WD2, ATT ERROR, VEL ERROR
ATTITUDE MANEUVERS	RCS DETAIL DATA DISPLAY POINTING/RENDEZ NAV/ORB	RCS JET CMD & PC UNIV PTG SETTINGS, PYOM, ATTITUDE, RATES,
OMS BURN	GN ON-ORBIT SUMMARY OMS/RCS MANEUVER	BURN ATT, IMU RT OMS TVC, DELTA-V, BURN ATT IMU RM, BITE, RATE
	CONTROLLERS/SWITCHES RCS DETAIL DATA DISPLAY HYDRAULICS DETAIL	DAP PBI MODE RCS JET CMD & PC
APU START		APU PRESS, FCS CHANNELS ASA & ATVC DRIVER, POS FDBK
ENTRY	RCS DETAIL DATA DISPLAY ASA DETAIL	RCS JET CMD & PC RPC, DRIVER, POS FDBK, SEC DELTA-P
	FLIGHT CONTROL HYDRAUL HYDRAULICS DETAIL	ASA & ATVC POS, FAIL APU PRESS, FCS CHANNELS DRIVER OUT, POSITION FDBK
GPS	AEROSURFACE STATUS GPS/NAV INTEGRATED	ASA POS, FAIL GPS RCVR STATUS, MODE, SATS, FOM, GDOP, TACAN & RA DATA
	GPS MONITOR	CHANNEL STATUS, RCVR STATUS, ENCRYPT KEY STATUS, LAT, LON
	GPS NAVIGATION	CHANNEL STATUS, RCVR STATUS, ENCRYPT KEY STATUS, LAT, LON
TACAN	INTEGRATED NAVAIDS SYS INTEGRATED COMM/NAVAID TACAN SYSTEM	TACAN, MLS, RA DATA TACAN RNG, BRG, CHANNEL, AGC
	COMM/NAV SOFTWARE HYDRAULICS DETAIL	TACAN RNG, BRG, MODE, AGC... TACAN PWR, MLS PWR, RA PWR
SSME REPO AT M=8		APU PRESS, FCS CHANNELS ASA & ATVC DRIVER, POS FDBK
	GN 1ST STAGE ASCENT ATVC DETAIL AIR DATA SYSTEM	SSME POSITION, ATT, ERR, RT ATVC CMD, POS, FAIL, APU PRESS
AIR DATA		ADTA PRESSURES, DEPLOY, STOW INDICATIONS
HAC, A&L, TOUCHDOWN MLS	CONTROLLERS/SWITCHES MSBLS SYSTEM MONITOR	RHC, FCS MODE... AZ, EL, RNG, LOCK...
	COMM/NAV SOFTWARE	TACAN PWR, MLS PWR, RA PWR
RA	COMM/NAV SOFTWARE GPS/NAV INTEGRATED	TACAN PWR, MLS PWR, RA PWR GPS RCVR STATUS, MODE, SATS, FOM, GDOP, TACAN & RA DATA
	RA SYSTEM MONITOR	RA ALT, LOCK, PWR...
POST LANDING SSME REPO BFS ENGAGE	ATVC DETAIL NAVAIDS BFS DISPLAY	ATVC CMD, POS, FAIL, APU PRESS TACAN DATA

REFERENCES

1. NASA 450-CAP-EMCC (Formerly 532-CAP-EMCC) Space Shuttle Program Emergency Mission Control Center Activation an Operations Procedures (9/02).
2. JSC-26843 Flight Control Operations Handbook (FCOH) Shuttle Operations, Final, Rev B, CPN-4 (03/23/98).
3. EMCC Drill, conducted on October 16, 2003, and supported by DF62/Michael L. Sarafin, Kevin A. Dunn, and W. Jason Helms.

TITLE

POSTFLIGHT REPORT FORMAT

PURPOSE

To provide the format for a quick but thorough completion of the Guidance and Control (GNC) postflight reports while providing for consistency between reports.

PROCEDURE

Complete the report within one month after touchdown of the flight. The lead GNC is responsible for compiling the report. The Lead GNC should use his/her discretion to determine the significant issues to include in the report. The list below provides a basic guideline but is not limited to only these items:

- A. Front page stating flight, vehicle number and the date the report was completed
- B. Title page including the name, position and signature of each GNC Flight Control Room (FCR) operator
- C. Table of contents
- D. General information such as crew names, GNC team members including On-the-job trainees (OJT's), launch and landing dates, software load, and launch inclination (Figure 11.12 -1)
- E. Prelaunch issues
- F. Significant issues/Problems worked for the flight
- G. Detailed Test Objectives (DTO's); Gravity Gradient, Programmed Test Inputs (PTI's), etc.
- H. Significant Flight Data File, Flight Rules, and Launch Commit Criteria (LCC) changes
- I. New GNC system performance
- J. Training issues
- K. Event times for both Greenwich Mean Time (GMT) and Mission Elapsed Time (MET). Include the following times and any other times for significant events such as deploys, cabin depress/repress, Extra-vehicular activity (EVA), inertial measurement unit (IMU) downmodes for powerdowns, OPS transitions after waiveoffs, etc.:

<u>EVENT</u>	<u>GMT</u>	<u>MET</u>
OPS 9 TO 1 TRANSITION	DDD/HH:MM:SS	DDD/HH:MM:SS
LIFTOFF		
MECO		
OMS 2 TIG		
OPS 1 TO 2 TRANSITION		
OPS 2 TO 8 TRANSITION		
OPS 8 TO 2 TRANSITION		
OPS 2 TO 3 TRANSITION		
DEORBIT BURN TIG		
HYDRAULIC REPRESS		
MM 304 TRANSITION		
TOUCHDOWN		
OPS 3 TO 9 TRANSITION		
SSME REPOSITIONING		

L. Appendix - Include the following:

- a. Quick-look landing data
- b. IMU Drift data
- c. As-flown Attitude Timeline (from Pointing Officer)

Place the HUD/COAS data in the HUD/COAS data books. A copy of this book is in both the Mission Control Center and the GNC library.

GENERAL INFORMATION

Launch date:
Landing date:
Vehicle:
Inclination:
Flight software load:

Crew: CDR
 PLT
 MS/EV1
 MS/EV2

GNC Flight Control Team Members

	<u>Prime</u>	<u>OJT</u>
Ascent/Entry GNC		
Control		
Sensors		
Orbit 1 GNC		
Orbit 1 Support		
Orbit 2 GNC		
Orbit 2 Support		
Planning (Orbit 3) GNC		
Planning (Orbit 3) Support		

Figure 11.12-1, Example-General Information Section of the Post Flight Report

TITLE

LEAD GNC RESPONSIBILITY CHECKLIST

PURPOSE

To provide a checklist of responsibilities for the Lead GNC operator to follow each flight.

INSTRUCTIONS

This SCP lists in tabular form the activities to work each flight. Use the blank line next to each item to sign off completed items or to note non applicable items. A description of each item follows the list. A copy of the checklist should be retained in the flight folder.

The lead GNC operator must ensure that all required items are completed, but can delegate activities to team members and group personnel.

PREFLIGHT RESPONSIBILITIES

Date & Sign, N/A

1. Support Payloads Operations Working Group (POWG) and/or Joint Operations Panel (JOP) meetings. _____
2. Schedule a DAP tag-up with Draper Labs and Engineering Structures (ES) personnel. Review payload operations which require off-nominal orbit DAP configurations. Determine if real-time uplink of control accel (notch filters and/or mass properties) is anticipated. Obtain a copy of the Draper Labs' DAP Modes and Constraints Memo. _____
3. Provide Flight-specific Workstation Requirements _____
4. Schedule IMU star alignments (SOO and/or maneuvers) and HUD calibrations (when required) with FAO _____
5. Coordinate with INCO for time periods where GNC low data rate TFL will be used. Verify IMU align, HUD calibration, GPS DTO, SIGI DTO plans are in place for GNC low data (if required). Provide low data rate times and activities to DTO sponsors, and FDOs/GPOs (for use with GPS) as necessary. _____
6. Coordinate elevon positioning (park) with PROP, FAO, and PAYLOADS, if required. _____
7. Ensure flight-specific FDF inputs are in place. Inputs should include Items on (as necessary); Auto reboost, TCS, THC power-up transients, GPS DTO, SIGI DTO, DAP tuning DTO, Structural DTO, Entry PTIs, etc). (Elevon schedules, PTIs, Body Bending Filter, RCS Critical Entry CC, TCS entry config, THC power up transients, GPS config., etc.) _____
8. Review Flight Specific LRU configuration (I.e., Star Trackers, TACANs, TCS, etc). _____
9. Verify Flight-Specific Mission Rules _____
10. Provide LCC/MEL/MML inputs (ref. SCP 11.14 for MEL) _____
11. Review training issues and test schedules _____
12. Track vehicle status _____
13. Coordinate Orbit Variable Parameter (VP) plan with Lead DPS Officer _____
14. Organize GNC team briefing _____
15. Ensure INCO has current GNC command procedures _____

16. Produce Flight Readiness Review (FRR) data pack _____
17. Review OPS Notes and Waivers _____
18. Verify with the GNC GA that the workstations have been configured for flight operations (L-30 days) _____
19. Check availability of EMCC documents _____
20. Check console document readiness to ensure latest document version on console per DF Master list on web and FDF Errata pack. _____
21. Ensure required Calibration Curve Updates to the FEP _____
22. Distribute pagers _____
23. Tag up with KSC, BNA, and Rockwell USA counterparts. _____
24. Assign Postflight Report topics, if required _____
25. Ensure the flight directories on all workstations get cleaned out. (L-2 days). _____

POSTFLIGHT RESPONSIBILITIES

Date & sign, N/A

-
- | | |
|--|-------|
| 1. Gather flight data | _____ |
| 2. Verify COAS/HUD plots are updated (when performed) | _____ |
| 3. Attend Crew Debrief Meeting(s) | _____ |
| 4. Construct GNC Quick Look report | _____ |
| 5. Submit FD evaluations | _____ |
| 6. Organize Section TAG UP | _____ |
| 7. Write GNC Postflight Report | _____ |
| 8. Send IMU data to Engineering Directorate counterparts | _____ |
| 9. Submit flight team roster | _____ |
| 10. Report GNC-sponsored DTO results | _____ |
| 11. Create flight data binder | _____ |
| 12. Handover information to next Lead GNC | _____ |
| 13. Complete Post-flight Actions List | _____ |

DETAILED DESCRIPTIONS OF RESPONSIBILITIES

The following section contains a discussion of each item in the preceding checklist.

PREFLIGHT RESPONSIBILITY

1. Support Payloads Operations Working Group (POWG) and Joint Operations Panel (JOP) meetings.

Ensure support of these meetings for your flight/payloads as required. Discuss issues of interest and/or controversy with the section. If required, involve systems experts in the resolution of issues. In many cases, these meetings are well under way if not complete by the time the lead GNC starts following the mission. However, GNC input is usually requested when needed. The first POWG/JOP is typically held 6 to 12 months before flight, depending on the complexity of the mission, and whether a mission of similar payload has been previously flown.

2. Schedule a DAP tag-up with Draper Labs and Engineering Structures (ES) personnel. Review payload operations which require off-nominal orbit DAP configurations.

Schedule a DAP tag-up with Draper Labs (CSDL/Mike Martin, Ray Barrington, Rob Hall, etc); Engineering Structures (ES/James Dagan); and the lead Pointing officer to review station and/or payload operations which require off-nominal orbit DAP configurations. Pay special attention to tight attitude deadbands or high rate maneuvers, either of which could lead to control/stability problems. For Alt DAP constraints and recommendations, see "Alternate DAP Mode Constraints, Guidelines, and Performance Assessment" (CSDL-R-2380, D. Zimpfer, 1992). Determine what the DAPs are used for and set up workarounds if needed. For Spacehab flights, contact BNA/Bob Friend, since Engineering Structures/ES and Draper Labs are not typically involved with Spacehab flights. Schedule the final DAP Tag-up between MOD, Draper Labs, and ES between L-1 month and L-1 week to review mission plans and late changes.

Incorporate flight specific DAP requirements into DAP tables, reboost procedures, etc as required and allow Draper Labs and ES to review them as necessary.

Obtain a copy of the Draper Labs DAP Memo published for every flight, documenting any flight specific DAP constraints and preflight analysis.

Determine if a real-time uplink of notch filters/mass properties to define a new control accel is anticipated.

3. Provide Flight-Specific Workstation Requirements

The workstation requirements include any special comps or programs to meet flight requirements. Examples of these are the DAP Downlist Monitor (for OI-23), the star table monitor (for STS-60 low GNC data rate), and the TCS monitor (for STS-64 and subs), and the Fly-Cast Maneuver MSKView display and RTPLOTs (for STS-99). Because of the long lead times involved with development, testing, and certification, these items should be identified early. Requirements are due prior to L-3 months (prior to the 1st flight specific sim), to allow time to develop the application, time to train with it during flight specific training, and provide shelf life to resolve any bugs discovered during sims and testing, prior to the L-30 day workstation configuration management lock-down.

4. Schedule IMU star alignments (SOO and/or maneuvers) and HUD/COAS calibrations (when required) with FAO, Pointing, and Prop

Work with FAO, Pointing, and Prop early in the Flight Planning, to schedule IMU SOO aligns and/or maneuvers. Be sure the schedule is appropriate for the IMU configuration as stated in the Flight Rules. Work with FAO, Pointing, and Prop to schedule a CDR HUD calibration if an expected HUD LOS vector data has not been acquired on at least two missions after vehicle major modification or after the CDR HUD is removed and replaced.

5. Coordinate with INCO for time periods where GNC low data rate TFL will be used. Verify IMU align, star table, COAS/HUD cal, GPS DTO, DAP Tuning DTO, and Structural Test DTO plans (if required) are in place for GNC low data.

Coordinate with INCO for time periods in the flight plan where GNC low data rate TFL will be used. Verify when these periods are, how long they will last, and check that all GNC systems activities relating to these time periods can be carried out. Inform DTO customers when low data rate should be expected (I.e., coordinate with FDO/GPO for GPS operations, Engineering customers for GPS/SIGI DTOs, Draper Labs and Engineering Structures for DAP DTOs, etc.).

6. Coordinate elevon positioning (park) with PROP and FAO, if required

Elevon positioning may be used on-orbit in order to conserve propellant. If so, work with PROP and FAO to determine on-orbit elevon positioning schedule using the Orbit Ops Checklist procedure.

7. Ensure flight-specific FDF inputs are in place.

Inputs should Include Items on (as necessary); Auto reboost procedure, rule constraints, DAP table Inputs; TCS procedures and PGSC procedures; THC power-up transient procedural work-arounds; GPS DTO 700-14 operations procedures, PGSC procedures, and flight rule constraints; SIGI DTO procedures, and PGSC procedures; DAP tuning DTO procedures, rule constraints, and DAP Table Inputs; Structural DTO procedures, rule constraints, and DAP table Inputs; Entry PTI procedures and constraints, etc. Check with the section FDF coordinator on all generic and flight-specific inputs that are required. Verify that these changes are implemented correctly. Flight Specific Procedures (ORB OPS FS, Payload OPS FS, etc. are generally released in a Basic version of the applicable book at about 1-month prior to Flight Operations Review (FOR). Changes to the Flight Supplements may be made via DN at any time prior to the Flight Operations Review (FOR), which is typically held at Launch-3 months. Between FOR and Launch-1 month any Flight Data File procedure change requires a 482. All 482s must be in prior to L-30 days, unless it is a Safety-of-Flight Issue, in which case it may be processed right up to launch.

Confirm that the Ascent Switch List, Post Insertion, D/O Prep and Entry C/L books have the correct GPS switch and antenna cb configuration for the Orbiter GPS since the configurations are vehicle dependant. In addition, confirm the corresponding switch and cb configurations for GPS/SIGI Developmental Test Objectives (DTOs) that may also be manifested on these flights.

8. Review flight specific LRU configurations (i.e., Star trackers, TACANs, TCS, etc)

Review the planned STKR configuration with the appropriate Engineering Directorate subsystem managers to determine which type of LRU is flying (SSST vs IDT).

Review the planned TACAN configuration (Gould vs Collins) and associated circuit breaker (cb) configuration. Verify the configuration with the subsystem manager, KSC, BNA, USA, EGIL, EECOM, and the VITT team (if required).

All vehicles have been equipped with direct current (dc) cb's to accommodate the Collins TACAN's. This provides the flexibility to fly a mixed fleet configuration. The unused cb's will have special 'boots' placed over them to tell the crew to leave them open throughout the flight.

If this flight uses the TCS, several items need to be accomplished:

a. TCS FDF config

Verify that the Payload Ops Checklist, Entry Switch List Verification procedure contains a check that the TCS is powered off for entry, as referenced by the Deorbit Prep Checklist (since there is no easy way of verifying this through telemetry, the crew check is important). Also, check with the Rendezvous Officer to ensure the TCS procedures to be used are accurate and up to date.

b. TCS Power config

Use the Cargo Integration Review (CIR) drawings to determine the power and data connections for the TCS. Also, check INCO to see if all the TCS data will be received normally through the PDI data stream (since it may conflict with other payloads' data).

c. TCS technical support

If desired, contact the DPS/Nav and Rndz/Nav training leads to see when their training session with the crew is scheduled - GNC can usually participate in this session or request one of their own.

Obtain the TCS MER flight support schedule from Engineering counterparts (during the flight, use the GNC COORD loop to contact the TCS support personnel).

9. Verify Flight-Specific Mission Rules

Ensure that the flight rules annex contains the flight-specific GNC rules. It may contain rules in section 8, such as one for GPS DTOs. Depending on the mission type, other sections concerning the space station or payload(s) will probably contain rules relating to GNC. Be sure to cross check the Volume A and Volume C rules for any generic rule constraints (if applicable). Flight Specific rules are generally released in a Basic version of the Flight Rules Annex at about 6 months prior to flight for review. Changes to the Flight Rules Annex may be made via DN at any time prior to the Flight Operations Review (FOR), which is typically held at Launch-3 months. Between FOR and Launch-1 month any Flight Rule Annex change will require a Flight Rule CR submitted via the Workflow Flight Rule CR system available off the DA8 webpage.

10. Provide LCC/MEL/MML inputs

Check with the section LCC engineer on the status of any generic LCC changes. Minimum equipment list (MEL) inputs for flight specific requirements are due to DF T/A for systems integration about L - 19 weeks (examples include the RCS Activity Lights that were added to the MEL for STS-99). Use SCP 11.14 to get the baseline MEL for the particular type of flight being flown, and add any additional requirements as required (check with the section LCC/MEL engineer). Any flight specific requirements not listed in SCP 11.14 must be coordinated with and approved by our KSC counterparts, and the Flight Director Integration Support Office.

11. Review training issues and test schedules

Those who perform the ILC will prepare and distribute a summary of any problems to the section. Brief the flight control team on important dates such as the ILC, start of flight-specific sims, TCDT, etc.

Be aware of the certification status of the whole team Flight Controller Certification paperwork must be submitted and signed off by the Group Lead no later than L-30 days, unless a waiver is submitted with the FRR package.

During training, remind the crew of hardware specific behavior (Examples include LRUs that nominally fail self-test (star trackers, AADTs, etc.)).

12. Track vehicle status

The lead person should periodically check the status of the Orbiter in its preparation for flight. This is accomplished mainly through the daily status reports from KSC which are distributed on email, or by checking the status on the internet (address: <http://p51.ksc.nasa.gov>). To be familiar with any anomalies that will be flown as is, GNC Post-Flight Reports should be reviewed.

13. Coordinate Orbit Variable Parameter (VP) plan with Lead DPS Officer

The lead should coordinate any Orbit VP requirements with the Lead DPS Officer no later than L-1 month. Inputs provided to DPS should include the parameters required including the memory address and nomenclature, and the time frame required (i.e., docked phases, etc). The Lead DPS Officer will build the uplink loads necessary to support GNC VP requests and coordinate the use of all VP slots with the VP users. Examples include Orbit DAP Undesired Accelerations for R, P, Y, required during docked phases, and Star Tracker Mode Flags during all orbit phases.

14. Organize GNC team briefing

Brief the teams on the specific objectives, configuration, and constraints of the mission. Include payloads, DTOs, PTIs, unique DAP constraints, new procedures, contingency flight note procedures, contingency IFM procedures, etc.

15. Ensure INCO has current GNC command procedures

INCO maintains three copies of the Command Procedures Handbook (one for the flight director, one for INCO, and the master copy in DF24). It is GNC's responsibility to ensure

that INCO has the most recent versions of the command procedures from the GNC Console Handbook. (If a procedure change is made, GNC must get FOIG approval before using the change on console, per the FCOH).

16. Produce Flight Readiness Review (FRR) data pack and COFR

Use the format provided by the DF T/A to produce the FRR and the Certification of Flight Readiness (COFR) statement. Generic copies of both packages are provided on the network (see the previous Lead GNC). These inputs are due about L - 4 weeks. Contact KSC, BNA, and USA counterparts for a vehicle/systems status. Include the vehicle-specific hardware behavior noted above. The COFR statement lists several flight-specific documents and drawings that may contain G&C related information. Perform a review of them to ensure we address any impacts. These documents and drawings are contained in the DF Division Library. These products are completed electronically, reviewed by the Group Lead, and delivered electronically to the Systems Division T/A. The cover sheet is signed by the Group Lead and branch chief hand-delivered to the T/A.

17. Review OPS Notes and Waivers

Ask the section flight software engineer to schedule a section review if the flight will use a new OI software release, or if any new FSW DRs have been written since the last flight.

18. Verify with the GNC GA that the workstations have been configured for flight

Check with the GNC Group Administrator on the status of the GNC off-line programs and flight specific applications. The cutoff time for changes is L - 30 days. Ensure that they are downloaded from configuration management (CM), and online workstation applications are located on the cert mode DNAV, and work properly the week before the flight. Ensure workstations are configured for flight by a GNC GA by L-1 day.

19. Gather EMCC (Emergency Mission Control Center) documents

Confirm this with the assigned Ascent/Entry GNC. Check that all materials are ready within a week of the flight. The GNC Group Lead has the official documents in his office.

20. Check Console Document Readiness

Using the FDF Status Sheet from the MOD/DO Master List, perform a complete inventory of all GNC, Control/Support, and Sensors console FDF books, ensuring that all flown PCNs are incorporated. If any are out of date, contact the FDF POC.

Using the MOD/DA8 and DF Master Document Lists (located in <http://stic.jsc.nasa.gov/database/iso9000/docs>), verify that all copies of the Flight Rules, G&C Console Handbook, and SSSH contain the most recent versions.

21. Calibration Curve Updates to the FEP

Check the Post MCC Build Configuration letter for any GNC parameters which require Calibration Curve updates. This memo will be delivered via e-mail approximately seven days prior to launch. The Post MCC Configuration memo which defines changes which have occurred post Flight Cycle, and must be manually entered prior to flight for the FEP, MOC and Data Driver. GNC is responsible for updating the FEP for any GNC parameters. See FCOH SOP 4.7.5 FEP Temporary/Permanent Calibration Changes for the procedures required to perform this change. The calibration curve change is done using the Telemetry Services application on the Master DNAV under Global Apps. The user manual for Telemetry Services is available (through DNAV, Global Apps, EDP, Reference Documents, CCF) in the Consolidated Communications Facility (CCF) Software User's Handbook (LOR-TR1742, July 1995) Volume III - TELCOM POSITION, Section 3.6. Reserved

22. Ensure pager distribution

This is normally performed by the GNC Group Lead or Flight Lead, who distributes pagers to each FCR operator. The pager numbers follow:

<u>Pager</u>	<u>Pager No.</u>
Ascent/Entry	281-434-5442
Orbit 1	281-434-5488
Orbit 2	281-434-5443
Planning (Orbit 3)	281-434-5444
GA (primary)	713-978-8069

23. Tag up with KSC, BNA, and USA counterparts

Provide KSC with our console staffing and phone numbers. A prelaunch timeline is available from Bill Patrick (FTS 1-321-861-3830) at KSC.

24. Assign Postflight Report topics

The Lead GNC will write the post flight report, but can still delegate certain topics he/she feels would be better covered by someone else in the section (e.g. control operator can write about entry performance). Provide each team member with their postflight report assignments before the flight. This allows each team member time to gather information or work on their topics during the flight. This saves turnaround time for the report

25. Ensure the flight directories on all workstations get cleaned out.

Sim data should be moved or deleted prior to the start of prelaunch console support. This provides a clean space for flight data to be saved, and reduces the likelihood of sim data being used inadvertently during flight. This task can be delegated to the GNC GA or a member of group familiar with the MCC workstations. The sim data can be moved to a clearly labeled sim sub directory, or moved to another location (i.e. the "noncritical" partition of the file servers). The following directories should be cleared.

- /users/gnc/Data/SSPXXX/*
- ODRC directories: /mcc/rw_remote/common/mews/iss/flights/STS-XXX/data/gnc/*
- local workstation files (/mcc/rw_local and /mcc/rw_temp) on each workstation.

POSTFLIGHT RESPONSIBILITY

1. Gather flight data

Complete gathering of all pertinent data as soon as possible (especially the aero and landing parameters which the Flight Director and FDO want ASAP). The post-landing quicklook is typically done by CONTROL or the A/E GNC during post-landing, but must be completed within 48 hours of landing, and provided electronically (or in hard-copy) to the A/E Flight Director, FDO, Weather, and A/E CAPCOM. Coordinate this with all three teams.

Shortly after landing the ELOG files should be stored off and/or printed. This needs to be done prior to the first post-landing simulation on this flight's sim load. The GNC GA can assist with this task.

2. Verify HUD plots are updated (when performed)

The lead GNC or the person assigned to do the HUD calibration postflight report should update the flight history plots kept in the GNC library and on console.

3. Attend Crew Debrief Meeting(s)

The lead GNC and anyone else directed should attend these meetings. Prepare questions on any and all aspects of the mission of concern to GNC. There are several debriefs, from the Payload debrief to the MER debrief (in which each discipline reviews their system's flight anomalies) to the PGSC debrief, etc.

4. Construct GNC Quick Look report

The lead GNC presents this at the first Systems Issues after the flight. Follow the format used in previous reports (located in World/Divisions/DF/Private/DF62/Flights).

5. Submit FD evaluations

Flight Director evaluation forms should be filled out and submitted electronically to the DF Division Chief.

6. Organize Section tag-up

Debrief section personnel on specifics of the mission (should be done at the first section meeting after the flight.) If a meeting is not possible, use e-mail.

7. Write GNC Postflight Report

Refer to SCP 11.12 for guidelines. Publish the report within a month of touchdown. Start the report during flight, if time permits, using the PC. A preliminary copy is due on console before the next flight, and the final report is due before the next flight of that vehicle. Once the report is complete and signed off by all FCR operators on the flight, submit the report to the GNC Group Lead, and ask the DF62 webmaster to post the report on the GNC webpage.

8. Send IMU data to Engineering Directorate counterparts

Send a copy of the IMU torquing angles and the IMU Drift program output to ISL/Jock Torres. Engineering will incorporate the flight data into the IMU performance data base.

9. Submit flight team roster

Turn in a team training roster to the training records office (via MCC Training Roster), reporting the number of hours for each flight phase that each team member worked.

10. Report GNC-sponsored DTO results (as applicable)

Turn in any flight data and DTO result summaries to Program Office, Engineering, etc., as applicable. Be sure to list any lessons learned, procedure change recommendations, or new constraints. Examples include Fly-Cast Maneuver DTO 260 on STS-93, and GPS DTO 700-14 operations tests on STS-91 and subs.

11. Create flight data binder

All flight data that should be saved, is to be placed into a three ringed STS-XXX Flight Data binder and stored in the GNC library. This binder will be the one central location for the flight-specific data and information. The flight-specific data binder should contain the following sections:

- L-1 day briefing
- Lead GNC checklist
- FRR, CoFR, and Delta FRR
- Final anomaly lists (including official MER problem list)
- FCR and MPSR logs
- ELOG Message print-out (FCR and MPSR log)
- Important hardcopies (clearly annotated)
- Other important miscellaneous data

12. Handover information to next Lead GNC

As a wrap-up to the flight when most of the loose ends have been tied, the lead GNC should hand over any issues or items of interest, as they apply, to the lead GNCs for the next flight and the next flight of the same vehicle.

13. Complete Post-flight Actions List

To ensure all issues and problems from the flight are worked, build a list of actions required to address the issues (SCP changes, flight rule changes, FDF changes, etc.). Forward this list to the group lead for assignments.

TITLE

FLIGHT SPECIFIC MEL DEVELOPMENT

PURPOSE

To guide the user through the preparation of the Mission Specific Minimum Equipment List (MEL) Equipment Exceptions list.

BACKGROUND

The Minimum Equipment List is contained in Appendix H of the Launch Commit Criteria (LCC) document. This list contains all flight equipment and specifies the operational requirement of each equipment item for launch. This list is necessary because not all equipment is monitorable during the applicable timeframe of the LCC and therefore must be verified during turnaround or inflight testing.

The MEL also contains two separate lists of "exceptions" which pertain to equipment that is not required to be full-up or which has requirements that vary from flight to flight. These are the "Equipment Exceptions - All Missions" list found in MEL-02; and the "Equipment Exceptions - Mission Specific" list found in MEL-03. The Equipment Exceptions - All Missions list (MEL-02) contains the equipment which does not require full capability and whose requirements do not change from flight to flight. The Equipment Exceptions - Mission Specific list (MEL-03) contains those items whose requirements vary based on mission specifics. This SCP pertains to the preparation of the mission specific list (MEL-03) which must be submitted for each flight.

In order to standardize the preparation of the mission specific exceptions, four basic MISSION TYPEs are identified. These are:

- PAM/Syncom deploy and Spacelab
- IUS deploy
- RMS/SPDS deploy
- ISS Specific (Rendezvous/Prox Ops Mission)

The use of standardized mission specific equipment exceptions lists, for most missions, eliminates the necessity to develop the requirements each flight. If more than one MISSION TYPE is combined on the same flight, the generic requirements for each type should be combined to provide the composite MEL requirements for the flight.

PROCEDURE

A template for each of the four predefined MISSION TYPEs is maintained on the shared drive and kept by the Systems Division Technical Assistant (DF TA). When the MEL inputs are due to the DF TA, the Lead GNC should copy the template from the shared drive and modify the appropriate template as necessary based on the specific requirements of the flight.

Each of the templates assumes a daylight landing for nominal end of mission (NEOM) as well as aborts. If a night landing is planned for either NEOM or any abort, then both radar altimeters and both HUDs are required.

For missions that have combinations of the above MISSION TYPEs, such as an RMS deploy as well as a rendezvous, then the templates should be combined using the more stringent requirement from each template.

(MISSION TYPE - PAM/SYNCOM DEPLOY or SPACELAB)

NSTS 16007 LAUNCH COMMIT CRITERIA AND BACKGROUND
SSID: MEL-13

=====

EQUIPMENT EXCEPTIONS - MISSION SPECIFIC - STS XXX

LRU/FUNCTION -----	REQ'T -----	SSID -----	MEL REF -----	NOTES -----
<u>GNC</u>				
AFT RHC XDUCRS	0 of 3 / axis	None	MEL-04	Fwd RHC can be used as backup for evasive mnvr
AFT THC CNTCTS	0 of 3 / axis/dir	None	MEL-04	Fwd THC can be used as backup for evasive mnvr
AFT DDU PWR SUP A,B,C	0 of 3	None	MEL-04	Fwd cntlrs can be used as backup
HUD	0* of 2	None	MEL-04	*CDR HUD reqd if night landing
FWD,AFT DAP CNTL LVLH	0 of 6	None	MEL-04	Not required
FWD,AFT ROTATION PRI	0 of 4	None	MEL-04	*4 of 4 if any ALT contact not available
FWD,AFT ROTATION ALT	0 of 4	None	MEL-04	Alternate DAP not required
FWD,AFT TRANSL X NORM	0 of 4	None	MEL-04	PULSE mode default for X transl is acceptable
FWD,AFT TRANSL X PULSE	0 of 4	None	MEL-04	PULSE mode default for X transl is acceptable
FWD,AFT TRANSL Y NORM	0 of 4	None	MEL-04	PULSE mode default for Y transl is acceptable
FWD,AFT TRANSL Y PULSE	0 of 4	None	MEL-04	PULSE mode default for Y transl is acceptable
FWD,AFT TRANSL LOW Z	0 of 4	None	MEL-04	Lo Z desir but free dft for deploy is backup
FWD,AFT TRANSL Z NORM	0 of 4	None	MEL-04	PULSE mode default for Z transl is acceptable
FWD,AFT TRANSL Z PULSE	0 of 4	None	MEL-04	PULSE mode default for Z transl is acceptable
FWD,AFT TRANSL Z HIGH	0 of 4	None	MEL-04	PULSE mode default for Z transl is acceptable

(MISSION TYPE - IUS DEPLOY)

NSTS 16007 LAUNCH COMMIT CRITERIA AND BACKGROUND
SSID: MEL-13

=====

EQUIPMENT EXCEPTIONS - MISSION SPECIFIC - STS XXX

=====

LRU/FUNCTION -----	REQ'T -----	SSID -----	MEL REF -----	NOTES -----
<u>GNC</u>				
AFT RHC XDUCRS	0 of 3 / axis	None	MEL-04	Fwd RHC can be used as backup for evasive mnvr
AFT THC CNTCTS	2 of 3 in +X & -X	None	MEL-04	Launch with cap to perf nominal deploy proc
AFT DDU				
PWR SUP A,B,C	2 of 3	None	MEL-04	Required to support THC
HUD	0* of 2	None	MEL-04	*CDR HUD reqd if night landing
FWD,AFT DAP CNTL LVLH	0 of 6	None	MEL-04	Not required
FWD,AFT ROTATION PRI	0 of 4	None	MEL-04	*4 of 4 if any ALT contact not available
FWD,AFT ROTATION ALT	0 of 4	None	MEL-04	Alternate DAP not required
FWD,AFT TRANSL X NORM	0 of 4	None	MEL-04	PULSE mode default for X transl is acceptable
FWD,AFT TRANSL X PULSE	0 of 4	None	MEL-04	PULSE mode default for X transl is acceptable
FWD,AFT TRANSL Y NORM	0 of 4	None	MEL-04	PULSE mode default for Y transl is acceptable
FWD,AFT TRANSL Y PULSE	0 of 4	None	MEL-04	PULSE mode default for Y transl is acceptable
FWD,AFT TRANSL LOW Z	2 of 2	None	MEL-04	Launch with cap to perf nominal deploy proc
FWD,AFT TRANSL Z NORM	0 of 4 either sw	None	MEL-04	PULSE mode default for Z transl is acceptable
FWD,AFT TRANSL Z PULSE	0 of 4	None	MEL-04	PULSE mode default for Z transl is acceptable
FWD,AFT TRANSL Z HIGH	0 of 4	None	MEL-04	PULSE mode default for Z transl is acceptable

(MISSION TYPE - RMS/SPDS DEPLOY)

NSTS 16007
SSID: MEL-13

LAUNCH COMMIT CRITERIA AND BACKGROUND

=====

EQUIPMENT EXCEPTIONS - MISSION SPECIFIC - STS XXX

=====

LRU/FUNCTION -----	REQ'T -----	SSID -----	MEL REF -----	NOTES -----
<u>GNC</u>				
AFT RHC XDUCRS	3 of 3 / axis	None	MEL-04	One fault tol reqd all axes/dir for nom proc
AFT THC CNTCTS	3 of 3 / axis	None	MEL-04	One fault tol reqd all axes/dir for nom proc
AFT DDU PWR SUP A,B,C	3 of 3	None	MEL-04	Reqd to supt one fault tol in the RHC and THC
HUD	0* of 2	None	MEL-04	*CDR HUD reqd if night landing
FWD,AFT DAP CNTL LVLH	0 of 6	None	MEL-04	Not required
FWD,AFT ROTATION PRI	0 of 4	None	MEL-04	*4 of 4 if any ALT contact not available
FWD,AFT ROTATION ALT	4 of 4	None	MEL-04	Alternate DAP required as backup for payload loads
FWD,AFT TRANSL X NORM	0 of 4	None	MEL-04	PULSE mode default for X transl is acceptable
FWD,AFT TRANSL X PULSE	0 of 4	None	MEL-04	PULSE mode default for X transl is acceptable
FWD,AFT TRANSL Y NORM	0 of 4	None	MEL-04	PULSE mode default for Y transl is acceptable
FWD,AFT TRANSL Y PULSE	0 of 4	None	MEL-04	PULSE mode default for Y transl is acceptable
FWD,AFT TRANSL LOW Z	2 of 2	None	MEL-04	Launch with cap to perf nominal deploy proc
FWD,AFT TRANSL Z NORM	0 of 4 either sw	None	MEL-04	PULSE mode default for Z transl is acceptable
FWD,AFT TRANSL Z PULSE	0 of 4	None	MEL-04	PULSE mode default for Z transl is acceptable
FWD,AFT TRANSL Z HIGH	0 of 4	None	MEL-04	PULSE mode default for Z transl is acceptable

(MISSION TYPE - ISS SPECIFIC)

NSTS 16007 LAUNCH COMMIT CRITERIA AND BACKGROUND
SSID: MEL-13

=====

EQUIPMENT EXCEPTIONS - MISSION SPECIFIC - STS XXX

LRU/FUNCTION -----	REQ'T -----	SSID -----	MEL REF -----	NOTES -----
<u>GNC</u>				
AFT RHC XDUCRS	3 of 3 / axis	None	MEL-04	One fault tol reqd in all axes for nom proc
AFT THC CNTCTS	3 of 3 / axis/dir	None	MEL-04	One fault tol reqd in all axes for nom proc
AFT DDU PWR SUP A,B,C	3 of 3	None	MEL-04	Reqd to support the aft THC and RHC. All reqd for high prob of mission success
HUD	0* of 2	None	MEL-04	*CDR HUD reqd if night landing
FWD,AFT DAP CNTL LVLH	4 of 6	None	MEL-04	Required for 1 fault tol during prox ops
FWD,AFT PRI	4 of 4	None	MEL-04	Launch w/ 1 fault tol to select PRCs by nom meth
FWD,AFT ALT	4 of 4	None	MEL-04	Alternate DAP required for nominal ops
X NORM	4 of 4	None	MEL-04	FWD,AFT TRANSL Required for 1 fault tol during prox ops
FWD,AFT TRANSL X PULSE	4 of 4	None	MEL-04	Required for 1 fault tol during prox ops
FWD,AFT TRANSL Y NORM	4 of 4	None	MEL-04	Required for 1 fault tol during prox ops
FWD,AFT TRANSL Y PULSE	4 of 4	None	MEL-04	Required for 1 fault tol during prox ops
FWD,AFT TRANSL LOW Z	4 of 4	None	MEL-04	Required for 1 fault tol during prox ops
FWD,AFT TRANSL Z NORM	4 of 4	None	MEL-04	Required for 1 fault tol during prox ops
FWD,AFT TRANSL Z PULSE	4 of 4	None	MEL-04	Required for 1 fault tol during prox ops
FWD,AFT TRANSL Z HIGH	4 of 4	None	MEL-04	Required for 1 fault tol during prox ops
FWD, AFT DAP SPARE PBI	4 of 4	None	MEL-04	Required for docking
TCS	1 of 1	None	None	Required for range and range rate during ISS approach and fly-around

RATIONALE

Table 11.14 - I, MEL Requirements and Rationale, provide the detailed rationale for the requirements in the generic Mission Dependent Exceptions MELs. A generic MEL may be modified on a flight specific basis considering the unique objectives of that mission. The rationale for any flight specific modification should accompany the MEL when it is submitted, i.e. summarized in the NOTE column or detailed on a separate page.

TABLE 11.14-I - MEL REQUIREMENTS AND RATIONALE

AFT RHC TRANSDUCERS	<p>MISSION TYPE: PAM/SYNCOM and IUS Deploys REQUIREMENT: 0 of 3 per axis The aft rotational hand controller is not required since the payload is deployed with a positive separation velocity. It is highly unlikely that any evasive maneuvers would be required to avoid recontact with the payload.</p> <p>MISSION TYPE: SPDS/RMS Deploy and ISS Specific REQUIREMENT: 3 of 3 per axis The aft rotational hand controller is required to be full up. This provides one fault tolerance (controller remains usable without crew intervention after first failure) for accomplishing the primary mission.</p>
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TABLE 11.14-I - MEL REQUIREMENTS AND RATIONALE (CONT'D)

<p>AFT THC TRANSDUCERS</p>	<p>MISSION TYPE: PAM/SYNCOM Deploy REQUIREMENT: 0 of 3 per axis & direction The aft translational hand controller is not required since the payload is deployed with a positive separation velocity. It is highly unlikely that any evasive maneuvers would be required to avoid recontact with the payload.</p> <p>MISSION TYPE: IUS Deploy REQUIREMENT: 2 of 3 in -X & +X axes The aft translation hand controller is required to have 2 of 3 contacts in both directions at liftoff. This provides the capability to perform the nominal deploy procedures and protects for a failed high contact. The crews train to use the forward THC as a backup if a failure should no-op the aft THC.</p> <p>MISSION TYPE: SPDS/RMS Deploy and ISS Specific REQUIREMENT: 3 of 3 per axis & direction The aft translational hand controller is required to be full up. This provides one fault tolerance (controller remains usable without crew intervention after first failure) for accomplishing the primary mission.</p>
<p>AFT DDU</p>	<p>MISSION TYPE: PAM/SYNCOM Deploy REQUIREMENT: 0 of 3 power supplies None of the three internal power supplies are required. The crew trains to use the forward controllers in the event of loss of aft station capability.</p> <p>MISSION TYPE: IUS Deploy REQUIREMENT: 2 of 3 of A, B, and C Two of the three flight controller power supplies (A,B,C) are required to provide the required THC capability.</p> <p>MISSION TYPE: SPDS/RMS Deploy REQUIREMENT: 3 of 3 A, B, and C All three flight controller power supplies are required to provide the required RHC and THC capability.</p> <p>MISSION TYPE: ISS Specific REQUIREMENT: 3 of 3 power supplies All three internal power supplies are required. The power supplies are required to provide the required RHC and THC redundancy.</p>

TABLE 11.14-I - MEL REQUIREMENTS AND RATIONALE (CONT'D)

<p>HUD</p>	<p>MISSION TYPE: Planned abort or EOM night landing REQUIREMENT: Left HUD</p> <p>HUDs are desirable to compensate for the lack of visual cues during a night landing. The left (CDR's) HUD is required so that we launch with the capability to support landings in darkness. Once on orbit, a mission will not be shortened for loss of either or both HUDs. However, a daylight landing is required, if possible, per flight rules if only one HUD is available for entry. Consideration will be given to replacing the left HUD with the right one if the left one fails in flight.</p> <p>MISSION TYPE: Planned daylight abort and EOM landing REQUIREMENT: 0 of 2 No requirement exists for HUDs either for abort or EOM landings in daylight.</p>
<p>FWD,AFT DAP CNTL LVLH</p>	<p>MISSION TYPE: PAM/SYNCOM, IUS, and SPDS/RMS Deploys REQUIREMENT: 0 of 6 contacts No requirement exists for manual LVLH capability except during prox ops.</p> <p>MISSION TYPE: ISS Specific REQUIREMENT: 4 of 6 contacts One fault tolerance is required for proximity operations.</p>

TABLE 11.14-I - MEL REQUIREMENTS AND RATIONALE (CONT'D)

<p>FWD,AFT PRI Switch</p>	<p>MISSION TYPE: PAM/SYNCOM, IUS, and SPDS/RMS Deploys REQUIREMENT: 0 of 4 contacts, if all ALT contacts available These two switches control manual selection of the primary RCS jet control mode. If 4 of 4 ALT DAP switches are available, then the requirement for the PRI pb's is 0 of 4. This is because the ALT DAP can be configured to have almost the same capability as the PRI DAP (it will not fire 4 aft jets for a plus pitch maneuver), there is automatic upmoding to PRI during translation maneuvers, and the PRI DAP can be recovered with a transition to OPS 3 and then back to OPS 2.</p> <p>MISSION TYPE: ISS Specific REQUIREMENT: 4 of 4 contacts One fault tolerance (OFT) is required in the capability for the crew to select PRCS. Although ALT can often be used to emulate PRI, trying to implement such a workaround during a critical operation like rndz/prox ops is highly undesirable.</p>
<p>FWD,AFT ALT Switch</p>	<p>MISSION TYPE: PAM/SYNCOM and IUS Deploys, Spacelab REQUIREMENT: 0 of 4 Contacts PRI can serve as an adequate backup for this type of mission. However, for flights that do not have large propellant margins, the ALT DAP may be required as a measure to save propellant for the loss of vernier jets.</p> <p>MISSION TYPE: SPDS/RMS Deploys, ISS Specific REQUIREMENT: 4 of 4 contacts The ALT DAP is used as a backup to the vernier jets for any RMS or SPDS operations, in order to reduce loads imparted on the payload and/or RMS/SPDS. ALT DAP Is nominally used during rendezvous.</p>

TABLE 11.14 - I - MEL REQUIREMENTS AND RATIONALE (CONT'D)

FWD,AFT TRANSL X NORM Switch	MISSION TYPE: PAM/SYNCOM, IUS, and SPDS/RMS Deploys REQUIREMENTS: 0 of 4 contacts The DAP defaults to the PULSE translation mode. Either of the PULSE or NORM modes is acceptable. MISSION TYPE: ISS Specific REQUIREMENTS: 4 of 4 contacts Both switches are required to be full up (2 of 2 contacts each switch) to launch with one fault tolerance to nominally perform the translation maneuvers required during rendezvous.
FWD,AFT TRANSL X PULSE Switch	MISSION TYPE: PAM/SYNCOM, IUS, and SPDS/RMS Deploys REQUIREMENTS: 0 of 4 contacts The DAP defaults to the PULSE translation mode. Either of the PULSE or NORM modes is acceptable. MISSION TYPE: ISS Specific REQUIREMENTS: 4 of 4 Both switches are required to be full up (2 of 2 contacts each switch) to launch with one fault tolerance to nominally perform the translation maneuvers required during rendezvous (station keeping).

TABLE 11.14 - I - MEL REQUIREMENTS AND RATIONALE (CONT'D)

<p>FWD,AFT TRANSL Y NORM Switch</p>	<p>MISSION TYPE: PAM/SYNCOM, IUS, and SPDS/RMS Deploys REQUIREMENTS: 0 of 4 contacts The DAP defaults to the PULSE translation mode. Either of the PULSE or NORM modes is acceptable.</p> <p>MISSION TYPE: ISS Specific REQUIREMENTS: 4 of 4 contacts Both switches are required to be full up (2 of 2 contacts each switch) to launch with one fault tolerance to nominally perform the translation maneuvers required during rendezvous.</p>
<p>FWD,AFT TRANSL Y PULSE Switch</p>	<p>MISSION TYPE: PAM/SYNCOM, IUS, and SPDS/RMS Deploys REQUIREMENTS: 0 of 4 contacts The DAP defaults to the PULSE translation mode. Either of the PULSE or NORM modes is acceptable.</p> <p>MISSION TYPE: ISS Specific REQUIREMENTS: 4 of 4 contacts Both switches are required to be full up (2 of 2 contacts each switch) to launch with one fault tolerance to nominally perform the translation maneuvers required during rendezvous (station keeping).</p>
<p>FWD,AFT TRANSL LO Z Switch</p>	<p>MISSION TYPE: PAM/SYNCOM REQUIREMENTS: 0 of 4 contacts There is no strong need for lo Z attitude control or translation capabilities.</p> <p>MISSION TYPE: IUS and SPDS/RMS Deploys REQUIREMENTS: 2 of 2 contacts either switch One switch is required to be full up (2 of 2 contacts) to launch with the capability to perform the nominal deploy procedures.</p> <p>MISSION TYPE: ISS Specific REQUIREMENTS: 4 of 4 contacts Both switches are required to be full up (2 of 2 contacts each switch) to launch with one fault tolerance to nominally perform the translation maneuvers required during rendezvous (Inside 1000ft to ISS).</p>

TABLE 11.14-I - MEL REQUIREMENTS AND RATIONALE (CONT'D)

<p>FWD,AFT TRANSL Z NORM Switch</p>	<p>MISSION TYPE: PAM/SYNCOM, IUS, and SPDS/RMS Deploys REQUIREMENTS: 0 of 4 contacts The DAP defaults to the PULSE translation mode. Either of the PULSE or NORM modes is acceptable.</p> <p>MISSION TYPE: ISS Specific REQUIREMENTS: 4 of 4 contacts Both switches are required to be full up (2 of 2 contacts each switch) to launch with one fault tolerance to nominally perform the translation maneuvers required during rendezvous.</p>
<p>FWD,AFT TRANSL Z PULSE</p>	<p>MISSION TYPE: PAM/SYNCOM, IUS, and SPDS/RMS Deploys REQUIREMENTS: 0 of 4 contacts The DAP defaults to the PULSE translation mode. Either of the PULSE or NORM modes is acceptable.</p> <p>MISSION TYPE: ISS Specific REQUIREMENTS: 4 of 4 contacts Both switches are required to be full up (2 of 2 contacts each switch) to launch with one fault tolerance to nominally perform the translation maneuvers required during rendezvous (station keeping).</p>
<p>FWD,AFT TRANSL Z HIGH</p>	<p>MISSION TYPE: PAM/SYNCOM, IUS, and SPDS/RMS Deploys REQUIREMENTS: 0 of 4 contacts This mode is not required because of the very low probability that an evasive maneuver (requiring all upfiring jets) will be required during orbit operations.</p> <p>MISSION TYPE: ISS Specific REQUIREMENTS: 4 of 4 contacts Both switches are required to be full up (2 of 2 contacts each switch) to launch with one fault tolerance to nominally perform the translation maneuvers required during rendezvous (evasive maneuvers).</p>
<p>FWD,AFT DAP SPARE PBI</p>	<p>MISSION TYPE: PAM/SYNCOM, IUS, and SPDS/RMS Deploys REQUIREMENTS: 0 of 4 contacts This switch is only used to perform a post-contact-thrust (PCT) sequence into a payload, and is not required for flights of this nature.</p> <p>MISSION TYPE: ISS Specific REQUIREMENTS: 4 of 4 contacts</p>

	<p>The all contacts are required to be full up (2 of 2 contacts each switch) to launch with one fault tolerance, to nominally perform the Post-Contact-Thrust (PCT) translation sequence that is required at docking to ensure proper docking mechanism mating conditions. L BF AUTO/MAN pb is available in the event both spare PBI's failed.</p>
TCS	<p>MISSION TYPE: PAM/SYNCOM, IUS, and SPDS/RMS Deploys REQUIREMENTS: 0 of 1 This hardware is not required for this type of mission.</p> <p>MISSION TYPE: ISS Specific REQUIREMENTS: 1 of 1 contacts This hardware is required during proximity operations and fly-around to provide the crew with autonomous range and range rate cues. Failure of the TCS unit requires use of the back-up Hand-Held Laser (HHL) that the crew operates manually and takes crew focus away from flying the rendezvous while in close proximity to ISS.</p>

TITLE

VARIABLE PARAMETER DOWNLIST

PURPOSE

To define the nominal GNC variable parameters, the GNC flight controller's (F/C) usage of these parameters, and how the variable downlist operates.

BACKGROUND

Variable parameters are downlisted from the onboard general purpose computers (GPC's) which are performing either the guidance, navigation, and control (GNC) function or the systems maintenance (SM) function. Each major function has an array of 10 half-words dedicated to the variable downlist. Each entry in the array is a 16-bit memory address. The contents of these addresses will be downlisted. Only parameters residing in addresses 00000 to 0FFFF are eligible for downlisting. The address in a variable parameter slot may be changed in one of two ways: via an MCC uplink generated by the DPS Officer, or via crew inputs to the DPS utility display SPEC 001. DPS will uplink variable parameter address changes during all operational sequences except Ops 1 and Ops 3. Variable parameters are available on the downlist in operational sequences 0, GNC 1, 2, 3, 8, or 9, and SM 2 or 4.

STS-78 EXAMPLE

Figure 11.15-1 lists the STS-78 nominal GNC variable parameter downlist. The purpose of this list is to give the F/C an idea of what a flight-specific variable parameter downlist can look like. The downlist parameters requested by sections other than GNC may change from flight to flight; however, the GNC requested parameters, associated slot numbers, and HAL names will not change unless requested by GNC according to procedures listed in FCOH SOP 4.8. The addresses may change from flight to flight according to the flight software version.

GNC normally has slots 4, and 5 in the GNC variable downlist during orbit . DPS will notify GNC during a flight or simulation if it is necessary to utilize one of these slots for other requirements.

MAJOR FUNCTION: GNC ASCENT				
TITLE: "GNC NOM ASCENT VP"				
DSM: 23001				
<u>RQST</u>	<u>SLOT</u>	<u>ADRS</u>	<u>DESCRIPTION</u>	<u>HAL NAME</u>
DPS	1	268F	PRI/SEC PORT SEL	CZ2B_MODE
"	2	2691	MMU ASSIGN GNC MF	CZ2B_MM_MF (2ND H/W)
"	3	9568	GPC SYNC FAIL POINTER	FCSSFFAIL (15TH H/W)
"	4	0E61	CRT I/O ERROR FLAG	DMIB_ERR_MSG
	5	----	OPEN	
	6	----	OPEN	
GPO	7	F664	●COMPUTED TARGET HP	CGZV_TGT_HP (1ST H/W)
"	8	F665	●COMPUTED TARGET HP	CGZV_TGT_HP (2ND H/W)
"	9	56D4	●VEHICLE WEIGHT	CGZV_WEIGHT_DISP (1ST H/W)
"	10	56D5	●VEHICLE WEIGHT	CGZV_WEIGHT_DISP (2ND H/W)

- Scaling required for this parameter; enter K=1 and Bias=0 for slots 7/8 and 9/10. Addresses for slots 7/8 are only valid in OPS 1.

MAJOR FUNCTION: GNC ORBIT				
TITLE: "GNC NOM ORBIT VP"				
DSM: 23002				
<u>RQST</u>	<u>SLOT</u>	<u>ADRS</u>	<u>DESCRIPTION</u>	<u>HAL NAME</u>
DPS	1	268F	PRI/SEC PORT SEL	CZ2B_MODE
"	2	2691	MMU ASSIGN GNC MF	CZ2B_MM_MF (2ND H/W)
"	3	9568	GPC SYNC FAIL POINTER	FCSSFFAIL (15TH H/W)
GNC	4	BAE3	-Z STKR MODE	CGYB_ST_MODE_IND (1ST H/W)
"	5	BAE4	-Y STKR MODE	CGYB_ST_MODE_IND (2ND H/W)
DPS	6	0E61	CRT I/O ERROR FLAG	DMIB_ERR_MSG
	7	----	OPEN	
	8	----	OPEN	
GPO	9	56D4	●VEHICLE WEIGHT	CGZV_WEIGHT_DISP (1ST H/W)
"	10	56D5	●VEHICLE WEIGHT	CGZV_WEIGHT_DISP (2ND H/W)

- Scaling required for this parameter; enter K=1 and Bias=0 for slots 9/10.

Figure 11.15-1.- STS-78 nominal variable parameter downlist.

UTILIZATION

A. GNC NOMINAL FLIGHT-TO-FLIGHT VARIABLE PARAMETERS

The variable downlist is utilized by GNC to display parameters not available in the downlist/downlink data. All the GNC variable parameters utilized by the GNC section are displayed in hexadecimal values. The following table describes how the GNC Flight Controller utilizes the variable parameters:

Orbit	Slot number	Description	Utilization
	4,5	Star tracker modes for the -Z and -Y star tracker	The following table lists the possible values of this variable parameter and their corresponding modes: 0000-term idle 1000-term idle 2000-target track 4000-star track 8000-self test

B. VARIABLE DOWNLIST VIEWING

Depending on the downlist, each of the 10 slots has a corresponding MSID:

Variable Parameter slot	Downlist		
	GNC	SM	OPS O
1	V92U5500CX	V92U5500CY	V92U5500CZ
2	V92U5502CX	V92U5502CY	V92U5502CZ
3	V92U5504CX	V92U5504CY	V92U5504CZ
4	V92U5506CX	V92U5506CY	V92U5506CZ
5	V92U5508CX	V92U5508CY	V92U5508CZ
6	V92U5510CX	V92U5510CY	V92U5510CZ
7	V92U5512CX	V92U5512CY	V92U5512CZ
8	V92U5514CX	V92U5514CY	V92U5514CZ
9	V92U5516CX	V92U5516CY	V92U5516CZ
10	V92U5518CX	V92U5518CY	V92U5518CZ

All ten variable parameters may be viewed on VP Scaling. This is a DPS provided display located on the Master DNAV/Shuttle/DPS/Real-Time (Data from DPS) menu.

Slots 4 and 5 may be viewed on GNC ORBIT. They are located in the Star Tracker data block and are aligned with the respective star tracker data.

REFERENCES

1. Flight Control Operations Handbook (FCOH), SOP 4.8, Variable Parameter Downlist.
2. DPS Console Handbook, SCP 7.7, DPS Variable Parameters.
3. PROP Console Handbook, SCP I.11.3, Variable Downlist.

TITLE

ORBIT OPERATIONS CHECKLIST

PURPOSE

The purpose of this SCP is to define those tasks and responsibilities assigned to the orbit teams during the orbit phase of flight.

PROCEDURE

Figure 11.16-1 represents all of the nominal orbit operations that the operators can expect to perform during a mission. A copy of this SCP should be placed in the MPSR log to provide a record of who performed the task as well as the time it was performed. If any of the entries are not applicable to a particular mission, they can be marked as N/A in the Operator column.

Figure 11.16-2 shows the LRU configuration for the current mission. This table should be filled in prior to flight.

EVENT	GMT DDD:HH:MM	OPERATOR
1. Verify Prelaunch Checklist and Sensors Prelaunch Checklist are complete (See SCP 1.4).	__:__:__	_____
2. Initialize IMUDRIFT (SCP 2.4).	__:__:__	_____
3. Pull data from ODRC to verify OMS TVC no-backs held during ascent.	__:__:__	_____
4. Verify all on-orbit OMS gimbal checks and calculate gimbal rates.	__:__:__	_____
5. Normalize REFSMMAT's in preparation for a scheduled/contingency COAS/HUD cal (SCP 2.10). If a COAS/HUD cal is scheduled, uplink the normalized REFSMMAT's.	__:__:__	_____
6. If a COAS/HUD cal is performed, run the COAS program using the downlist data after completing the COAS/HUD cal, (SCP 3.4).	(-Z) __:__:__ (HUD) __:__:__	_____
7. Check SSME positions daily to verify that they have not moved more than 2° from their stow positions. (Planning shift). Check days: FD1__FD2__FD3__FD4__FD5__FD6__FD7__FD8__FD9__ FD10__FD11__FD12__FD13__FD14__FD15__FD16__FD17__		_____
8. Record SSME Positions after repress in data file on the S: drive. (Use the file s:\Divisions\DF\Private\DF62\Ssme\Ssme_History.xls and make certain to record the data in the worksheet corresponding to the proper orbiter.)		_____
9. Verify during FCS C/O part 2 that ATVC channels did not bypass for the 5-sec duration (ORB OPS FCS MODE/SW TEST 7-23).	__:__:__	_____
10. Prior to the final transition of the BFS to OPS 3, verify the following: <ul style="list-style-type: none"> • All good IMU's are available in the BFS (e.g. IMU recovered on-orbit, etc.). • All available IMU's are good (e.g. aligned). • All failed IMU's in the PASS are deselected in the BFS (post OPS 3 transition). 	__:__:__	_____

Figure 11.16-1.- Orbit operations checklist.

IMU				
(Serial Number)	1: _____	2: _____	3: _____	
TACAN (S/N)	1: _____; _____	2: _____; _____	3: _____; _____	
STKR				
(IDT/SSST;	-Y: _____; _____	-Z: _____; _____		
S/N)				
ADTA				
(S/N)	1: _____; _____	2: _____; _____	3: _____; _____	4: _____; _____

Figure 11.16-2.- LRU Configuration

ADDITIONAL NOTES

One of the tasks in Figure 11.16-1 that deserves further explanation is the SSME position check (Item 7). The procedure for this item and some rationale for the task follow. Action is initially taken during ascent, with subsequent action once per day.

A hard copy of the Ascent Controls MSK display (or any display containing the SSME command, position, and driver values) should be printed by the Control Operator reasonably soon after the SSMEs have gone to the stow position. There is no specific mandatory time that this printout must be obtained, provided it is completed before the OMS burn. This ensures that the baseline data is not corrupted by any motion induced by the burn.

A printout of the SSME position data is also to be obtained once per day. This may come from the SSME Position display, or any other display providing position values for the main engines.

The average driver value at stow is computed and compared with the SSME position. This calculation should be recorded on a spreadsheet, such as the example shown on the next page. It is also located at s:\Divisions\DF\Private\DF62\Ssme\Ssme_sts90.xls. A ready to use template file, by the name of Ssme_template.xls, is also in the same folder. The spreadsheet created by the console operator should be stored in the Private\DF62\flights folder for future reference.

For actuators which have a suspected biased position transducer, data from past flights of that actuator (maintained in the history file described in Item 10 on the checklist) will be used to assess the likelihood of actually moving the actuator more than two degrees.

It is important to monitor the SSME position because command/position delta steps greater than two degrees under full hydraulic pressure risk damage to the hydraulic lines, leading to loss of that hydraulic system. Additionally, improperly positioned nozzles may suffer thermal damage during entry. Flight Rule A8-106, TVC-SSME Stow/Actuator Fluid Fill (Repressurization), may be consulted for more information.

Example Spreadsheet: Comparison of averaged driver positions with SSME Position.
(s:\Divisions\DF\Private\DF62\Ssme\Ssme_sts90.xls)

(Note: The first data entries at MET 000/00:15 are the averaged driver values following ME stow. Subsequent entries are the SSME actuator positions. The Cmd/Pos Δ's are the difference between the actuator position at the current MET and the average driver values at ME stow.)

	MET	CP Pos	Cmd/ Pos D	CY Pos	Cmd/ Pos D	LP Pos	Cmd/ Pos D	LY Pos	Cmd/ Pos D	RP Pos	Cmd/ Pos D	RY Pos	Cmd/Pos D
Driver Avg.	000/00:15	-0.300		0.100		-9.750		-3.400		-10.400		3.700	
Actuator	000/15:00	0.270	-0.570	-0.020	0.120	-9.600	-0.150	-3.350	-0.050	-9.810	-0.590	3.310	0.390
Positions	001/18:00	0.190	-0.490	-0.020	0.120	-9.260	-0.490	-3.220	-0.180	-9.560	-0.840	3.380	0.320
	002/19:00	0.190	-0.490	-0.020	0.120	-9.180	-0.570	-3.150	-0.250	-9.390	-1.010	3.380	0.320
	003/14:30	0.190	-0.490	-0.020	0.120	-9.180	-0.570	-3.150	-0.250	-9.300	-1.100	3.380	0.320
	004/10:20	0.190	-0.490	-0.020	0.120	-9.180	-0.570	-3.080	-0.320	-9.220	-1.180	3.380	0.320
	005/07:30	0.190	-0.490	-0.020	0.120	-9.180	-0.570	-3.080	-0.320	-9.140	-1.260	3.380	0.320
	006/09:00	0.190	-0.490	-0.020	0.120	-9.180	-0.570	-3.080	-0.320	-9.220	-1.180	3.310	0.390
	007/08:35	0.190	-0.490	0.050	0.050	-9.180	-0.570	-3.080	-0.320	-9.220	-1.180	3.310	0.390
	008/08:00	0.190	-0.490	0.050	0.050	-9.180	-0.570	-3.080	-0.320	-9.220	-1.180	3.310	0.390
	009/08:50	0.190	-0.490	0.050	0.050	-9.180	-0.570	-3.080	-0.320	-9.220	-1.180	3.310	0.390
	010/12:54	0.190	-0.490	0.050	0.050	-9.180	-0.570	-3.080	-0.320	-9.140	-1.260	3.310	0.390
	011/12:39	0.190	-0.490	0.050	0.050	-9.180	-0.570	-3.080	-0.320	-9.140	-1.260	3.310	0.390
	012/10:29	0.190	-0.490	0.050	0.050	-9.180	-0.570	-3.080	-0.320	-9.140	-1.260	3.310	0.390
	013/13:01	0.190	-0.490	0.050	0.050	-9.180	-0.570	-3.080	-0.320	-9.140	-1.260	3.310	0.390
	014/12:21	0.190	-0.490	0.050	0.050	-9.180	-0.570	-3.080	-0.320	-9.140	-1.260	3.310	0.390
	015/12:33	0.190	-0.490	0.050	0.050	-9.180	-0.570	-3.080	-0.320	-9.140	-1.260	3.240	0.460

TITLE

RTPLOT USER'S GUIDE

PURPOSE

To provide flight controllers a quick look reference in the operation of the RTPLOT application. For greater detail, the RTPLOT User's Guide (available via the GNC Website page and on console in the "CCC Guides" binder) should be consulted.

BACKGROUND

RTPLOT provides a means of plotting data (e.g. telemetry, MOC comps, and workstation comps) in real-time. There are three classes of plots within RTPLOT; continuous, window, and scrolling. A continuous plot is a traditional X vs. Y plot which saves to a data file stored on the workstation. A window plot displays the data relative to a time, such as MET, and also saves the information into a data file. A scrolling plot is similar to a window plot, but the data is not saved to a file. The user can change many of the plot characteristics from within the program. The color of the text of an iconified plot indicates its status: a white plot is disabled, a green plot is active, and a red plot is active but the plotted values are out of limits (see Set Limits).

PROCEDURE

RTPLOT can nominally be run from the *Realtime* pull-down menu accessed from the GNC DNAV menu. The user has a choice of different configurations containing mission phase-specific plots - i.e., ascent/entry or orbit. It is not required for each console position to run different configurations of RTPLOT, since each position writes to different hard drives (two programs cannot write to the same data file).

```
/plotfile.name -ex extension -n "name"
```

All plot config files should be stored in the '/mcc/cert-apps/common/gnc/rtplot/plot' directory. For the standard versions, the names are in the format 'position.plot' (i.e., aeg.plot, orb.plot). The extension is a character string that is added on to the end of the data file names. This is necessary so that each configuration of RTPLOT is writing to different data files. The name is the text that is displayed as the title of the RTPLOT window (e.g. Orbit RTPLOT).

A. SETTING UP A PERSONAL CONFIG

In the RTPLOT application, under the Configs menu, each user's name appears with the choice of five saved configurations. By selecting a name and configuration (as required) under the Configs menu, that particular window configuration is recalled and the program automatically resizes windows and opens appropriate class windows. This procedure is the same as in ELOG.

If you have not previously defined a configuration, the following steps will define a personal configuration.

Initial Setup of a Configuration File:

- 1a. Select the appropriate name under the Configs menu.
- 1b. Select the appropriate configuration .
2. Resize the main window and class windows appropriately.
3. Under the Commands menu, select Save Config. A dialog will ask for confirmation to save the configuration file to:
/users/gnc/Data/rtplot/configs/\$\$\$\$.configs\$
4. Click Okay to complete the action.

B. CUSTOMIZING PLOTS

1. Commands Menu

The Commands menu allows the user to access RTPLOT capabilities. The menu is shown in Figure 1 with a brief description of each option.

COMMANDS	
Plot Info	Turns on information mode. The cursor becomes a +.
X,Y Info	Returns X,Y coordinate of cursur inside plot area.
Update Rate	Sets how often RTPLOT plots new data (e.g. 1 sec/sample).
Set Limits	Change the min & max values, time span, or limit lines.
Scale Type	Changes the type of plot: continuous, window, or scrolling and provides access to default settings.
Ena/Disable	Enable or disable a plot.
Clear Plot	Clear all data from a plot (and erase data from any associated files).
Save Plot	Save current plot data in <i>filename.sav</i> . (Different name for each plot).
Print Data	Prints data in a tabular format to printer.
Print Plot	Prints selected plot.
Label	Places label on plot at point of crosshair.
Tile Plot	Tiles selected plots within the current main widow size.
Save Config	Save current window config. to file specified under Configs menu.
Un/corral	Allows plots to be moved from the main window to the desktop. Will not iconifiy when the application is iconified.
Locate	Allows uniconifying of a selected plot without searching for specific icon
Exit RTPLOT	Quits RTPLOT.

Figure 1. Commands Menu and Description.

The following procedures summarize the typical actions required by the console operator with regards to the Commands menu.

a. Setting Limits

When Set Limits is commanded and a plot chosen, a window will pop up with 6 choices; X-axis maximum and minimum, Y-axis maximum and minimum, and limits. Limit lines can be drawn on the plot by placing values in the appropriate boxes, and the lines can be cleared by blanking the boxes. An iconified plot will have red lettering if the plotted values are outside the user-specified limits. The boundaries for the X and Y-axes can be set with this command, also. Unfortunately, RTPLOT sometimes changes the user inputted values to something else (e.g. a max of 1.5 becomes 2) so experimentation is necessary. With a window plot, the user can look at data that has scrolled off the plot and is saved in the data file by changing the X-axis limits (using the time format). The plot must be disabled first so that the next data point does not make the plot rescale itself to RTPLOT-determined values.

b. Selecting All Plots

In order to select all of the plots instead of just one, simply hold down the control key when the item is selected from the Commands menu. This applies to the following commands: Update Rate, Set Limits, Change Type, Ena/Disable, Clear Plot, Print Data, and Save Plot.

2. Window Manipulation

The plot windows can be manipulated in RTPLOT using a series of somewhat user-hostile commands. The commands are listed/summarized below:

1. De-Iconify - Click the icon with any mouse button.
2. Move Icon - Hold down the control key and click on icon using L or C mouse button.
3. Move Plot - Click and hold down on top bar of plot using any mouse button.
4. Iconify Plot - Click on Iconify box in top right corner with any mouse button.
5. Show X,Y Position - Position pointer anywhere within plot window.
6. Show Slope - Position pointer within window and hold down L or C mouse button. If the pointer is moved, the slope between the original point and the current pointer position is shown.
7. Resize Plot Window - Position pointer anywhere on the plot and press and hold down the R mouse button. The plot can then be resized as desired, but a minimum size does exist.
8. Enlarge Plot - Click the R mouse button when the pointer is in the window and that plot will be enlarged to the size of the RTPLOT window.

C. SPECIAL PLOT FILES

Special plot files can be created to be used by RTPLOT. The best way to learn how to make new plots is to look at one that already exists. Figure 2 shows an example plot file. More than one plot can be in each file, assuming that each starts with a **PLOT:** command. The most common commands are explained here:

PLOT: {plot/icon name}

This command must be on the first line of every plot.

DATA FILE: {data file name}

Defines the data file and path used by RTPLOT. The extension option (-ex) will append to the end of the data file name.

DISABLE: {TRUE or FALSE}

If TRUE, the plot will come up disabled. If FALSE, the plot will come up enabled.

NAME: {plot icon/window name}

Defines a plot's window/icon name.

RATE: {update rate - default 1}

This is the time between data points (seconds per sample). Use discretion with large dathis - a fast data rate (a low number) on a long-running plot will create a very ta file.

TITLE: {plot title}

Defines a plot's title.

TYPE: {Continuous, Window, or Scroll}

Defines the plot type. For X vs. Y plots, use Continuous. For plots with time as the X axis, use Window or Scroll. Scroll plots do not save the data once it goes off the screen. If a continuous plot is made with a unit of time as the x-axis, the scale of the plot will increase as the time increases. All data received by a continuous plot is shown, which is useful if the user does not want data plotted versus time to scroll off the plot.

X MSID: {MSID}

For Window or Scroll plots, you may use MET in place of the MSID.

X NAME: {x-axis name}

You need one of these for each X MSID.

X SPAN: {size of x-axis}

For Window or Scroll plots, use the time format (DDD/HH:MM:SS).

X UNITS: {x-axis units}

You need one of these for each X MSID. This merely puts a label on the plot next to the label.

Y MSID: {MSID}

You need one of these for each plot. You can plot as many variables as you want.

Y NAME: {Y-axis name}

You need one of these for each Y MSID.

Y COLOR: {color of plot line}

You need one of these for each Y MSID. Good, predefined colors include red, yellow, green, purple, and white.

Y UNITS: {Y-axis units}

You need one of these for each Y MSID. This merely puts a label on the plot next to the label.

X MIN:, X MAX:, Y MIN:, Y MAX: {limits for the axes}

You can specify these to define the initial size of the plot window. However, RTPLOT has a mind of its own when it comes to limits. Also, do not use X MIN or X MAX when you are using a scroll or window plot - use X SPAN instead.

D. NOMINALLY USED PLOTS

The following is a listing of suggested plots to be used for specific mission phases. This is not a detailed listing of every available plot but should provide a guide as to what plots should be monitored for each flight phase.

1. Prelaunch (Ascent/Entry plot config)

Sensors :

- a. PRELAUNCH GYRO X(Y)(Z) : Plots IMU 1 vs. 2, 1 vs. 3, and 2 vs. 3 gyro deltas against time.

Control :

- a. none

2. Ascent (Ascent/Entry plot config)

Sensors :

- a. GRND-IMU VX(Y)(Z) : Plots the change in velocity in the components between ground radar tracking and each IMU against time. These are useful in making IMU delimita decisions.

- b. IMU VEL DIFF : Plots IMU 1 vs. 2, 1 vs. 3, and 2 vs. 3 velocity deltas against time. The RM value is also plotted in Ops 3 (Entry or TAL aborts). The values are in units of ft^2/sec^2 but can be converted to units of μG 's by the following formula :

$$\# \mu G = \sqrt{(\text{downlisted } v^2)} \times \frac{1}{15.35 \text{ sec}} \times \frac{10^{-6} \mu G}{32.2 \frac{\text{ft}}{\text{sec}^2}}$$

Control :

- a. RGA RATES : Plots RGA roll, pitch, and yaw rates against time.
- b. L,R PITCH and YAW : Plots OMS TVC gimbal positions.
- c. L,R ADI ATT, RATES, ERRORS : Plots ADI roll, pitch, and yaw attitude, rates, and errors in LVLH against time.

3. Orbit (Orbit plot config)**Support :**

- a. IMU RM, X(Y)(Z) ACCL DLTS, GYRO X(Y)(Z) : Plots IMU attitude RM and IMU-to-IMU relative accelerometer and gyro deltas against time. When at the two-level on IMU's, the GYRO X/Y and IMU X/Y plots can be used, where X/Y are the two active IMU's.
- b. -Y(-Z) FOV and INT : Plots positions and intensities of objects in the star tracker field of view. Useful during self tests and rendezvous operations.
- c. DAP ATT and RT ERR, TOT ERR, and ROLL, PITCH, YAW PP : Plots orbit DAP roll, pitch, and yaw rates and errors against time. Phase plane (PP) plots are used in conjunction with the Phase Plane application (*GNC DNAV > APPS > Phase_Plane*).

4. Entry (Ascent /Entry plot config)**Sensors :**

- a. GRND-IMU VX(Y)(Z) : see Ascent Sensors
- b. IMU VEL DIFF : see Ascent Sensors
- c. GND-TAC RNG, BRG : Plots deltas between each TACAN's range or bearing and radar-derived values against time. Used in making TACAN delimita decisions.
- d. ADTA VS RDR (NAV) : Plots the ADTA 1, 2, 3, and 4 altitude against ground radar altitude (for nominal entries) or against the downlinked nav state (for aborts or other entries without radar tracking).
- e. GND-MLS AZ, EL, RNG : Plots deltas between each MLS's azimuth, elevation, and range values and radar-derived values against time.

- f. RA ALT : Plots RA 1 and 2 altitude against the downlinked nav state. Used for determining the health of the RA's during the final phase of entry.

Control :

- a. RGA RATES : see Ascent Control
- b. L,R ADI ATT, RATES, ERRORS : see Ascent Control
- c. ASA Sec ΔP 's

E. MISCELLANEOUS INFORMATION

1. Change History

Whenever a change is made to a RTPLOT file, a description of your changes should be placed at the beginning of the file. This description should include your name, the date, and a summary of the changes. In the plot file, an '@' is used to denote a comment line.

2. RTPLOT User's Guide

For more detail on RTPLOT, reference the user's guide available via the GNC Website

3. References

McCluney, R. K. *RTPLOT SCP, MECH, VOL /JSC-18341*,.

@ GNC REAL-TIME PLOT FILE
@ LAST UPDATE: 3-8-93 JD
@ 3-29/30-93 JN Added Accelerometer and Resolver Plots
@ 4-13-92 JN Added plots, modified acc deltas and res deltas
@ 4-15-93 SS Added plots for A/E GNC (see end of file)
@ 4-22-93 JN Made mods after STS-56,added Sensors entry
@ plots
@ 5-10-93 JN Updated time format
@ 5-25-93 JN Mod for spt position
@ 6-9-93 JN Added OMS plots
@ 7-2-93 JN Changed time format back (not my fault!)
@ 7-9-93 JN Added Gyro 1/3 Deltas, etc and RSS vs. RM
@ 7-15-93 JN Compiled all plots into this one file. All
@ will come up disabled. Also organized the plot
@ so they come up in a reasonable order. Changed
@ data file structure. Got rid of SCROLL command
@ occurrences for new version of RTPLOT
@

PLOT:

NAME: TOT ERR
TITLE: Total Errors
FONT: 8X13
RATE: 5
TYPE: SCROLL
DISABLE: TRUE
DATA FILE: /user/gnc/RTPLOT/data/toterr.aegnc
X SPAN: 000/00:15:00
X MSID: MET

Y MSID: V95H7490C
Y NAME: R TOT ERRS
Y UNITS: Degrees
Y COLOR: red

Y MSID: V95H7491C
Y NAME: P TOT ERRS
Y UNITS: Degrees
Y COLOR: green

Y MSID: V95H7492C
Y NAME: Y TOT ERRS
Y UNITS: Degrees
Y COLOR: yellow

Figure 2. Sample Plot File

TITLE

CRANS - Configurable Real-time Analysis System

DESCRIPTION

The purpose of this SCP is to provide a GNC specific guide to the CRANS application. Information on logic, matrix, configuration, and other programming topics is available in the CRANS User Guide available in the MMACS Console Handbook, JSC-26101, SCP 15.6.

CRANS provides the capability to display event lights that are driven by specially defined logic. Event lights are arranged in a matrix which can be opened or iconified by clicking the left mouse button on either the icon body or in the small box in the upper right corner of the matrix, respectively. The color of the icon label indicates whether an event is true in that matrix: green labels indicate nothing is true in the matrix, while red indicates one or more items are true, and white indicates a true event or events which has been acknowledged. Any changes occurring in a matrix with a white label will result in the label returning to red until the changed event is acknowledged.

Icons and matrices can be rearranged as desired by the operator. To move an icon, the keyboard control button is pressed while clicking/holding the left mouse button and dragging the icon to the desired location in the CRANS window. To move a matrix, place the cursor in the matrix title bar, click/hold the left mouse button, and drag the matrix to the desired location. Configurations can then be saved to be recalled anytime in the future. Several generic configurations are provided to allow for multiple configurations.

The operator can interrogate CRANS to display the event logic by pointing to the event with the cursor, then clicking the center mouse button. Events can be manually made true by pointing to the event, then clicking the left mouse button. The event is then permanently "failed ON", until the process is repeated to toggle the event off.

Event boxes can contain multiple levels of events. This feature is used throughout GNC CRANS to better utilize workstation real estate. Events which are nested in these multi-level boxes are generally mutually exclusive to avoid masking of events when another event in the box is true. The exceptions to these are the high level monitors for BITES and LRU power status. As an example, the IMU 1 HW BITE event is considered true whenever a HW BITE is present. Special arrangement in the logic makes the entire list of BITES available by pointing the cursor on the event and clicking/holding the left mouse button. A submenu of all H/W BITES is then displayed, with the offending BITE showing up as red. The BITE can then be acknowledged, thereby making the event box active to detect another BITE.

The color scheme selected for GNC CRANS was designed to easily detect off-nominal conditions, but also to convey the configuration of GNC systems at a glance. A Dark Gray/Light Gray approach was used to indicate the event box being either off or that an event was true, but was a nominal configuration. Color schemes for off-nominal conditions are the standard red/amber/green lights:

Red - Warning. An LRU or system has failed.

Salmon - Commfault

Amber/Gold/Orange - Attention. System or LRU configuration requires assessment.

Green - LRU powered on

Dark Gray - Event box is not active or no events are true

Light Gray - Event box is active and condition is expected

Blue - Event box is active, condition is expected, but has changed

White - Event box is active, condition is expected, but has changed

DNAV/CRANS Menu selections are indicated by the following convention:

MENU 1^MENU 2^...^MENU N^<Application/Function Name>

Mouse actions are indicated by braces preceded by keyboard actions, if required:

(CNTL,ALT,SHIFT){Mouse action}

Some other features which have not been optimized in GNC CRANS, but may be found useful is the Commonality, Fail Result, and Reference features. These features become available when one or more event box is "tagged" using the right mouse button. Tagging two or more event boxes, and then requesting commonality will result in a list of GNC CRANS logic events which are common to the tagged events. Tagging one or more event, then requesting Fail Result will provide a list of failed, i.e. "true", GNC CRANS events. Finally, tagging one or more items and requesting Reference will result in a list of all GNC CRANS events which have the tagged events in common. These features can be useful in what-if analysis, but the operator should keep in mind these features are not optimized, and could be misleading.

The Help feature provides both information on logic driving a selected event, and supplementary information provided by the programmer. It is invoked using the middle mouse button.

Acknowledging (or sometimes called Suppressing) an event allows the logic to continue to use the event box for monitoring. A single event can be acknowledged using the center mouse button. Multiple true events can be acknowledged using the Suppress feature. Doing this allows the operator to easily monitor for transients and changes to configurations, particularly when many events are active, and pattern recognition of changes is difficult.

PROCEDURES

A.) *STARTING THE APPLICATION*

On the desired workstation DNAV Menu:

GNC^RealTime^<CRANS Application>

B.) *ENDING THE APPLICATION*

On the CRANS Window:

Commands^Exit CRANS <Return>

C.) *REARRANGING MATRICES/ICONS*

On the CRANS Window:

1. Move cursor to select an icon or matrix title bar
2. CNTL{Click/Hold Left}
3. Drag item to desired position and release.

D.) *SAVING A CONFIGURATION*

On the CRANS Window:

1. Select configuration to be saved:

Configs^<name>^<config>

2. Arrange matrices/icons per previous procedure
3. Commands^Save Config <Return>

E.) *ACKNOWLEDGING AN EVENT*

On the CRANS Window:

1. Move cursor to an open place (no events selected).
2. {Click/Hold Center}
3. Move cursor to an event.
4. {Click Left}

OR

1. Commands^Suppress

2. Move cursor to matrix
3. {Click Left}

F.) INTERROGATING A HELP FILE

On the CRANS Window:

1. Move cursor to an event.
2. {Click Center}

G.) LEAVING HELP MODE

On the CRANS Window:

Commands^Help Off

H.) TAGGING/UNTAGGING EVENTS

On the CRANS Window:

1. Move cursor to an event.
2. {Click Right}
3. To remove the tag, repeat or Commands^Clear Tags

I.) DISPLAYING COMMON EVENT LOGIC

On the CRANS Window:

1. Move cursor to an event.
2. {Click Right}
3. Repeat for all desired events
4. Commands^Commonality

J.) DISPLAYING FAILURE IMPACTS

On the CRANS Window:

1. Move cursor to an event.
2. {Click Right}
3. Repeat for all desired events
4. Commands^Fail Result

K.) *DISPLAYING OTHER EVENTS WHICH REFERENCE A SELECTED EVENT(S)*

On the CRANS Window:

1. Move cursor to an event.
2. {Click Right}
3. Repeat for all desired events
4. Commands^Reference

REFERENCES

CRANS User Guide, MMACS Console Handbook, JSC-26101, SCP 15.6

TITLE

G-MEM READ/WRITE PROCEDURES

PURPOSE

To establish a method by which onboard software can be dissected for better understanding and evaluated for possible alterations due to system failures or required workarounds.

ASSUMPTIONS

The following list of documents and software reports that are available for developing a General Memory (G-MEM) Read/Write (R/W):

A. PRIMARY AVIONICS SOFTWARE SYSTEM (PASS)

1. Guidance, Navigation, and Control (GNC) Detailed Design Specification (DDS)
2. AUTODOC
 - cd OI Products
3. HALSTAT
 - cd FSW Products
4. Master Source Listing
 - cd FSW Products
5. DASS (Memory MAP)
 - cd FSW Products
6. Map Report (I-LOAD)
 - cd FSW Products

B. BACKUP FLIGHT SYSTEM (BFS)

1. Program Requirements Document (PRD)
2. BFS OI BUILD
 - cd OI Products

C. FLIGHT CONTROL OPERATIONS HANDBOOK (FCOH)

D. STS OPERATIONAL FLIGHT RULES

BACKGROUND

This procedure allows for reviewing any software processed parameters in question. The capability exists to either read or write to onboard software, in main memory only, via crew input or G-MEM command uplink. Before accomplishing any G-MEM, consult Flight Rule A7-16 for the type of memory write to be accomplished.

PROCEDURES

A. *MEMORY ADDRESS LOOK UP*

1. Extract parameter from the applicable module using the Master Source Listing for PASS or the BFS OI Build for BFS. For PASS, use the AUTODOC for parameter breakdown (e.g., arrays, bit structures) if necessary.
2. Use the Map Report (I-LOAD) or HALSTAT to find the memory location(s), phase, and other information on the parameter.
3. A parameter can either be structured or nonstructured.
4. If the parameter is not structured, the HALSTAT report gives all pertinent information of applicable phase and parameter address, proceed to step 9; otherwise, continue.
5. If the parameter is part of a structure, or a structure itself, look for the "SEE STRUCTURE _____" statement in HALSTAT. This structure can be found in the structure templates area at the beginning of HALSTAT listing.
6. The resulting structure shows software phase and the base address of the structure. Phase description is shown in Table 11.19-I.
7. Sum, in HEX, the template offset of the parameter with the base address of the structure.
8. The HEX result is the actual address of the parameter.
9. For PASS, use the appropriate Memory Map to locate or verify memory location. On the flight software cd there is a memory map report for each memory configuration, such as Dass-GNC1 for OPS 1.
10. For BFS, use HALSTAT located within BFS OI BUILD on cd to locate the address.

TABLE 11.19-I.-PASS PHASE SUMMARY FOR MASS MEMORY PHASE TABLE

Phase no.	Memory Configuration	Description
1*	N/A	GPC Bootstrap Loader and Mini-Directory
2	ALL	Resident System Software
3	1, 2, 3, 8, 9	GNC Major Function Base (GNC-MFB)
4	1	Ascent and abort OPS (GNC 1/6-A)
5	2	On-Orbit OPS (GNC2-A)
6	3	Entry OPS (GNC 3-A)
7	8	Vehicle utility on-orbit OPS (GNC 8)
8	9	Vehicle utility pre-count OPS (GNC 9)
9	6	Vehicle utility checkout function base (VCO-FB)
10	N/A	Not Used
11	N/A	Not Used
12	6	Vehicle utility mass memory OPS (PL9)
13	N/A	Not Used
14	4,5	SM Function Base (SM-FB)
15	4	Orbit-doors OPS (SM2)
16	5	Spacelab Support OPS (SM4); reserved
17,18	N/A	Reserved for growth
19	N/A	Payload control supervisor sequences (PCS)
20	N/A	P/L Checkpoint; reserved
21	N/A	SM data checkpoint
22	N/A	IMU calibration checkpoint
23	N/A	PDI decom format load (DFL)
24	N/A	PDI fetch pointer memory load (FDL)
25	N/A	Telemetry format loads
26	N/A	GPC-STP/SW loaders (GPC-STP, SSL, LOAD)
27-34	N/A	TBL)
35-60	N/A	Subsystem configuration management (SCM) Roll-in displays

*Not currently in the PASS Phase Table

B. READ/WRITE OPERATIONS

The INFORMATION SECTION of FCOH 3.3.3 provides the necessary information to assist you in filling out the appropriate worksheet (JSC Form 781, R/T Memory Write Worksheet).

1. Real-time GPC read operations can be accomplished using a GPC memory read (FCOH, section 3.3.3.A, GPC MEMORY READ/WRITE), or the capability of the variable downlist (FCOH, Section 4.8, VARIABLE PARAMETER DOWNLIST USAGE). Prior to performing a memory write, a memory read is accomplished to verify the current value of the data. If a GPC memory read is accomplished, use JSC Form 781 contained in FCOH 3.3.3. If a memory write is to be performed by crew input on SPEC 0, it may not be necessary to perform a dedicated memory read as the memory will actually be read prior to the write and can be verified by the crew and ground on SPEC 0.
2. Real-time GPC write operations are broken down into preflight approved and verified, preflight approved and unverified, and unapproved (HIP POCKET) memory write operations.
 - a. For preflight-approved GPC memory write operations with the present conditions the same as in the G-MEM Maintenance Release Authorization Signature Sheet (MRAS), refer to FCOH section 3.3.3.B.1, GPC MEMORY READ/WRITE PROCEDURE.
 - b. For preflight-approved GPC memory write operations with the present conditions not the same as in the G-MEM MRAS, refer to FCOH section 3.3.3.B.2, GPC MEMORY READ/WRITE PROCEDURE.
 - c. For preflight approved and unverified, and HIP POCKET GPC memory write operations, refer to FCOH section 3.3.3.C, GPC MEMORY READ/WRITE PROCEDURE.

C. MEMORY WRITE PROCEDURE

The following information should help you to fill out JSC Form 781 (R/T Memory Write Worksheet) for HIP POCKET G-MEM's, preflight approved and unverified G-MEM's, and preflight approved G-MEM's when present conditions are not the same as in the MRAS. Electronic copies of the GMEM forms can be found on the DS-22 website at http://mod.jsc.nasa.gov/ds/ds22/Console_Forms.cfm. The flight controller should also check the information section of section 3.3.3, GPC Memory Read/Write, in the FCOH.

1. For page 1, fill out your name, the current GMT, date, and sections I through III with the appropriate data. In section IV, state briefly the objective of the memory write.
2. For page 2 (section VI), fill in the appropriate data, which can be obtained from the flight software CDs using DXR. The example shown here is intended to double the AA 1 scale factor (in PASS) to correct for a scale factor error observed during FCS checkout where AA 1 measured half the normal axis acceleration measured by AA's 2,3 and 4. Memory addresses and Hex values must be obtained using flight software CDs (DXR). To convert between hex and decimal, the GNC program HTOD should be used.

In this example, the data would be filled out as follows:

REAL TIME MEMORY WRITE WORKSHEET

PAGE 2 OF 2

VI.	S / W Name (HAL Name)	Parameter (FSSR Name)	Address (5 Digits)	MaskWord or Desired	Initial Actual	Final Actual
	CGPS_NORM_ACC_SCALE(1)	AA1 NORMSF, WORD 1	3932C	3E10	3D83	3E10
	CGPS_NORM_ACC_SCALE(1)	AA1 NORMSF, WORD 2	3932D	624E	126E	624E

- At this point, a CHIT should be filled out explaining the situation and the solution (i.e., the G-MEM). The copy to the MER will initiate the development and verification of the memory write operation.

TABLE 11.19-II.- G-MEM DATA PARAMETERS (PASS)

Name	HAL name	MSID	Address	Phase
IMU 8X Resolver Offset (RO, PO, AZL IRO)*				
IMU 1 Outer Roll	CGMS_RESOFFFEST(1,1)	V90H7650C	___ ___	3
IMU 1 Pitch	CGMS_RESOFFFEST(1,2)	V92H2620C	___ ___	
IMU 1 Azimuth	CGMS_RESOFFFEST(1,3)	V92H2610C	___ ___	
IMU 1 Inner Roll	CGMS_RESOFFFEST(1,4)	V99H2615C	___ ___	
IMU 2 Outer Roll	CGMS_RESOFFFSET(2,1)	V90H7651C	___ ___	
IMU 2 Pitch	CGMS_RESOFFFSET(2,2)	V99H2621C	___ ___	
IMU 2 Azimuth	CGMS_RESOFFFSET(2,3)	V99H2611C	___ ___	
IMU 2 Inner Roll	CGMS_RESOFFFSET(2,4)	V99H2616C	___ ___	
IMU 3 Outer Roll	CGMS_RESOFFFSET(3,1)	V90H7652C	___ ___	
IMU 3 Pitch	CGMS_RESOFFFSET(3,2)	V99H2622C	___ ___	
IMU 3 Azimuth	CGMS_RESOFFFSET(3,3)	V99H2612C	___ ___	
IMU 3 Inner Roll	CGMS_RESOFFFSET(3,4)	V99H2617C	___ ___	
IMU Gyro Torquer Scale Factor (KTX, KTY, KTZ)				
IMU 1/X-Axis	CGMS_TORSCFA(1,1)	V99G2500C	___ ___	3
IMU 1/Y-Axis	CGMS_TORSCFA(1,2)	V99G2503C	___ ___	
IMU 1/Z-Axis	CGMS_TORSCFA(1,3)	V99G2506C	___ ___	
IMU 2/X-Axis	CGMS_TORSCFA(2,1)	V99G2501C	___ ___	
IMU 2/Y-Axis	CGMS_TORSCFA(2,2)	V99G2504C	___ ___	
IMU 2/Z-Axis	CGMS_TORSCFA(2,3)	V99G2507C	___ ___	
IMU 3/X-Axis	CGMS_TORSCFA(3,1)	V99G2502C	___ ___	
IMU 3/Y-Axis	CGMS_TORSCFA(3,2)	V99G2505C	___ ___	
IMU 3/Z-Axis	CGMS_TORSCFA(3,3)	V99G2508C	___ ___	
RGA/AA Compensation Scale Factor				
RGA 1 Roll SF	CGPS_ROLL_SCALE(1)	V97U3418C	___ ___	6
RGA 2 Roll SF	CGPS_ROLL_SCALE(2)	V97U3419C	___ ___	
RGA 3 Roll SF	CGPS_ROLL_SCALE(3)	V97U3420C	___ ___	
RGA 4 Roll SF	CGPS_ROLL_SCALE(4)	V97U3421C	___ ___	
RGA 1 Pitch SF	CGPS_PITCH_SCALE(1)	V97U3422C	___ ___	6
RGA 2 Pitch SF	CGPS_PITCH_SCALE(2)	V97U3423C	___ ___	
RGA 3 Pitch SF	CGPS_PITCH_SCALE(3)	V97U3424C	___ ___	
RGA 4 Pitch SF	CGPS_PITCH_SCALE(4)	V97U3425C	___ ___	

*The value of these parameters may also be obtained from the Shuttle Orbiter Inertial Measurement Unit S/N X Preflight Report as generated and supplied by JSC/Inertial System Lab (ISL).

TABLE 11.19-II.- CONCLUDED

Name	HAL name	MSID	Address	Phase
RGA 1 Yaw SF	CGPS_YAW_SCALE(1)	V97U3426C	___ ___	6
RGA 2 Yaw SF	CGPS_YAW_SCALE(2)	V97U3427C	___ ___	
RGA 3 Yaw SF	CGPS_YAW_SCALE(3)	V97U3428C	___ ___	
RGA 4 Yaw SF	CGPS_YAW_SCALE(4)	V97U3429C	___ ___	
AA 1 Norm SF	CGPS_NORM_ACC_SCALE(1)	V97U3414C	___ ___	6
AA 2 Norm SF	CGPS_NORM_ACC_SCALE(2)	V97U3415C	___ ___	
AA 3 Norm SF	CGPS_NORM_ACC_SCALE(3)	V97U3416C	___ ___	
AA 4 Norm SF	CGPS_NORM_ACC_SCALE(4)	V97U3417C	___ ___	
AA 1 Lat SF	CGPS_LAT_ACC_SCALE(1)	V97U3404C	___ ___	6
AA 2 Lat SF	CGPS_LAT_ACC_SCALE(2)	V97U3405C	___ ___	
AA 3 Lat SF	CGPS_LAT_ACC_SCALE(3)	V97U3406C	___ ___	
AA 4 Lat SF	CGPS_LAT_ACC_SCALE(4)	V97U3407C	___ ___	
AA 1 L Misalign	CGPS_LAT_ACC_MISALIGN(1)	V97U8739C	___ ___	6
AA 2 L Misalign	CGPS_LAT_ACC_MISALIGN(2)	V97U8740C	___ ___	
AA 3 L Misalign	CGPS_LAT_ACC_MISALIGN(3)	V97U8741C	___ ___	
AA 4 L Misalign	CGPS_LAT_ACC_MISALIGN(4)	V97U8742C	___ ___	
IMU Redundant Gyro Delta Bias				
DDFR (IMU 1)	CGMV_DELTA_DDFR(1)	V99U5870C	___ ___	3
DDFR (IMU 2)	CGMV_DELTA_DDFR(2)	V99U5871C	___ ___	
DDFR (IMU 3)	CGMV_DELTA_DDFR(3)	V99U5872C	___ ___	
IMU Low-gain Accelerometer Scale Factors				
IMU 1/X	CGMS_ACC_SFLO(1,1)	V99A2520CC	___ ___	3
IMU 1/Y	CGMS_ACC_SFLO(1,2)	V99A2521CC	___ ___	
IMU 1/Z	CGMS_ACC_SFLO(1,3)	V99A2522CC	___ ___	
IMU 2/X	CGMS_ACC_SFLO(2,1)	V99A2523CC	___ ___	
IMU 2/Y	CGMS_ACC_SFLO(2,2)	V99A2524CC	___ ___	
IMU 2/Z	CGMS_ACC_SFLO(2,3)	V99A2525CC	___ ___	
IMU 3/X	CGMS_ACC_SFLO(3,1)	V99A2526CC	___ ___	
IMU 3/Y	CGMS_ACC_SFLO(3,2)	V99A2527CC	___ ___	
IMU 3/Z	CGMS_ACC_SFLO(3,3)	V99A2528CC	___ ___	

NOTE: Each parameter in Table 11.19-II has two HEX words for address and data associated with each address.

TABLE 11.19-III.- G-MEM DATA PARAMETERS (BFS)

Name	HAL name	MSID	Address
IMU 8X Resolver Offset			
IMU 1 Outer Roll	OFFSET(1,1)		___ ___
IMU 1 Pitch	OFFSET(1,2)		___ ___
IMU 1 Azimuth	OFFSET(1,3)		___ ___
IMU 1 Inner Roll	OFFSET(1,4)		___ ___
IMU 2 Outer Roll	OFFSET(2,1)		___ ___
IMU 2 Pitch	OFFSET(2,2)		___ ___
IMU 2 Azimuth	OFFSET(2,3)		___ ___
IMU 2 Inner Roll	OFFSET(2,4)		___ ___
IMU 3 Outer Roll	OFFSET(3,1)		___ ___
IMU 3 Pitch	OFFSET(3,2)		___ ___
IMU 3 Azimuth	OFFSET(3,3)		___ ___
IMU 3 Inner Roll	OFFSET(3,4)		___ ___
IMU Gyro Torquer Scale Factor			
IMU 1/X-Axis	KTX(1,1)		___ ___
IMU 2/X-Axis	KTX(1,2)		___ ___
IMU 3/X-Axis	KTX(1,3)		___ ___
IMU 1/Y-Axis	KTY(2,1)		___ ___
IMU 2/Y-Axis	KTY(2,2)		___ ___
IMU 3/Y-Axis	KTY(2,3)		___ ___
IMU 1/Z-Axis	KTZ(3,1)		___ ___
IMU 2/Z-Axis	KTZ(3,2)		___ ___
IMU 3/Z-Axis	KTZ(3,3)		___ ___
IMU Low-gain Accelerometer Scale Factors			
IMU 1/X	KIX(1,1)		___ ___
IMU 1/Y	KIY(1,2)		___ ___
IMU 1/Z	KIZ(1,3)		___ ___
IMU 2/X	KIX(2,1)		___ ___
IMU 2/Y	KIY (2,2)		___ ___
IMU 2/Z	KIZ (2,3)		___ ___
IMU 3/X	KIX (3,1)		___ ___
IMU 3/Y	KIY (3,2)		___ ___
IMU 3/Z	KIZ (3,3)		___ ___

*The MSID's for the BFS IMU 8X Resolver Offsets and Gyro Torquer Scale Factors are the same as the PASS.

D. G-MEM INFORMATION

Any G-MEM is restricted from use in any GPC memory configuration to which site-applied patches, GPC Read/Write Procedures or other memory alterations have been introduced to the base release system. In addition, G-MEM's are restricted for use only once within a GPC memory configuration. G-MEM procedures are authorized for use with numerical values defined in the reference MRAS (i.e., when an MRAS exists). Use of any numerical value or memory address different from those explicitly enumerated in the reference MRAS will require recertification and no subset or portion of the entire procedure defined in the referenced MRAS shall be attempted. Also, G-MEM's are restricted from use in any GPC memory configuration during a period when any faults, errors, off-nominal processing, or hardware failures are present.

HIP POCKET G-MEM'S

1. The IMU CALIBRATION TERMS READ/WRITE capability carries MRAS# AXXX-903 (for BFS MRAS/EO# VP708134C02), where XXX is the flight designation (e.g., 077). This G-MEM should be done only in OPS 201 and 301.
2. The IMU 8X RESOLVER OFFSET (SCP 2.3) capability should be done in OPS 201 or 301 and will transition. A MASS MEMORY READ (SPEC 21, ITEM 19) or an IPL of all PASS GNC computers will initialize these terms to their prelaunch values and therefore must be reaccomplished.
3. The GYRO TORQUER SCALE FACTOR (SCP 2.12) capability requires an OPS transition for it to work. This procedure can be accomplished in OPS 2 or 3. A MASS MEMORY READ (SPEC 21, ITEM 19) or IPL of all PASS GNC computers will initialize these terms to their prelaunch values and therefore must be reaccomplished.

REFERENCE

STS Operational Flight Rules, Flight Rule A7-16.

Flight Control Operations Handbook (FCOH), Section 3.3.3, GPC Memory Read/Write Procedure.

TITLE

ELOG USER'S GUIDE

PURPOSE

To aid flight controllers in the operation of the GNC ELOG program.

BACKGROUND

ELOG provides a method of logging telemetry events in real-time. An event is defined as the comparison of an MSID value to a constant. When the comparison is true, the event is logged to a file and to the program window, tagged by GMT, MET, altitude, Mach number, Vrel and Qbar. A text message is generated to represent the logged event. Related events are assigned to a class group or groups for easier manipulation. These classes define the display windows for the events. The program allows for acknowledging an event; counters are displayed showing the number of unacknowledged events and total events by class to aid in event tracking. An information mode provides the user with a method of examining and changing event parameters from within the program.¹

PROCEDURE

To execute ELOG, select it from the GNC DNAV MENU, under "Realtime" in the MCC. Under the Configs menu, each user's name appears. By selecting a name under the Configs menu, the outline of the window will appear for placement

A. *SETTING UP/RECALLING A PERSONAL CONFIG*

Under the Configs menu, each user's name appears. By selecting a name under the Configs menu, that particular window configuration is recalled and the program automatically resizes windows and opens appropriate class windows.

If you have not previously defined a configuration, the following steps will define a personal configuration.

Initial Setup of a Configuration File:

1. Select the appropriate name and configuration number under the Configs menu.
2. Resize the main window and class windows appropriately.
3. Under the Commands menu, select Save Config. A dialog will ask for confirmation to save the configuration file to:

MCC: /users/gnc/Data/elogconfigs/**position**.config &

Where "**position**" is gnc, sen, con-sup, or obs.

4. Click Okay to complete the action.

B. CUSTOMIZING ELOG WINDOWS/FILES

1. Commands Menu

The Commands menu allows the user to access ELOG capabilities. The menu is shown in Figure 1 with a brief description of each option.

Commands	
Event Info	Turns on information mode. The pointer becomes a +.
Set Tags	Allows user to tag an event with MET, GMT, Mach, altitude, etc.
Ena/Disable	Enable or disable a class of events for logging. The cursor becomes a +.
Update Rate	Sets how often ELOG checks for new events.
Filter	Sets the number of times an event is true before it is logged to a window.
Alarm	Turns alarm on/off. (Any non-zero number turns alarm on).
Acknowledge	Allows user to acknowledge entire classes of events. The cursor becomes a +.
Print Log	Prints a selected class of events to the printer.
Save Config	Saves the current window config. under the user name selected in Configs.
Exit ELOG	Quits ELOG.

Figure 1. Commands Menu and Description.

The following procedures summarize the typical actions required by the console operator with regards to the Commands menu. For all actions, *Select* refers to clicking with the left mouse button.

a. Clearing Previously Logged Events

1. Select `Event Info` from the `Commands` menu. The pointer will turn into a cross hairs, +. Refer to Figure 2 for menu selection.
2. Click the cross hairs pointer on a class window, either open or iconified. The entire ELOG window will then show event information. This is known as the information mode.
3. Under `Commands`, select `Clear Log`. `Clear Log` appears in the place of the `Save Config` option in the information mode.
4. Select `Info Off` from the `Commands` menu to return to the normal event logging mode. `Info Off` appears in the place of the `Event Info` option in the information mode.
5. All class windows should now be clear and ready to log new events.

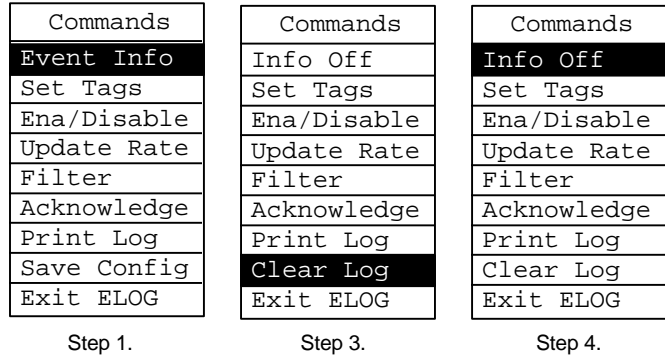


Figure 2. Menu Selections to Clear Log.

b. Setting Event Tags

1. Select `Set Tags` from the `Commands` menu. The pointer transforms to a cross hairs icon, +.
2. Click on the class window that you want to change.
3. A dialog appears with tag options such as MET, GMT, Mach, altitude, Qbar and Vrel. Select the items that you want each event tagged with by clicking on their box (Box will turn green). If you want to turn off a tag, just click the tag's box (Box will turn white).
4. Click `Okay`. The class window will now show the selected tags before the event message.

2. Window Manipulation

On ELOG start-up, all class windows are iconified and located along the right side of the main ELOG window. To open a class window, simply click the icon with the left mouse button. To resize an opened class window, position the pointer in the lower right-hand corner, depress the right mouse button and resize as desired. To move a class window, click on the class title with the left mouse button and drag the window. Additionally, a class window icon may be moved by holding the control key and clicking on the icon with the left mouse button. These manipulations are summarized in Figure 3. Note that most McCluney programs handle window manipulation the same way.

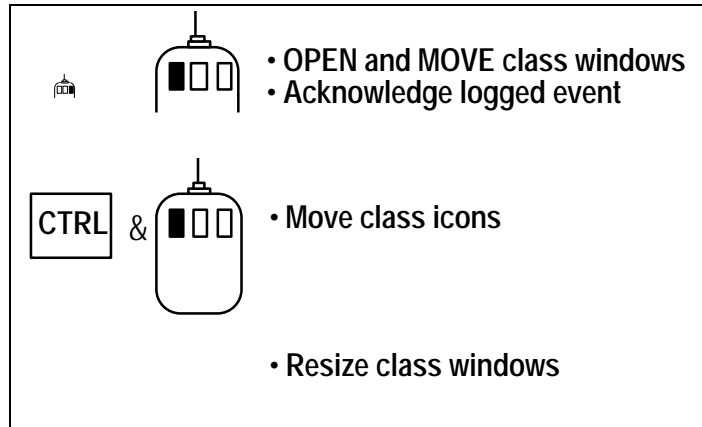


Figure 3. Mouse and Key Combinations for Window Manipulation.

3. Changing the Event File

The event file is a text file which identifies the events that ELOG will log to the program window and log file. This event file, typically named `elog.event`, informs the program to which class the event belongs, what comparison must be true for the event to log, and specifies colors of the message. An example of a line in the event file is given below in Figure 4 with explanation of its components.

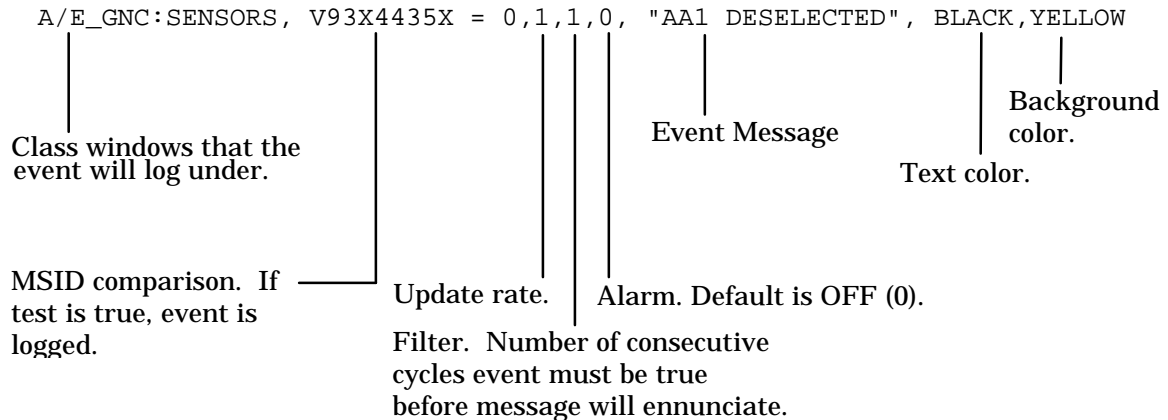


Figure 4. Event File Explanation.

The greatest attribute of ELOG is that it can be easily modified to log new events via changes in the event file. The procedure below outlines the steps necessary to change the event file, either real time or otherwise:

1. Make a copy of the current event file using the following commands:

```

cd /users/gnc/Data/elog (If not already in the proper directory)
cp elog.gnc new.event

```

2. Using the editor of your choice, make modifications to new.event following the example event line entry given in Figure 4.
3. Insert the necessary lines in the change history portion of new.event to indicate the date and type of change made. All line entries must begin with the character @, which informs ELOG that the line is a comment. A change history example is given below:

```
@ 9/19/93    Added THC contact deselects  
@           - George N. Controller
```

4. Restart ELOG from an XTerm window with the following command, substitute one of the five possible positions for **position**.

MCC:

```
/users/gnc/Data/elog/elog -e new.event -l position.log -s position.setup -bg  
whitesmoke &
```

¹ Paragraph based on Kevin Mc Cluney's *ELOG User's Guide*, Mech Vol/JSC-18341, June 11, 1993.

TITLE

ODRC COMPUTATIONS

PURPOSE

This SCP is to provide information about which GNC computations defined in the MCC Level B and C Requirements were implemented in ODRC. Also there were a few changes required in the computations to make them work in ODRC.

DESCRIPTION

A. IMU COMPUTATIONS

1. IMU Roll to Cluster Quaternion to matrix Conversion

This computation converts the IMU Roll to cluster quaternion to matrix to be used as an input to several other IMU computations.

A. Inputs

	IMU 1	IMU 2	IMU 3
q0	V90U2337C	V90U2341C	V90U2345C
q1	V90U2338C	V90U2342C	V90U2346C
q2	V90U2339C	V90U2343C	V90U2347C
q3	V90U2340C	V90U2344C	V90U2348C

B. Outputs

IMU 1:

M11G0105C	M12G0105C	M13G0105C
M21G0105C	M22G0105C	M23G0105C
M31G0105C	M32G0105C	M33G0105C

IMU 2:

M11G0106C	M12G0106C	M13G0106C
M21G0106C	M22G0106C	M23G0106C
M31G0106C	M32G0106C	M33G0106C

IMU 3:

M11G0107C	M12G0107C	M13G0107C
M21G0107C	M22G0107C	M23G0107C
M31G0107C	M32G0107C	M33G0107C

C. Logic

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.1.1.

2. ODRC IMU Roll-to-Roll file

A copy of the roll-to-roll matrices generated from SCP 2.7 should be given to the ODRC Help Desk with a request that the values be entered for the MED constants. The default values are identity matrices. The ODRC Help Desk is located in room 4327 of 30S (phone 36372 and fax number 36972).

RL2	T =	M11G0300M	M12G0300M	M13G0300M
		M21G0300M	M22G0300M	M23G0300M
RL1		M31G0300M	M32G0300M	M33G0300M

RL3	T =	M11G0301M	M12G0301M	M13G0301M
		M21G0301M	M22G0301M	M23G0301M
RL1		M31G0301M	M32G0301M	M33G0301M

RL3	T =	M11G0302M	M12G0302M	M13G0302M
		M21G0302M	M22G0302M	M23G0302M
RL2		M31G0302M	M32G0302M	M33G0302M

3. ODRC Saved REFSMMAT file

The saved REFSMMATs are initialized to identity matrices. To get the correct values saved, a copy of the REFSMMATs needs be given to the ODRC Help with a request that the values be entered into the MEDs below. The ODRC Help Desk is located in room 4327 of 30S (phone 36372 and fax number 36972).

NOTE: Today the IMU REFSMMATs are always on the downlist, so that this saved REFSMMAT file is not required. All ODRC IMU computation request can use the downlisted values.

<u>Downlist parameters</u>	<u>Stored parameters</u>
V99U3450C	M01G3450M
V99U3451C	M02G3451M
V99U3452C	M03G3452M
V99U3453C	M04G3453M
V99U3454C	M05G3454M
V99U3455C	M06G3455M
V99U3456C	M07G3456M
V99U3457C	M08G3457M
V99U3458C	M09G3458M
V99U3459C	M10G3459M
V99U3460C	M11G3460M
V99U3461C	M12G3461M
V99U3462C	M13G3462M
V99U3463C	M14G3463M
V99U3464C	M15G3464M
V99U3465C	M16G3465M
V99U3466C	M17G3466M
V99U3467C	M18G3467M

(continued on next pg)

<u>Downlist parameters</u>	<u>Stored parameters</u>
V99U3468C	M19G3468M
V99U3469C	M20G3469M
V99U3470C	M21G3470M
V99U3471C	M22G3471M
V99U3472C	M23G3472M
V99U3473C	M24G3473M
V99U3474C	M25G3474M
V99U3475C	M26G3475M
V99U3476C	M27G3476M

4. IMU to Reference Cluster Attitude Conversion

This computation provides the reference cluster Euler angles from each of the IMU's to the selected reference IMU in Euler order YAW, PITCH, ROLL.

Two MEDable Constants are available to be sent with any request for this computation output using the MED Override function on the MEWS Request for Operational Downlist Data.

1. Reference IMU MEDable constant (default value is 1);

M01G0300M = 1, 2, or 3 to select IMU 1, 2 or 3 as the reference IMU.

2. IMU REFSMMAT selection MEDable constant (default value is 4);

M04G0300M = 0, means use the saved REFSMMATs.

M04G0300M \neq 0, means use the downlisted REFSMMATs.

A. Inputs

1. Roll to cluster matrices
2. REFSMMATs
3. Roll-to-Roll matrices

B. Outputs

	IMU 1	IMU 2	IMU 3
ROLL	M01G0300C	M04G0300C	M07G0300C
PITCH	M02G0300C	M05G0300C	M08G0300C
YAW	M03G0300C	M06G0300C	M09G0300C

C. Logic

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.3.

5. Gyro misalignment (GYRO Deltas)

Two MEDable Constants are available to be sent with any request for this computation output using the MED Override function on the MEWS Request for Operational Downlist Data.

1. Reference IMU MEDable constant (default value is 1);

M01G0300M = 1, 2, or 3 to select IMU 1, 2 or 3 as the reference IMU.

2. IMU REFSMMAT selection MEDable constant (default value is 4);

M04G0300M = 0, means use the saved REFSMMATs.

M04G0300M ≠ 0, means use the downlisted REFSMMATs.

A. Inputs

Three roll to reference cluster matrices for each IMU which were generated as intermediate outputs from the IMU to Reference Cluster Attitude Conversion computation.

B. Outputs

	X	Y	Z	RSS
IMU 1/2	M11G0301C	M10G0301C	M12G0301C	M01G0305C
IMU 1/3	M14G0301C	M13G0301C	M15G0301C	M02G0305C
IMU 2/3	M17G0301C	M16G0301C	M18G0301C	M03G0305C

C. Logic

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.3.1.

6. IMU Euler Angle Comparisons (RSLVR Deltas)

Two MEDable Constants are available to be sent with any request for this computation output using the MED Override function on the MEWS Request for Operational Downlist Data.

1. Reference IMU MEDable constant (default value is 1);

M01G0300M = 1, 2, or 3 to select IMU 1, 2 or 3 as the reference IMU.

2. IMU REFSMMAT selection MEDable constant (default value is 4);

M04G0300M = 0, means use the saved REFSMMATs.

M04G0300M ≠ 0, means use the downlisted REFSMMATs.

A. Inputs

The reference cluster Euler angles computed in a previous computation.

	IMU 1	IMU 2	IMU 3
ROLL	M01G0300C	M04G0300C	M07G0300C
PITCH	M02G0300C	M05G0300C	M08G0300C
YAW	M03G0300C	M06G0300C	M09G0300C

B. Outputs

	ROLL	PITCH	YAW
RSLVR 1/2	M19G0902C	M22G0902C	M25G0902C
RSLVR 1/3	M20G0902C	M23G0902C	M26G0902C
RSLVR 2/3	M21G0902C	M24G0902C	M27G0902C

C. Logic

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.9.2.

7. IMU Velocity Comparisons (VEL Deltas)

This computation provides the velocities for each IMU in the reference IMU's coordinates and computes the velocity deltas. The velocity deltas are based on the start time of the ODRC request (i.e., the equivalent time of pressing the old delta-V reset pbi is the start time of the request).

Two MEDable Constants are available to be sent with any request for this computation output using the MED Override function on the MEWS Request for Operational Downlist Data.

1. Reference IMU MEDable constant (default value is 1);

M01G0300M = 1, 2, or 3 to select IMU 1, 2 or 3 as the reference IMU.

2. IMU REFSMMAT selection MEDable constant (default value is 4);

M04G0300M = 0, means use the saved REFSMMATs.

M04G0300M ≠ 0, means use the downlisted REFSMMATs.

A. Inputs

1. The IMU velocities in M50 coordinates:

	IMU1	IMU2	IMU3
VX	V95L0065C	V95L1065C	V95L2065C
VY	V95L0066C	V95L1066C	V95L2066C
VZ	V95L0067C	V95L1067C	V95L2067C

2. REFSMMATs

B. Outputs

1. The IMU reference velocities (REF VEL):

	IMU1	IMU2	IMU3
VX	M01G0901C	M04G0901C	M07G0901C
VY	M02G0901C	M05G0901C	M08G0901C
VZ	M03G0901C	M06G0901C	M09G0901C

2. The velocity differences between IMU's (VEL Deltas):

	X	Y	Z
IMU 1/2	M10G0901C	M13G0901C	M16G0901C
IMU 1/3	M11G0901C	M14G0901C	M17G0901C
IMU 2/3	M12G0901C	M15G0901C	M18G0901C

C. Logic

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.9.1.

8. IMU Accelerometer Bias (ACC Deltas)

The acceleration deltas are based on the start time of the ODRC request (i.e., the equivalent time of pressing the old delta-V reset pbi is the start time of the request).

Two MEDable Constants are available to be sent with any request for this computation output using the MED Override function on the MEWS Request for Operational Downlist Data.

1. Reference IMU MEDable constant (default value is 1);

M01G0300M = 1, 2, or 3 to select IMU 1, 2 or 3 as the reference IMU.

2. IMU REFSMMAT selection MEDable constant (default value is 4);

M04G0300M = 0, means use the saved REFSMMATs.

M04G0300M ≠ 0, means use the downlisted REFSMMATs.

A. Inputs

The velocity differences computed in the previous computation:

	X	Y	Z
IMU 1/2	M10G0901C	M13G0901C	M16G0901C
IMU 1/3	M11G0901C	M14G0901C	M17G0901C
IMU 2/3	M12G0901C	M15G0901C	M18G0901C

B. Outputs

	X	Y	Z
ACC 1/2	M28G0903C	M31G0903C	M34G0903C
ACC 1/3	M29G0903C	M32G0903C	M35G0903C
ACC 2/3	M30G0903C	M33G0903C	M36G0903C

C. Logic

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.9.3.

9. IMU Null Accelerations

The null accelerations are based on the start time of the ODRC request (i.e., the equivalent time of pressing the old delta-V reset pbi is the start time of the request).

The IMU REFSMMAT selection MEDable Constant is available to be sent with any request for this computation output using the MED Override function on the MEWS Request for Operational Downlist Data. The IMU REFSMMAT selection MEDable constant default value is 4.

M04G0300M = 0, means use the saved REFSMMATs.

M04G0300M ≠ 0, means use the downlisted REFSMMATs.

A. Inputs

1. The IMU velocities in M50 coordinates:

	IMU1	IMU2	IMU3
VX	V95L0065C	V95L1065C	V95L2065C
VY	V95L0066C	V95L1066C	V95L2066C
VZ	V95L0067C	V95L1067C	V95L2067C

2. REFSMMATs

B. Outputs

	X	Y	Z
NULL ACC 1	M01G0904C	M02G0904C	M03G0904C
NULL ACC 2	M04G0904C	M05G0904C	M06G0904C
NULL ACC 3	M07G0904C	M08G0904C	M09G0904C

C. Logic

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.9.4.

10. Square Root of IMU RM Threshold

A. Inputs

V90U2595C

B. Outputs

M01G4902C

C. Logic

$$M01G4902C = \text{SQRT} (V90U2595C)$$

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.49.2.

B. ADI ATTITUDE COMPUTATIONS

This computation outputs the ADI attitudes in degrees calculated from the downlisted sine and cosine of the angles.

A. Inputs

Left ADI	Sine	Cosine
Roll	V72H0910C	V72H0911C
Pitch	V72H0912C	V72H0913C
Yaw	V72H0914C	V72H0915C

Right ADI

Roll	V72H1010C	V72H1011C
Pitch	V72H1012C	V72H1013C
Yaw	V72H1014C	V72H1015C

Aft ADI

Roll	V72H1110C	V72H1113C
Pitch	V72H1111C	V72H1114C
Yaw	V72H1112C	V72H1115C

B. Outputs

	Left ADI	Right ADI	Aft ADI
Roll	M01G0200C	M04G0200C	M07G0200C
Pitch	M02G0200C	M05G0200C	M08G0200C
Yaw	M03G0200C	M06G0200C	M09G0200C

C. Logic

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.2.

C. BFS ADI ATTITUDE COMPUTATION

This computation outputs the Left BFS ADI attitudes in degrees calculated from the downlisted sine and cosine of the angles.

A. Inputs

Left ADI	Sine	Cosine
Roll	V98H2350C	V98H2355C
Pitch	V98H2351C	V98H2356C
Yaw	V98H2352C	V98H2357C

B. Outputs

Left ADI	Output
Roll	M01G0701C
Pitch	M02G0701C
Yaw	M03G0701C

C. Logic

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.7.1.

D. TACAN BEARING COMPUTATION

The purpose of this computation is to provide a special calibration for the TACAN bearing. The input parameters must have been calibrated using the MOC Calibrations. This computation will examine the appropriate bearing status bits and add 180 degrees to the bearing if necessary.

A. Inputs

	Bearing	Status
TACAN 1	V74H1535B	V74H1534B
TACAN 2	V74H1635B	V74H1634B
TACAN 3	V74H1735B	V74H1734B

B. Outputs

	Output
TACAN 1	M01G1101C
TACAN 2	M02G1101C
TACAN 3	M03G1101C

C. Logic

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.11.1.

E. BFS TACAN BEARING COMPUTATION

This computation provides the same special calibration for the BFS TACAN parameters that is described above for the PASS downlisted parameters.

A. Inputs

	Bearing	Status
TACAN 1	V98H3762C	V98H3760C
TACAN 2	V98H3805C	V98H3804C
TACAN 3	V98H3905C	V98H3904C

B. Outputs

	Output
TACAN 1	M01G1102C
TACAN 2	M02G1102C
TACAN 3	M03G1102C

C. Logic

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.11.2.

F. STAR TRACKER STATUS COMPUTATION

A. Inputs

V95J4930C -Y STAR TRACKER STATUS
V95J4929C -Z STAR TRACKER STATUS

B. Outputs

M01G4901R -Y STAR TRACKER STATUS
M02G4901R -Z STAR TRACKER STATUS

C. Logic

<u>INPUT (HEX)</u>	<u>OUTPUT (TEXT)</u>
1	FAIL
2	PASS
<u>INPUT (HEX)</u>	<u>OUTPUT (TEXT)</u>
3	FTRK
4	OFOV
5	HRTE
6	NTGT
ALL OTHER INPUTS	'BLANK'

The Star Tracker logic is defined in the STSOC-RQ-600286, Level B & C Requirements, paragraph 5.3.3.49.1.

G. THETA LIMIT COMPUTATION

A. Inputs

<u>MSID</u>	<u>Label</u>	<u>Units</u>	<u>Description</u>
V95L0151C	VREL	ft/sec	Orbiter relative velocity
V90H2202C	PHI	deg	Orbiter bank angle
V90H2217C	THETA	deg	Orbiter pitch angle
V90H6710C	SBPOS	%	Speedbrake position
V90Q8001C	MMODE	ND	Software major mode
V95L3029C	MACH	ND	Vehicle mach #

B. MEDable constants

<u>MSID</u>	<u>Label</u>	<u>Initial Value</u>	<u>Units</u>
M01G5000M	ORBM1	6456.0	slugs
M02G5000M	ORBM3	6456.0	slugs
M03G5000M	THETA_A(1,1)	-1.0	deg
M04G5000M	THETA_A(1,2)	0.0	deg/ft/sec
M05G5000M	THETA_A(1,3)	-18.0	deg
M06G5000M	THETA_A(1,4)	-0.105	ND
M07G5000M	THETA_A(1,5)	5.0E-05	sec/ft
M08G5000M	THETA_A(2,1)	-1.0	deg
M09G5000M	THETA_A(2,2)	0.0	deg/ft/sec
M10G5000M	THETA_A(2,3)	-18.0	deg
M11G5000M	THETA_A(2,4)	-0.105	ND
M12G5000M	THETA_A(2,5)	5.0E-05	sec/ft
M13G5000M	THETA_A(3,1)	-19.71	deg
M14G5000M	THETA_A(3,2)	0.01574	deg/ft/sec
M15G5000M	THETA_A(3,3)	-14.4	deg
M16G5000M	THETA_A(3,4)	-0.0674	ND
M17G5000M	THETA_A(3,5)	2.14E-05	sec/ft
M18G5000M	THETA_A(4,1)	-2.51	deg
M19G5000M	THETA_A(4,2)	0.005625	deg/ft/sec
M20G5000M	THETA_A(4,3)	-14.4	deg
M21G5000M	THETA_A(4,4)	-0.08	ND
M22G5000M	THETA_A(4,5)	2.875E-05	sec/ft
M23G5000M	THETA_B(1,1)	-13.0	deg
M24G5000M	THETA_B(1,2)	0.0	deg/ft/sec

M25G5000M	THETA_B(1,3)	-5.0	deg
M26G5000M	THETA_B(1,4)	-0.1125	ND
M27G5000M	THETA_B(1,5)	0.0	sec/ft
M28G5000M	THETA_B(2,1)	-13.0	deg
M29G5000M	THETA_B(2,2)	0.0	deg/ft/sec
M30G5000M	THETA_B(2,3)	-5.0	deg
M31G5000M	THETA_B(2,4)	-0.1125	ND
M32G5000M	THETA_B(2,5)	0.0	sec/ft
M33G5000M	THETA_B(3,1)	-36.338	deg
M34G5000M	THETA_B(3,2)	0.01988	deg/ft/sec
M35G5000M	THETA_B(3,3)	-2.65	deg
M36G5000M	THETA_B(3,4)	-0.277	ND
M37G5000M	THETA_B(3,5)	1.27E-04	sec/ft
M38G5000M	THETA_B(4,1)	-16.715	deg
M39G5000M	THETA_B(4,2)	0.0083125	deg/ft/sec
M40G5000M	THETA_B(4,3)	-2.65	deg
M41G5000M	THETA_B(4,4)	-0.124	ND
M42G5000M	THETA_B(4,5)	3.75E-05	sec/ft
M43G5000M	R1	900.0	ft/sec
M44G5000M	R2	1000.0	ft/sec
M45G5000M	R3	1700.0	ft/sec
M46G5000M	V-DEFAULT	2500.0	ft/sec
M47G5000M	PITCH_MAX	6.0	deg
M48G5000M	PITCH_MIN	2.5	deg
M49G5000M	WT_MON	5900.0	slugs
M50G5000M	WT/DENOM	1094.0	slugs

M51G5000M	DPDV	3.5	deg
M52G5000M	VB	1000.0	ft/sec
M53G5000M	VD	700.0	ft/sec

C. Constants

<u>MSID</u>	<u>Label</u>	<u>Value</u>	<u>Units</u>
SBMAX		98.6	deg
DEG_TO_RAD	(pi/180)	3.1416/180.0	ND
MACH_LIM		1.5	ND
SMALL		1.0E-08	ND

D. Outputs

<u>MSID</u>	<u>Label</u>	<u>Reset Value</u>	<u>Units</u>
M01G5000E	THETA_LIMITS	0	ND
M02G5000E	THETA_L_HI	0	ND
M03G5000E	THETA_L_LO	0	ND
M04G5000E	THETA_MAX	1.0	deg
M05G5000E	THETA_MIN	0.0	deg

E. Logic

The logic can be found in the Level B & C Requirements, STSOC-RQ-600286, paragraph 5.3.3.50.

TITLE

G&C MALFUNCTION PROCEDURES

PURPOSE

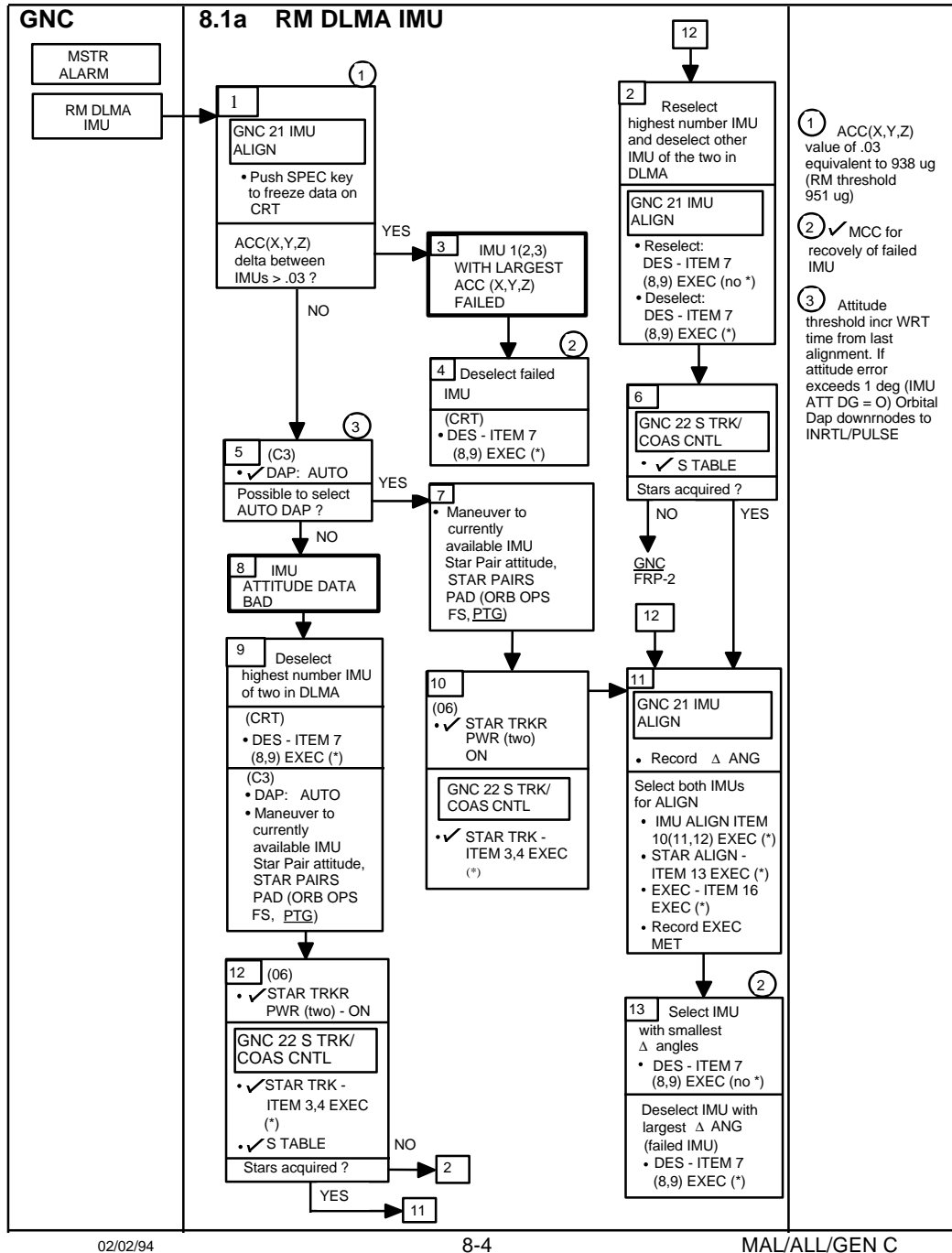
The purpose of this SCP is to capture the Malfunction Procedures that have been removed from the Flight Data File (FDF) MALFUNCTION PROCEDURES document.

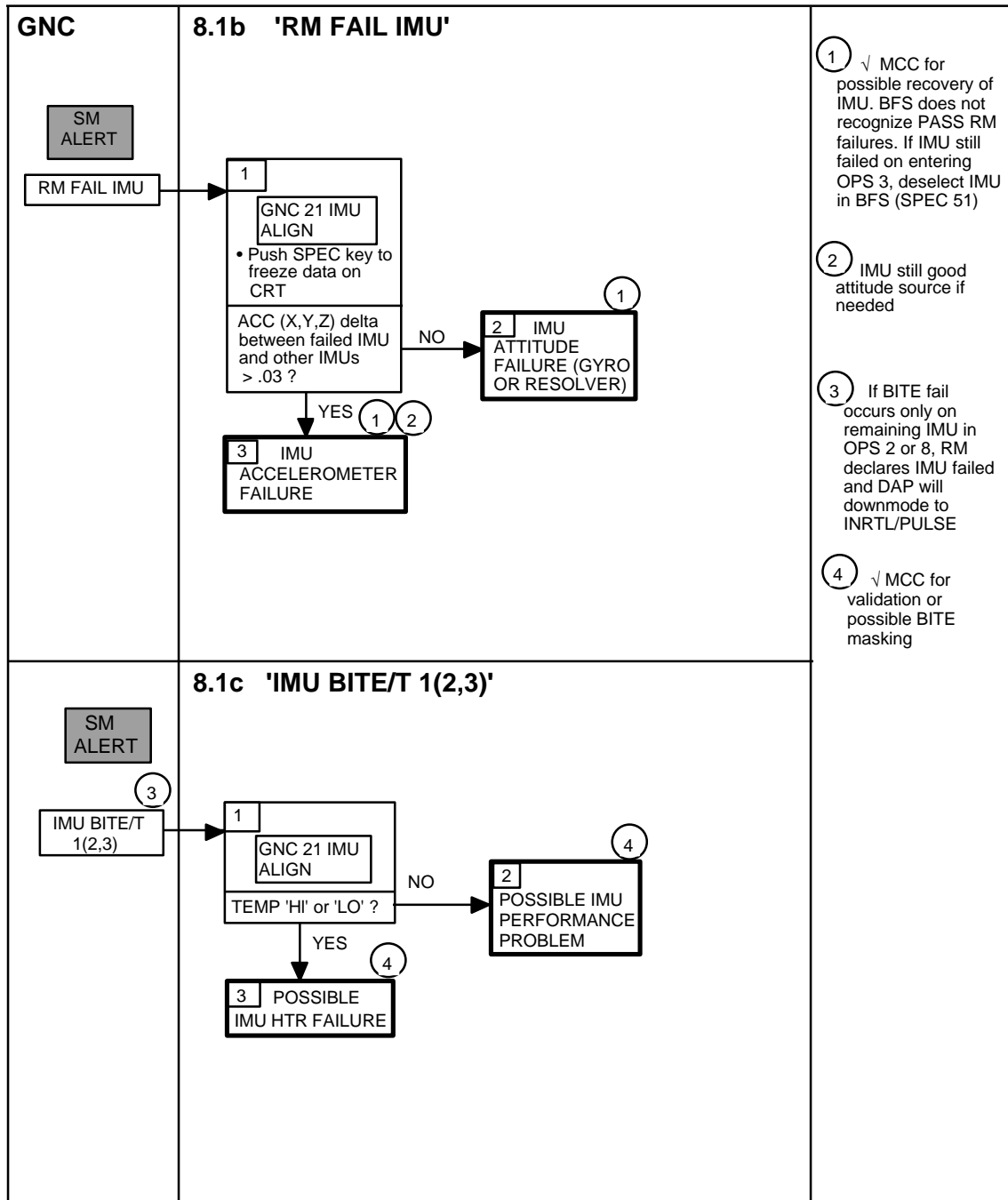
BACKGROUND

The G&C Malfunction Procedures were originally generated as standalone instructions for the Crew to resolve onboard anomalies in the absence of ground assistance. With the advent of the Tracking and Data Relay Satellite System (TDRSS), ground coverage and therefore MCC assistance is anticipated in virtually every scenario addressed within those procedures. In conjunction with an effort to reduce overall maintenance costs associated with FDF documentation, removal of the following non-time-critical procedures from the official MALFUNCTION PROCEDURES document has been recommended. However, the prudence of retaining these procedures for MCC reference, as well as a valuable training tool for newcomers to the G&C Section, has prompted generation of this SCP.

<u>Figure</u>	<u>Procedure</u>
1	8.1a "RM DLMA IMU"
2	8.1b "RM FAIL IMU"
	8.1c "IMU BITE/T 1(2,3)"
3	(*) 8.2a "RHC L (R,A)"
4	8.2b "SBTC/THC L(R,A)"
5	(*) 8.3a "STAR TRKR BITE"
6	(*) 8.3b "-Y(-Z) TRKR FAILS TO ACQUIRE STAR"
7	8.4a "COAS FAIL"
8	(*) 8.5a "OFF FLAG, ALL RATE POINTERS AND ERROR NEEDLES OUT-OF-VIEW, VALID IMU DATA"
	(*) 8.5b "OFF FLAG, VALID IMU DATA"
9	8.5c "RATE POINTER OR ERROR OUT-OF-VIEW, VALID IMU DATA"

(*) These MALFs have been updated based on 482s submitted by G&C personnel after the last published issue of the Malfunction Procedures document.

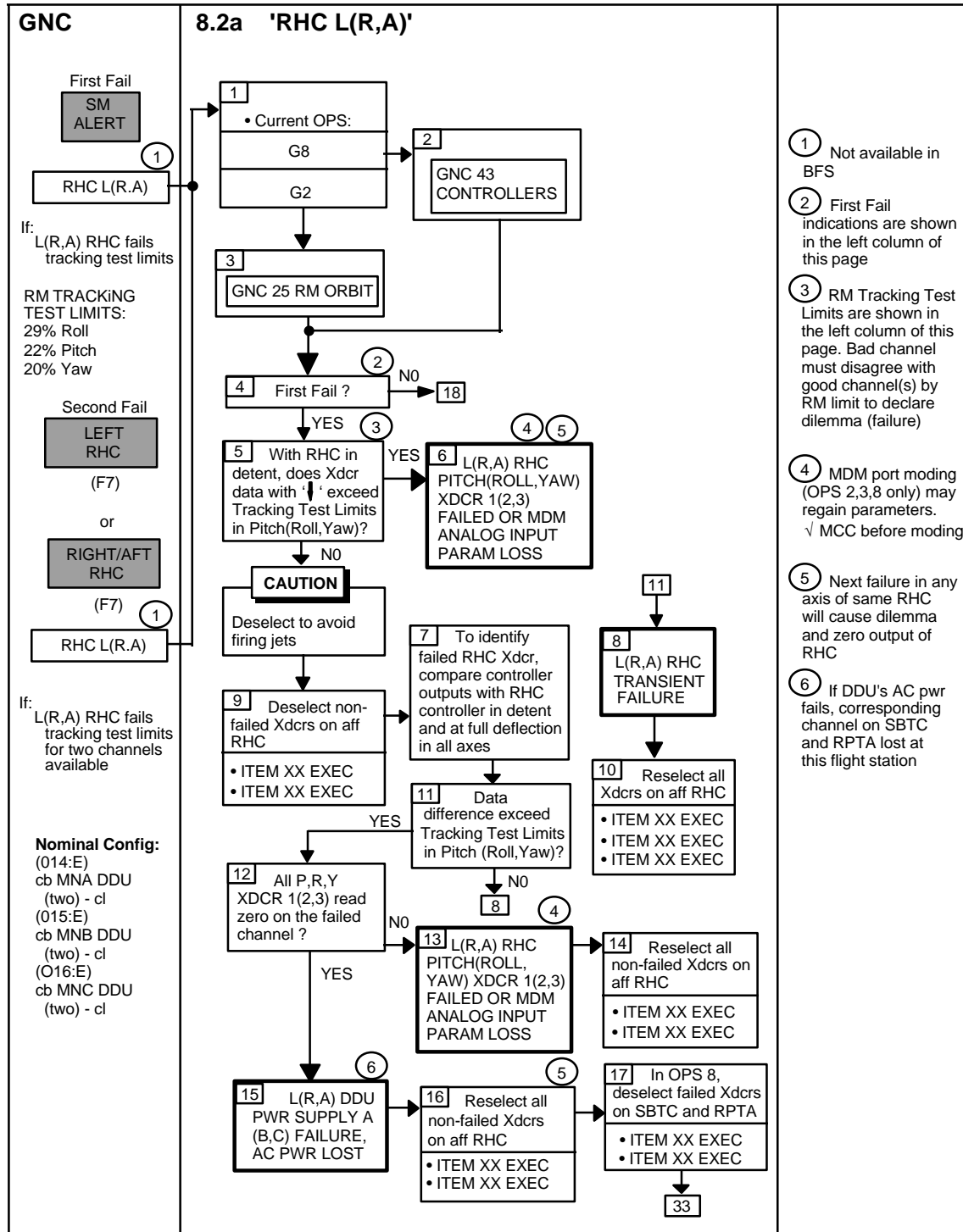


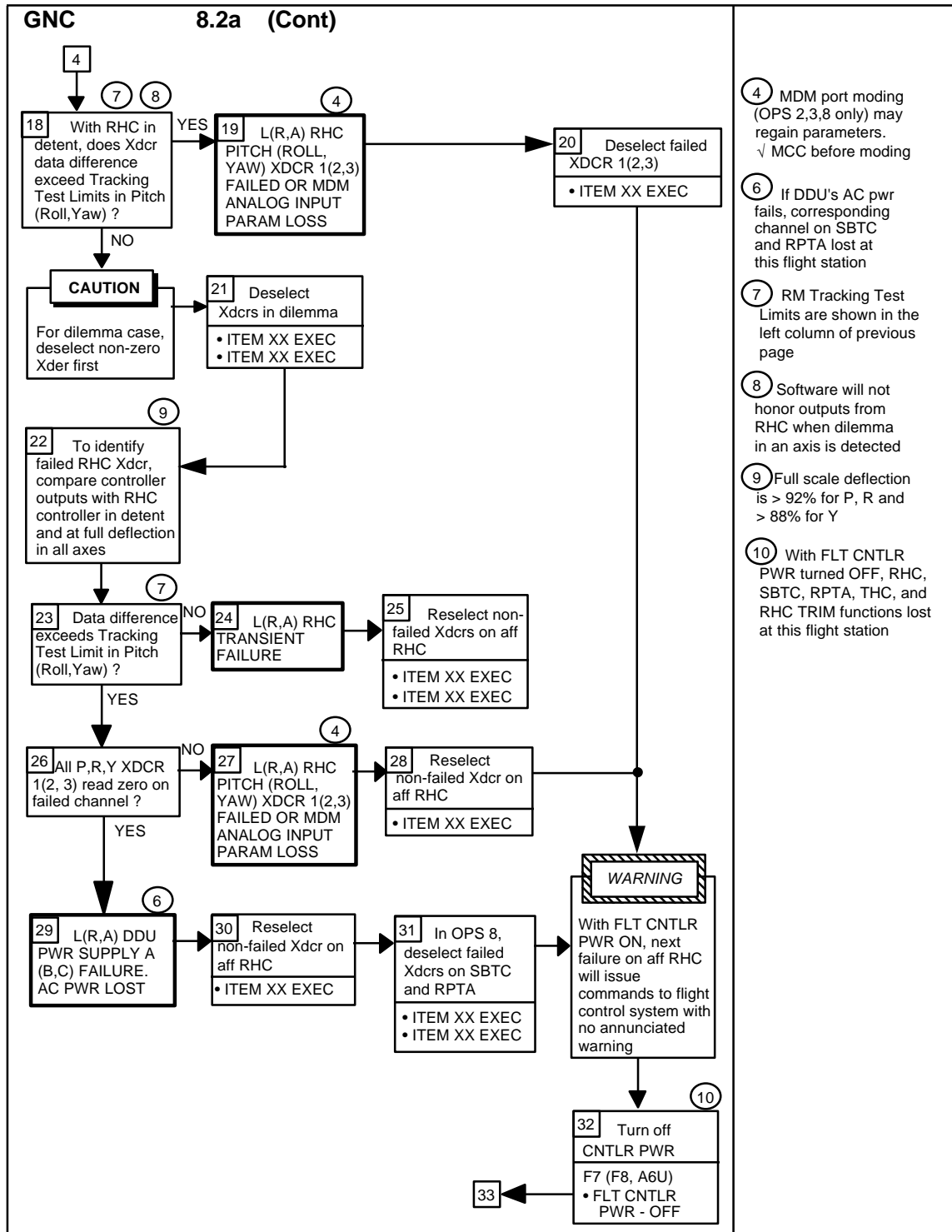


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8-5

MAL/ALL/GEN C

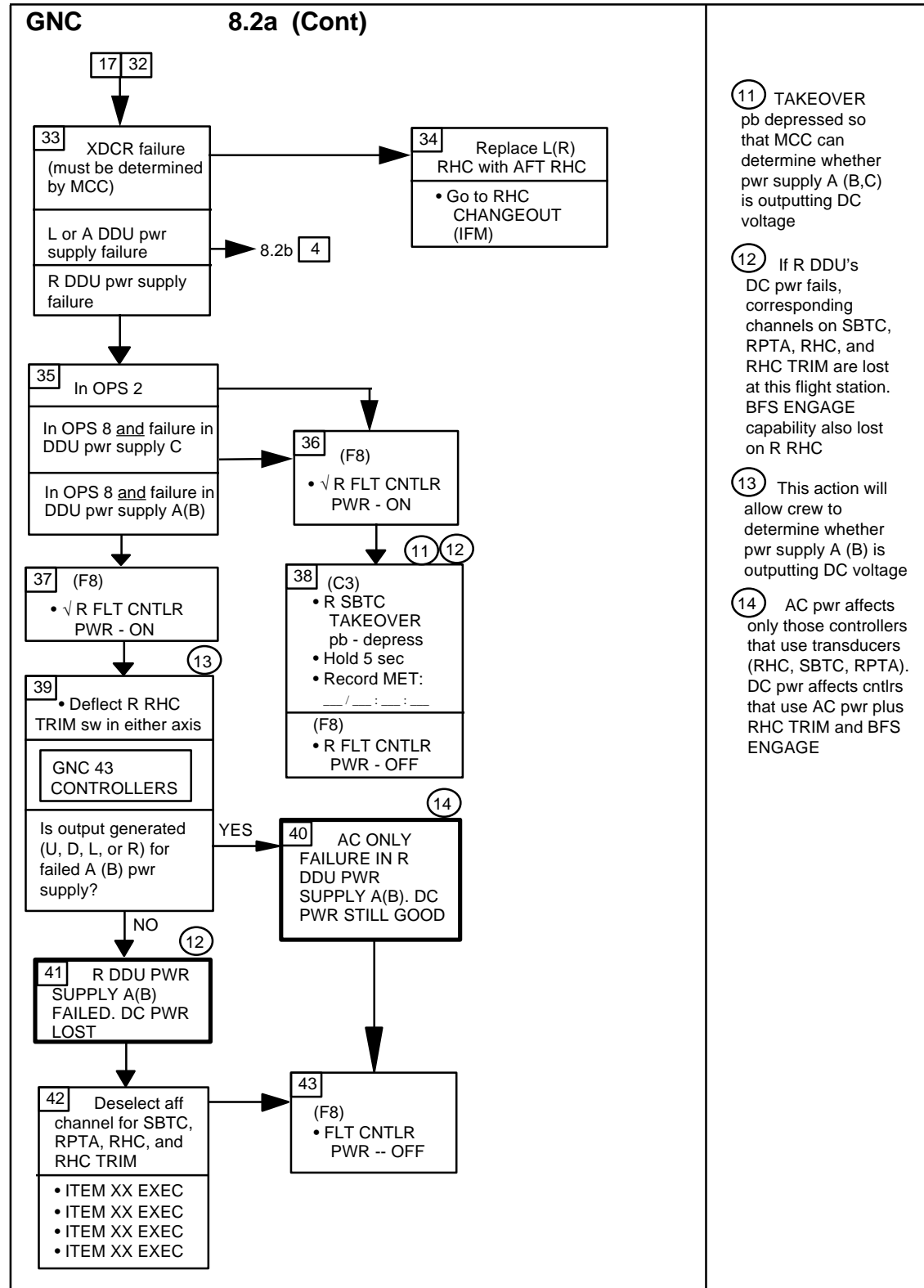


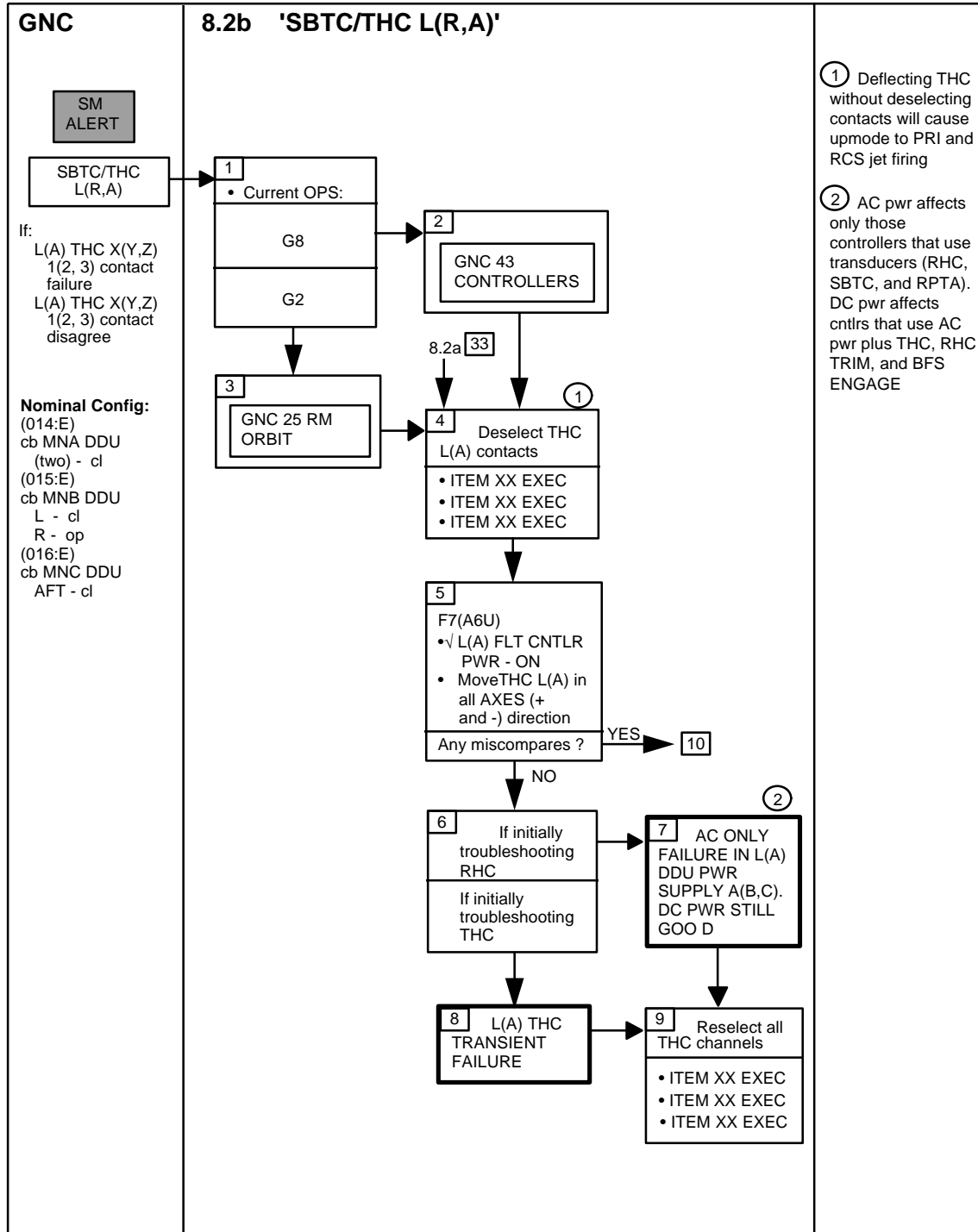


11/21/93

8-7

MAL/ALL/GEN C

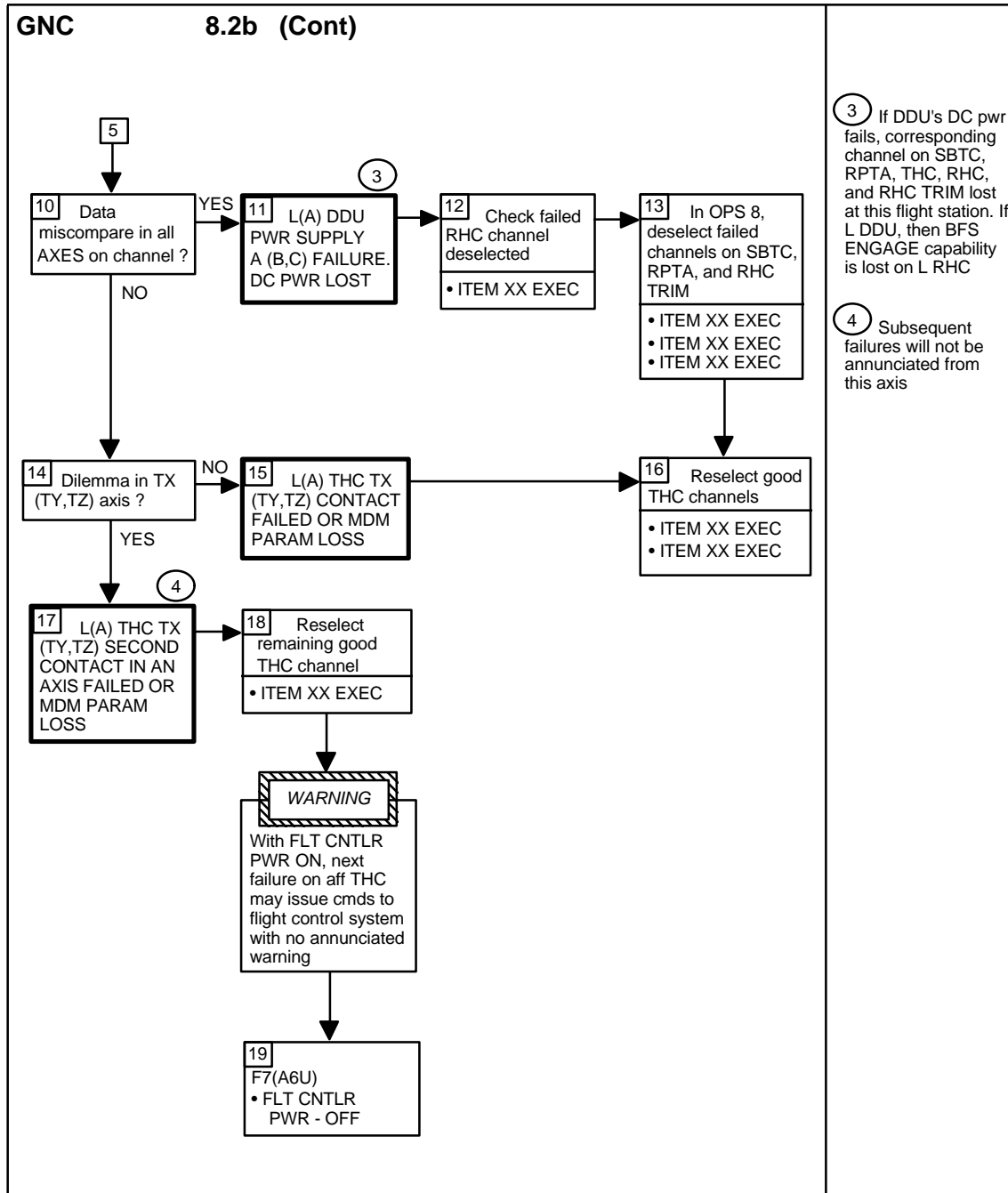




04/20/94

8-9

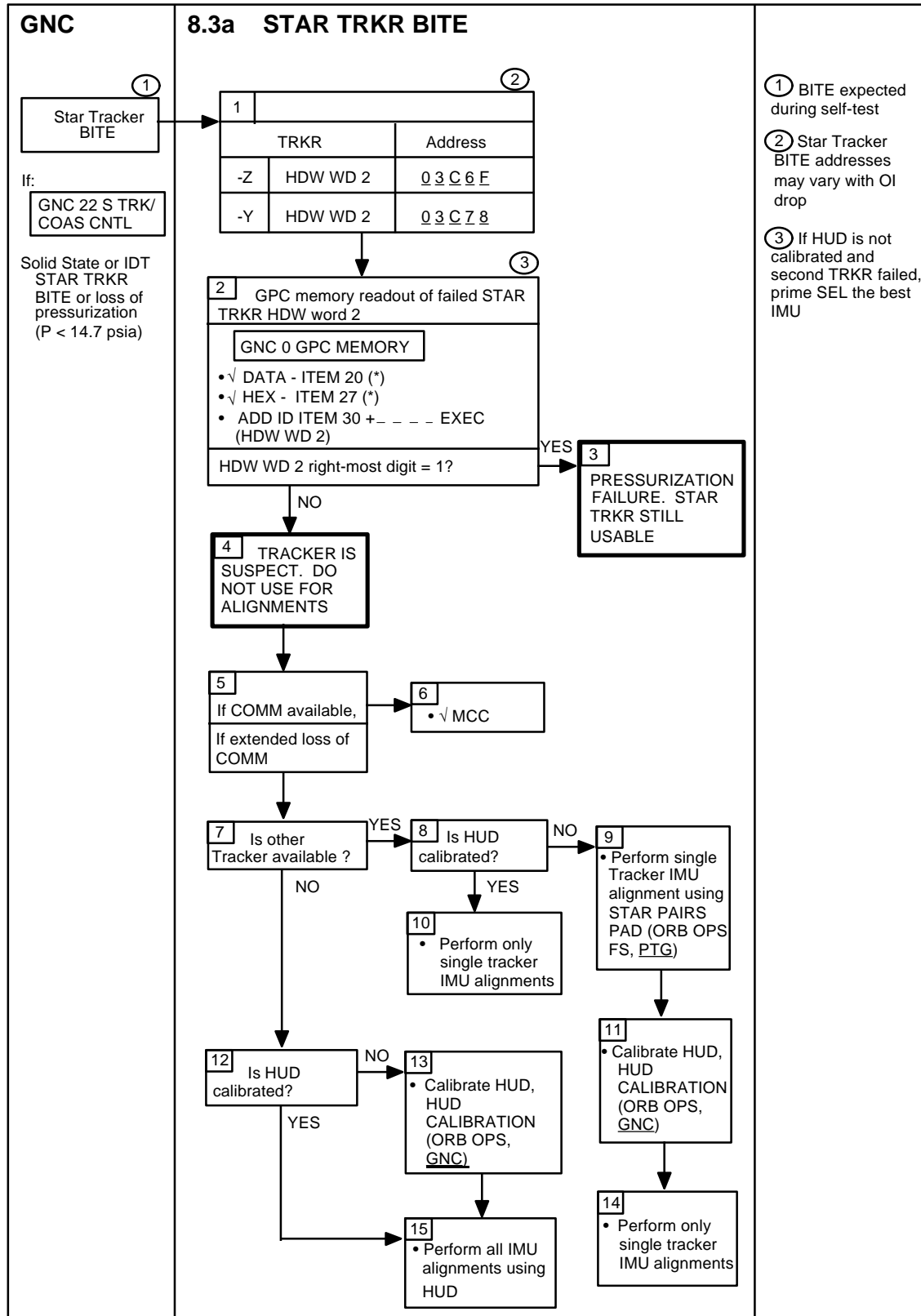
MAL/ALL/GEN C



12/01/93

8-10

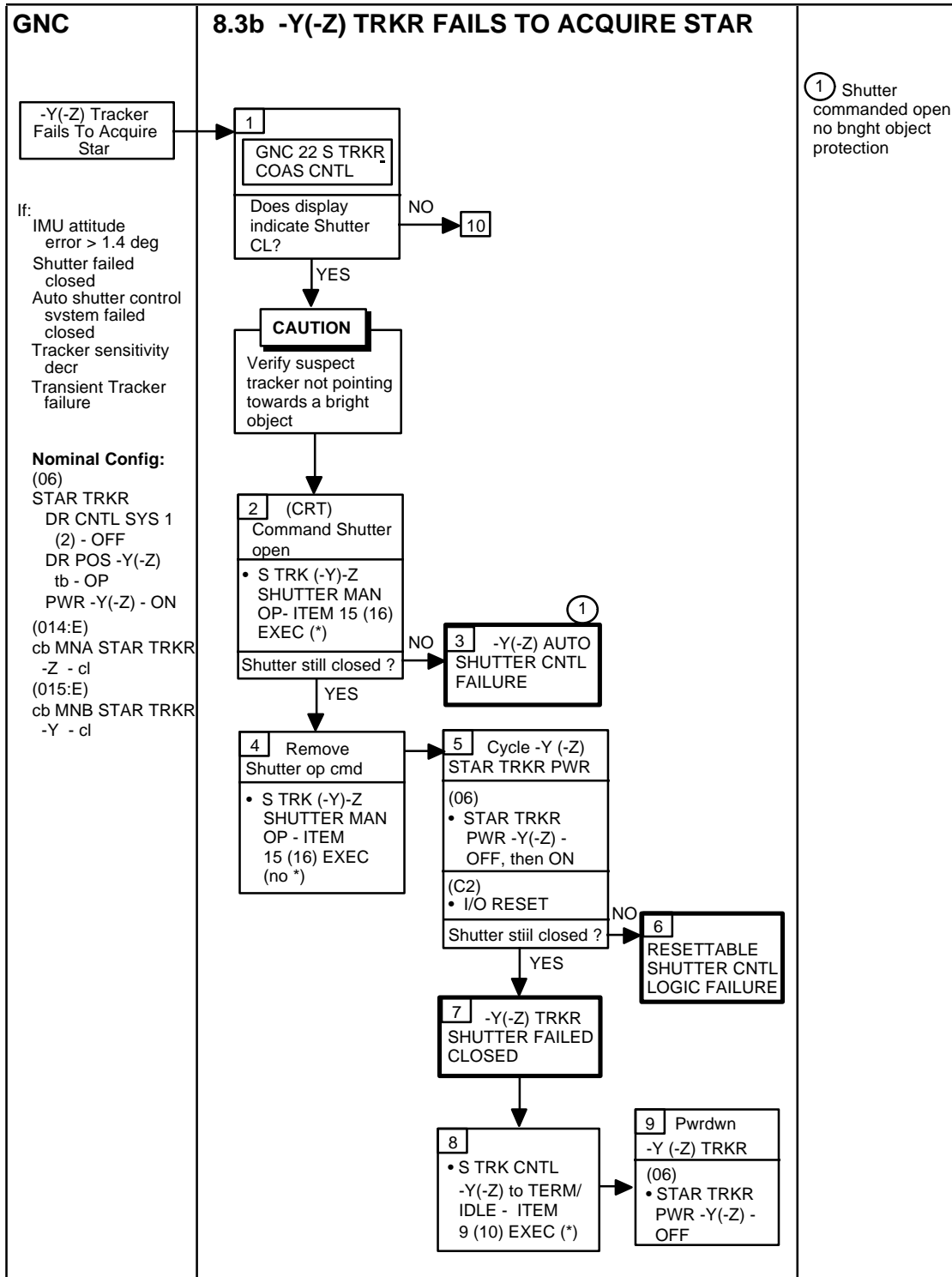
MAL/ALL/GEN C



02/23/95

8-12

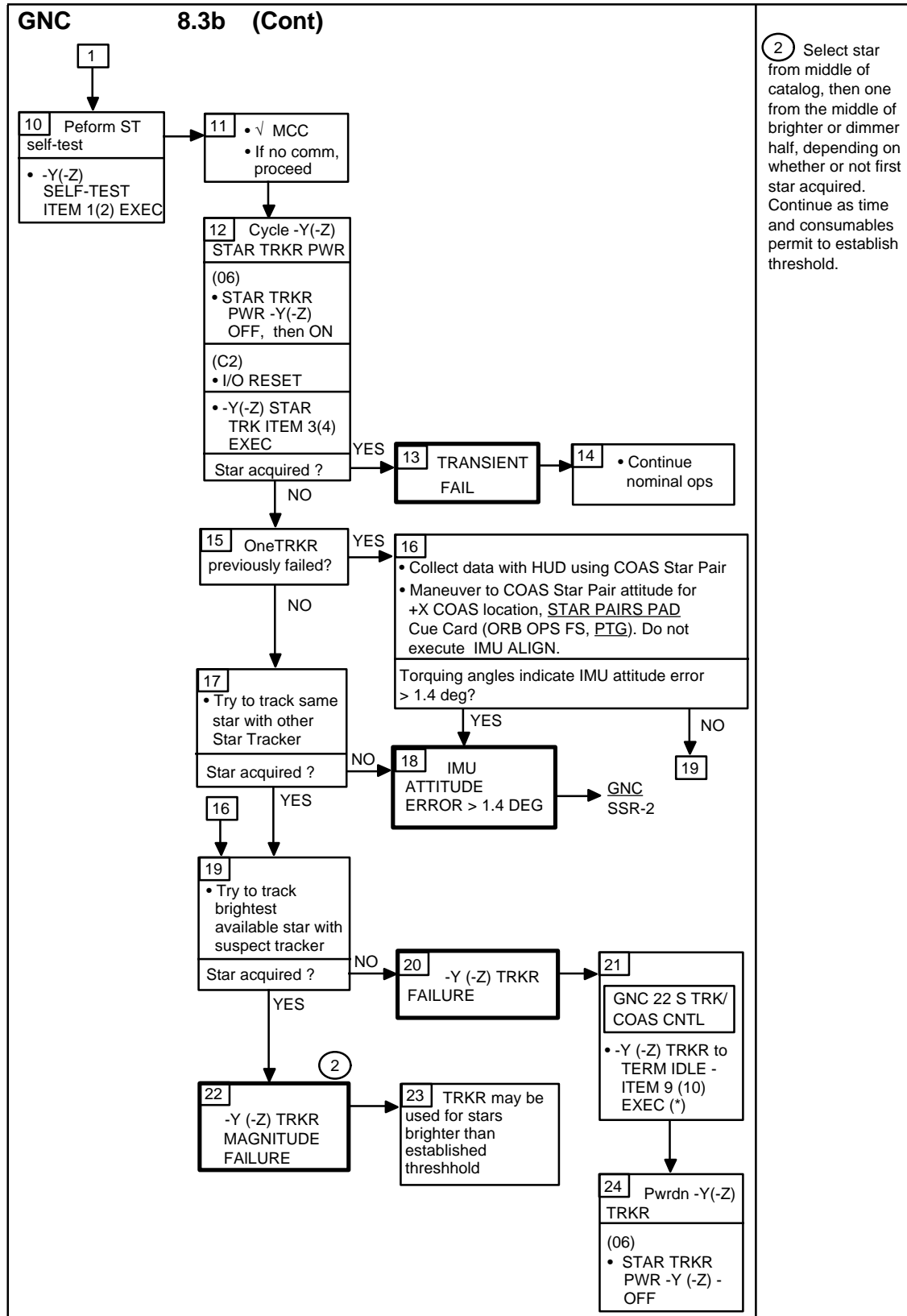
MAL/ALL/GEN C,8

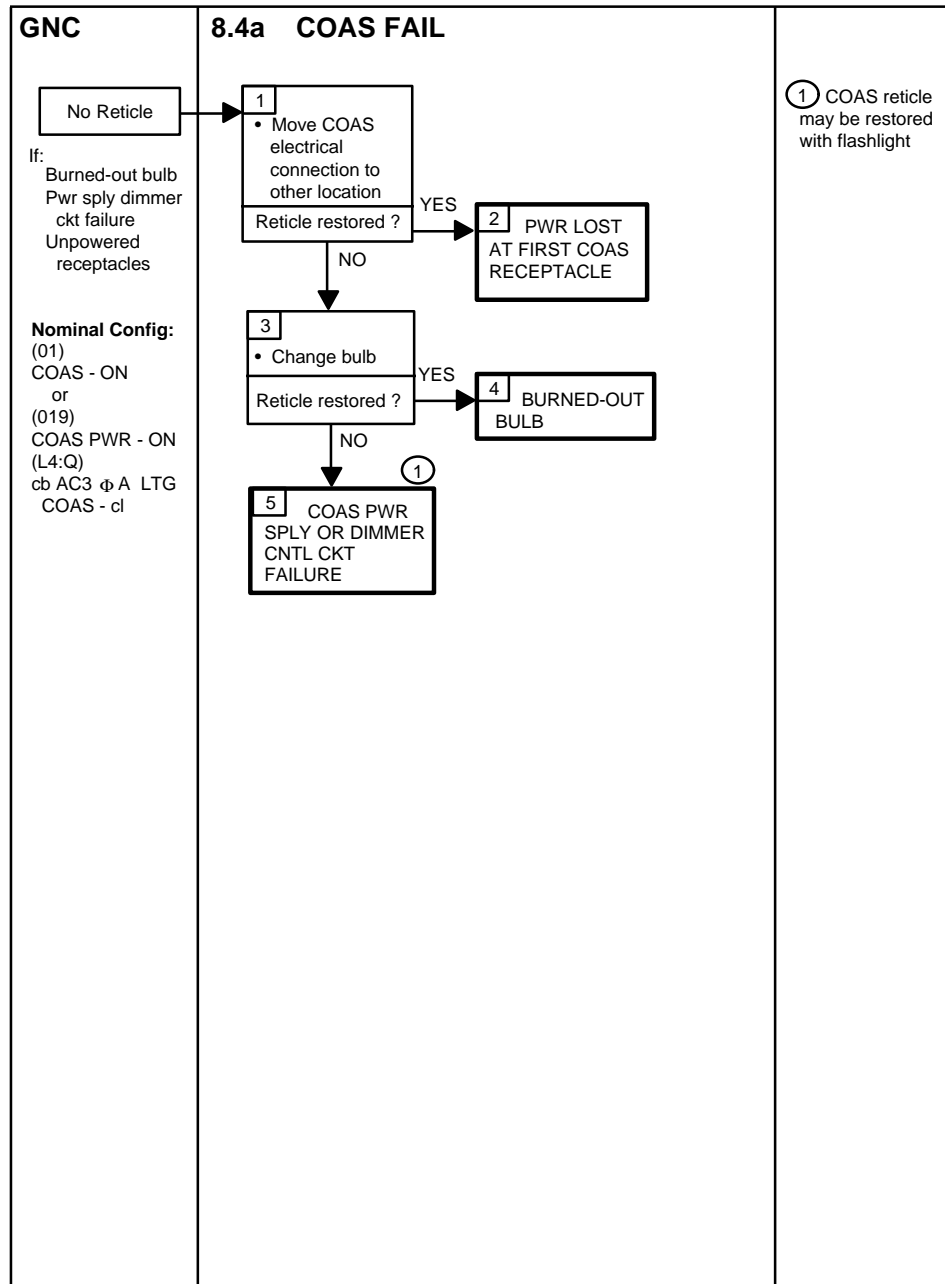


05/03/94

8-13

MAL/ALL/GEN C,1

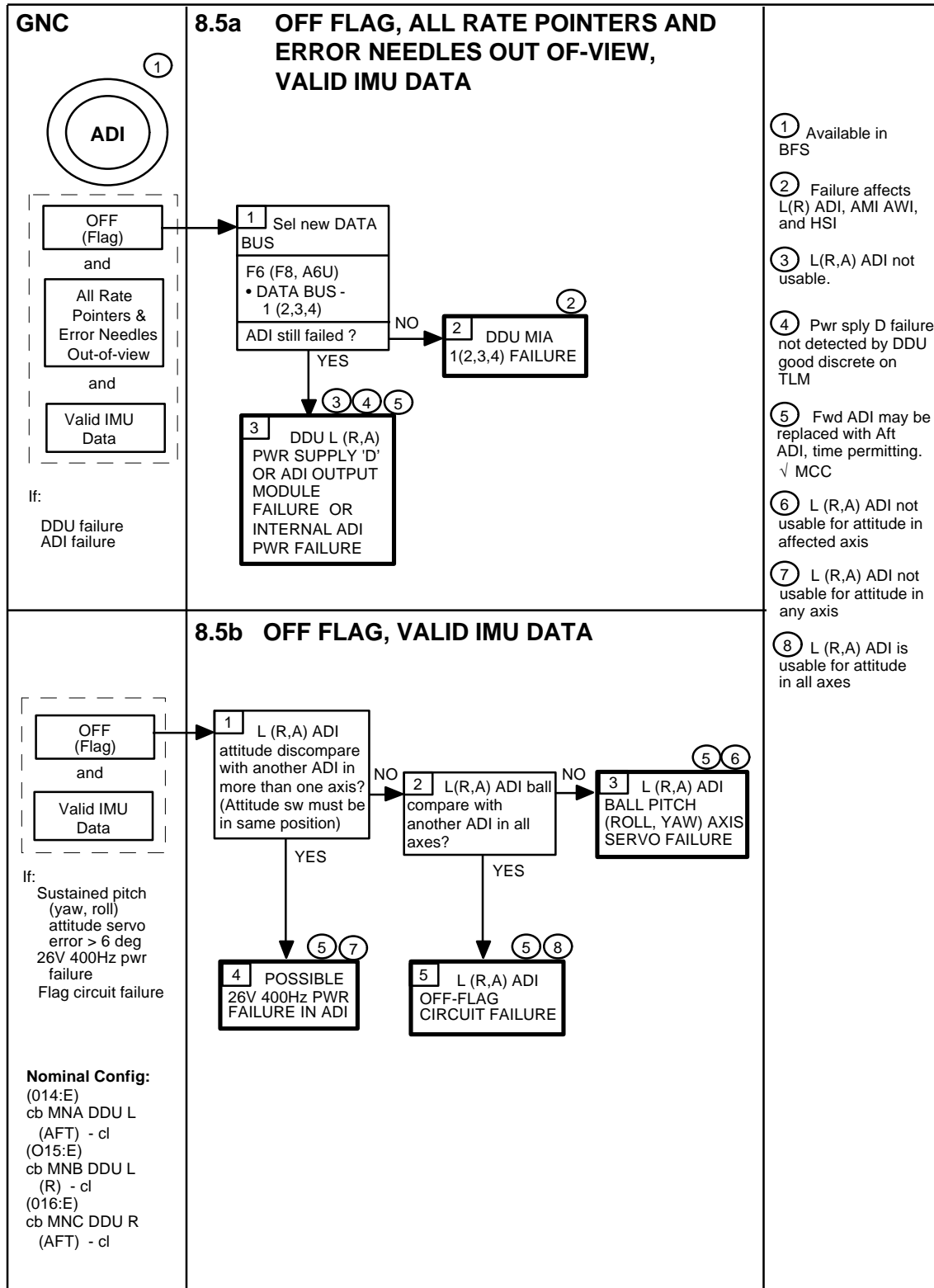


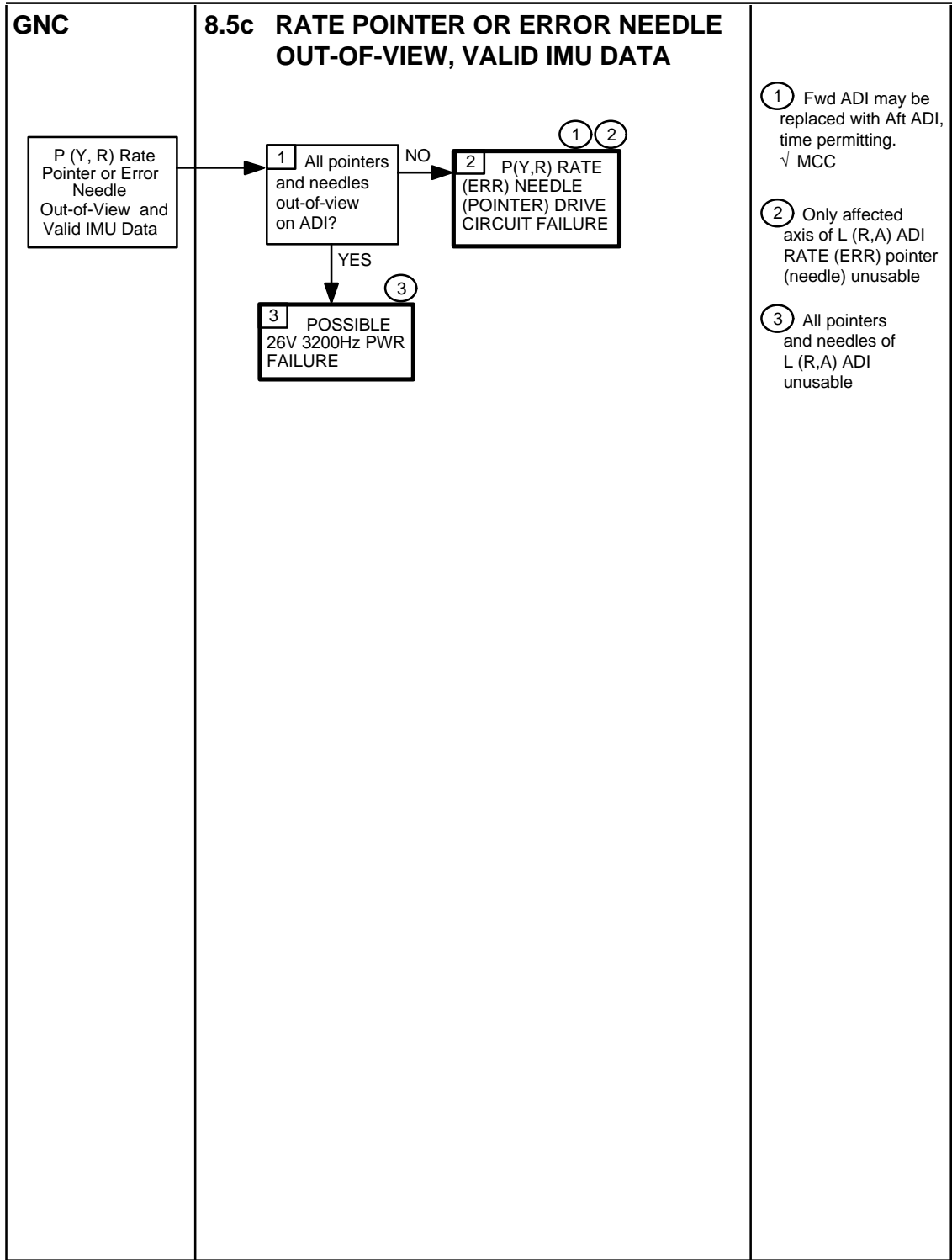


02/02/94

8-16

MAL/ALL/GEN C





11/21/93

8-19

MAL/ALL/GEN C

TITLE

Shuttle Quaternion Transfer to MCC-Moscow

PURPOSE

Provides a procedure to be used during Mir docked flight phase for providing MCC-Moscow with shuttle attitude data (Q_B_I and timetag) for Mir platform alignment/verification.

BACKGROUND

Due to restrictions on the Mir for acquiring star data when docked with the Shuttle, MCC-M desires Shuttle Q_B_I data for alignment/verification of Mir inertial platforms. The requirements are for both MCC-M and MCC-H to be AOS for at least ten minutes so that data can be compared between the spacecraft. The extent of MCC-H involvement is to acquire the desired data from the Orbiter Data and Retrieval Complex (ODRC) in a agreed format and to provide this data to the Russian Interface Officer (RIO) for transfer to MCC-M.

MCC-M requires the transfer approximately every 12 hours.

PREFLIGHT PROCEDURE

1. Confirm the IP address of the WIN95 PC. The network address can be verified at any time by running winipcfg. (Start > run > enter "winipcfg") Call the ODRC help desk (x3ODRC) and confirm that the IP address is registered for the "GNC" node ID.
2. If the IP addresses do not match:
Submit a "ODRC Registration/Deletion Form" to delete the old IP address and add the new IP address. Mr. K. A. Dunn is the Node Administrator for GNC PC MEWS configurations and will have to sign the form.

REAL-TIME FLIGHT OPERATIONS PROCEDURE

1. PCMEWS is located at "Start > Programs > Pc-mews". Remember, there is no "minit" window, just the individual programs.
2. The following subsystems should be available:
 - GNCThe flight should be available (or added via MEWS add flight option):
 - STS-xxxThe following tab formats should be available:
 - qbi_xfer (Q_B_I transfer)

3. When a “quaternion transfer” callout is found in the MCC column of the Flight Plan (or Execute Package), pull the desired data from ODRC and place it on the floppy disk for RIO.
 - Pull data of interest for flight/simulation with the qbi_xfer tab format.
Note: Use MCC Calibrations
Name the data file with the following format:
aXX.YYY
Where: XX = flight id
YYY = sequential file number
Example: a84.001, a84.002, a84.003, etc.
 - After evaluating the data on the screen, tab to a file without headers. Use the same file name. (It is stored in a different directory and will not conflict with the data file from ODRC.)
 - Verify 9 significant digits of accuracy to the right of the decimal point.
 - Copy the file to the floppy and pass it on to RIO specifying which file is to be transferred. (Should always be the last sequence number. i.e., a84.007 vs. a84.006)
c:\pcmews\flights\{flight#}\data\gnc\tab\{filename} ⇒ floppy disk
4. If you get/want the floppy back from the RIO, you will need to virus scan it before further use.

WARNING

Virus infection is very common in Russia. The PC that RIO uses is not connected to any MCC LAN for this reason. If we do not scan the disk upon return, we can be responsible for introducing a virus into the MODM network. Also, this would require significant time with security personnel and associated paper work. If you are not comfortable with this, get a new disk for any subsequent file transfers to RIO.

Do not use an unscanned floppy disk!

TITLE

MIS QUERY OPERATIONS

PURPOSE

This SCP introduces the user to the Mission Information System (MIS) Query Builder application. The use and purpose of MIS Query in the mission environment will be discussed.

DESCRIPTION

MIS Query is a computer application designed to assist flight controllers in providing flight operations support of Space Shuttle systems. MIS Query is the successor of a group of computer programs known as Shuttle Configuration Analysis Programs (SCAP). MIS Query allows the user to research the channelization and calibration of Orbiter, External Tank (ET), Solid Rocket Booster (SRB), and Spacelab Measurement Stimulus Identifications (MSIDs), Space Shuttle Program (SSP) Anomaly Reports, SSP Chit Reports, as well as other aspects of the Orbiter's attitude and specific missions.

PROCEDURE

Note- This SCP will be more useful to the user if MIS Query is run while reading this SCP. To initiate the MIS Query application the 'Query' option is selected from the 'MIS' selection on the Master D-NAV Global Applications menu. The MIS window is displayed after selecting the Query option. It takes a while to start the MIS Query application. Once the window entitled 'Mission Information System' appears, the user may begin a search. A search is a routine by which the computer, given certain parameters (Bus Terminal Unit (BTU) name, BTU card number, MSID, etc.), looks through the MIS database and finds articles that are of interest to the user. In conducting searches, the user may select from a list of preformed searches, or the user may create a new search.

Preformed Searches

Preformed searches are searches that were created by other users and saved to the MIS database. Any other user may view the results of these searches. In many cases the searches were created with variables that the user viewing the search must fill in. The MIS database includes searches that may be used to find a certain MSID's channelization, calibration, and downlist format. To access these searches, the user must deselect all disciplines in the 'Discipline' column. After this is done the user can scroll through the preformed searches listed under 'Files.'

MSID Channelization -

Selection of the 'SCAP1-Orbiter-Channelization Channelization Parameters for a Single Orbiter MSID', allows for the 'View' button to be selected. Selection of the 'View' button results in the 'Query Variable Input' window being displayed. By entering an MSID and selecting the 'Ok' button, the 'MIS Data Viewer' window will be displayed. The window will contain the channelization information on the input MSID. The information will include the number of bits in the MSID, the data type, transducer range and the owner(s).

MSID Calibration -

The MSID calibration coefficients can be accessed by selecting the 'SCAP1-Orbiter-Calibration Parameters for a Single Orbiter MSID' option from the MIS window, and entering the desired MSID in the 'Query Variable Input' window.

MSID Downlist Formats -

Similar to the MSID calibration, the telemetry downlist availability can be determined by selecting the 'SCAP1-Orbiter-Telemetry Telemetry Parameters for Single Orbiter MSID' option.

The 'gnc' discipline, found on the main MIS window also has several preformed searches that may be used for the same purposes as the searches on the MIS database. In order to access this or any other discipline, the user must scroll down the 'Discipline' column until 'gnc' or the user's specific discipline is found. To further narrow the search the user may select a specific user's file.

Creating a Search

The user may also create a search that suits their needs. This is a powerful option that allows the user to seek information on anything in the MIS database. To create a new search, the user will go to the pull down menu labeled 'File,' and click on the 'New' selection using the left mouse button. The 'UNTITLED' screen will appear. The user should proceed into the 'Selections' subwindow and left click on the 'Edit' button. The 'Selection Editor' window will appear. By placing the arrow in the box under 'No Table Selected,' the user can choose the table in which the desired data is located by a right click and then selecting the table out of the menu. Once a table has been selected, the title will appear in place of 'No Table Selected' as well as a list of parameters that are available under that table (Figure 6.13.1-1). These parameters can be selected with a left click, and added to 'Selections' subwindow with an additional left click on the 'Add' button (Figure 6.13.1-2). The user can select one parameter from one table, or multiple parameters from multiple tables. Once the user has all of the necessary parameters to be viewed in the 'Selections' subwindow, the 'Selections Editor' may be exited with a left click on the 'Close' button.

Proceeding to the 'Conditions' subwindow, the user will select the conditions by which MIS will look through its database to satisfy the user's selections. Once again, the user will left click on the 'Edit' button. The user can begin by placing the arrow in the top box and selecting a table with the right mouse button. Then a value may be chosen from the list by which MIS will search the database. After the value is chosen, the user must fill out the rest of the selections in order to meet the needs of their search (Figure 6.13.1-3.) The details of the options are covered in the MIS Query Builder User's Guide, and will not be covered entirely in this SCP since they are entirely depend on the user's needs. **Important:** If the user has selected two different tables in the 'Selections' subwindow, these tables must be linked in the 'Conditions Editor' in order to produce accurate results (Figure 6.13.1-4.) To do this the user will begin in the 'Conditions Editor' window by selecting a table and value in the 'Left Operand' box in the same manner as before. Selecting the 'Column' entry under 'Value Type,' allows the user to match the value in the 'Left Operand' subwindow with the same value from a different table in the 'Right Operand' subwindow. Once the user has made all of the necessary conditions, 'End' is selected as the last 'Logical Operator' and the window is closed with a left click on the 'Close' button.

Next, the user should select the values by which the search results will be ordered by with a left click on those values in the right box of the 'Order By' subwindow. To move these values into the left box, the user will click on the arrow pointing left beneath the left box. Finally, the proper flight must be selected in the 'flight' subwindow (Figure 6.13.1-5). To initiate the search, the user should left click on the 'Query' button. If a variable value type was entered in the 'Conditions Editor,' it will be necessary to enter that data at the computer's prompting (Figure 6.13.1-6). These variables may also be selected as 'optional' in which a search will be conducted even if the user does not fill this data in. When the search is done the results may be viewed in table form once the user left clicks on the view button (Figure 6.13.1-7). Now this search may be saved for future use by selecting the 'Save As' option from the 'File' pull down menu.

In order to exit MIS the user selects 'Exit' from the 'File' pull down menu.

Example

Enter MIS Query by selecting 'MIS Query' from the 'Global Apps' pull down menu from the master D-NAV 'Global Applications' menu.

Once the 'Mission Information System' window appears, select 'New' from the 'File' pull down menu.

Once the window labeled 'UNTITLED' appears, left click on the 'Edit' button in the 'Selections' subwindow.

Place the pointer in the large box under 'No Table Selected' and click with the right mouse button. Choose the 'SCAP Data-SCAP Orbiter Channelization' table from those that are listed.

Notice that 'No Table Selected' has been replaced by 'SCAP Orbiter Channelization,' which is the name of the table that was selected (Figure 6.13.1-1). From this box select 'MSID' with a left click. Left click on the 'Add' button and note the value's appearance

at the top of the 'Selections' subwindow for the 'UNTITLED' screen. Continue this process for 'Nomenclature', 'BTU name', and 'BTU Card' (Figure 6.13.1-2).

Return to the window that was previously right clicked in and select the 'SCAP Data-SCAP Owner' table with the right mouse button. Select the 'MSID Owner' value with a left click the left click on 'Add.' Left click on 'Close' to exit the window.

Left click on the 'Edit' button in the 'Conditions' subwindow.

Once again, values will be chosen from tables using the right mouse button after placing the arrow in the large box in the 'Left Operand' subwindow. Select 'MSID' from the 'SCAP Data-SCAP Orbiter Channelization' table. Under 'Value Type' choose 'Column.' In the 'Right Operand' subwindow select the value 'MSID' from the 'SCAP Data-SCAP Owner' table (Figure 6.13.1-4). Click on both 'MSID' selections and then click on the 'Add' button. This step insures that MIS recognizes the MSIDs from the 'SCAP Channelization' and 'SCAP Owner' tables as being the same MSIDs. This step must be done if two different tables with the same value, such as MSID, are used.

More than one condition may be used. Select the 'BTU Name' value from the 'SCAP Orbiter Channelization' table in the 'Left Operand' subwindow. Select value type 'Specific'(Figure 6.13.1-3). Select 'MDM FA2' under 'Data Type/Values'. Left Click on 'Add'. Repeat the following step selecting 'MSID Owner' from the 'SCAP Owner' table. Select 'GNC' under 'Data Type/Values', and left click on 'Add'. To make a variable condition, that is the computer asks the user what value to use when the search is run, click on 'Variable' in the 'Value Type' category.

Once all of the conditions have been set, the user may decide in what order the values should appear by using the 'Order By' box. In the right hand box of the 'Order By' subwindow, click on the value which the computer should sort by, then left click on the arrow pointing left beneath the left window. The selected value should change windows. Change the flight number to the desired flight (Figure 6.13.1-5). Once this screen is complete, left click on 'Query' and the search will be conducted.

This SCP highlights the information needed by the Guidance and Controls Systems Section. For more information see the MIS Query Builder User's Guide.

REFERENCES

1. Mission Information System (MIS) Query Builder User's Guide.

Figure 11.24-1

Figure 11.24-2

Figure 11.24-3

Figure 11.24-4

Figure 11.24-5

Figure 11.24-6

Figure 11.24-7

TITLE

GNC_VCR

PURPOSE

Provides an application for recording data from the playback dictionary during simulations or flights into a .sitf file, that may be replayed through the console operator's displays at the operator's convenience.

BACKGROUND

The GNC_VCR acts in the same manner as a normal VCR in that upon initiating the record function, it records all of the data that is used by GNC that is requested in the playback.dict file. The playback.dict file is similar to the GNC dictionary, with the exception that anything that is calculated by the GNC workstations is not included in order to avoid re-calculation. Whenever the user wants to conduct training or replay the data for any other reason, then they may do so by starting the replay function with the necessary displays and computations running. This replay is meant to replicate actual flight conditions of data, such that ideally the user would not know the difference.

RECORDING

1. On the DNAV, choose the "Playback" option.
2. Select "Start Recording"
3. Choose a filename for the recording.
4. Once enough data has been recorded, select "Stop Recording"

REPLAYING

1. On the DNAV, choose the "Playback" option.
2. Choose "Select Playback Source"
3. Choose "SITF"
4. Return to the DNAV, and choose the "Playback" option again
5. Choose "Start Playback Menu", this will initiate the yellow DNAV; if the user is using two workstations, steps 4 & 5 must be completed on each workstation.
6. Start displays per SCP 11.10
7. Go to the "Server Interface" display and select "Playback"

8. Select the appropriate file under the "File" menu.
9. Once the file has been selected, the user may start the data stream by clicking "Start"
10. When the user is finished they may stop the session by clicking the "Stop" button

Note: The user may replay a session by selecting the "Rewind" option under the "Playback" pull down menu, or they may select a new file for the session. However, whenever this is done, steps 4 & 5 of this procedure must be repeated in order to properly initialize the time_comp. It is only necessary to restart the yellow DNAV on one of the two workstations, preferably the workstation without the "Server Interface" window. If time_comp does not properly initialize, then the user may start it in an XEdit window by typing in the command path: /mcc/uncert_apps/common/gnc/accdp_bin/time_comp &