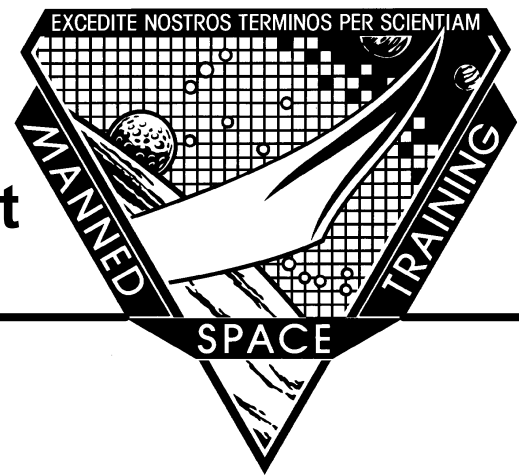


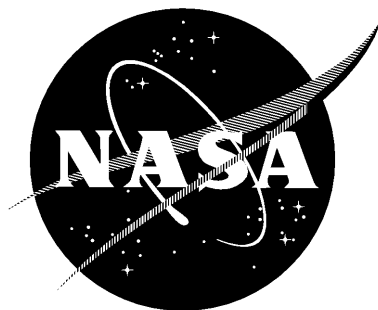
Inertial Measurement Unit Workbook

IMU 2102



**Mission Operations Directorate
Space Flight Training Division
Computer and Navigation Training Branch**

April 1995



National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

Inertial Measurement Unit Workbook

IMU 2102


April 1995

Prepared by

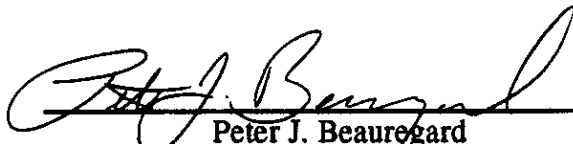


Lisa Martignetti
Instructor, DPS/Navigation Group

Approved by



Charles R. Moede
Lead, DPS/Navigation Group



Peter J. Beauregard
Lead, Computer and Navigation Branch



Jay Apt
Training Representative,
Astronaut Office

Mission Operations Directorate
Space Flight Training Division
Computer and Navigation Training Branch

Technical Support

Subject Matter Experts

Laurie Labra
Lisa Martignetti

Editor

Karlene Donaldson

Foreword

The content of this document was provided by the DPS/Navigation Group, Flight Training Branch, Space Flight Training Division, Mission Operations Directorate (MOD), Lyndon B. Johnson Space Center (JSC), National Aeronautics and Space Administration (NASA). Technical documentation support was provided by Integrated Documentation Services (IDS), Hernandez Engineering, Inc. Any questions concerning this training manual or any recommendations should be directed to the training manual book manager, Lisa Martignetti, at DT 23, 244-7203.

This material is for training purposes only and should not be used as a source of operational data. All numerical data, displays, and checklist references are intended as examples. To determine any prerequisites before using this document, consult the applicable Certification Plan. For shuttle manuals, consult the Flight Operations Support Personnel Training Guide (Blue Book) or the Crew Training Catalog. For Space Station manuals, consult the appropriate Space Station Certification Training Guide or Training Administration Management System (TAMS). The applicable training package should be studied before attending any classroom session or lesson for which this is a prerequisite.

A Training Materials Evaluation is included at the end of this document. Inputs on this sheet will be used to evaluate the lesson material. You do not need to sign the sheet.

Contents

Section	Page
1 Introduction	1-1
Performance Objectives	1-1
Questions	1-5
2 System Description	2-1
Performance Objectives	2-1
Gimbals	2-1
Gyros	2-2
Resolvers	2-3
Accelerometers	2-3
Stabilization Loops	2-4
Platform Reorientation	2-4
Skew	2-5
Built-In Test Equipment	2-5
Thermal Controls	2-7
Electrical Power	2-10
GPC Interface	2-14
Displays	2-14
Questions	2-23
3 System Operations	3-1
Performance Objectives	3-1
Modes of Operation	3-1
Preflight	3-2
Prelaunch	3-2
Ascent	3-3
Orbit	3-3
Reference Stable Member Matrix	3-4
IMU Alignment Options	3-4
Entry	3-9
Questions	3-11
4 System Malfunctions	4-1
Performance Objectives	4-1
Redundancy Management Scheme	4-1
Attitude Redundancy Management	4-2

Section	Page
Velocity RM	4-6
Thermal Control System	4-8
Data Path Failures	4-8
Questions	4-11
5 Differences in the BFS	5-1
Performance Objectives	5-1
Questions	5-5
 Appendix	
A Acronyms and Abbreviations	A-1
B Answers	B-1
C Mean of 1950 Coordinate System	C-1
D References	D-1

Figures

Section		Page
1-1	The IMU location	1-2
1-2	IMU platform assembly and coordinate system	1-3
2-1	IMU gimbal-mounted platform	2-2
2-2	Two-degrees-of freedom gyro	2-3
2-3	IMU skew	2-5
2-4	IMU air circulation	2-8
2-5	Panels L1 and L4	2-9
2-6	IMU electrical power interface	2-11
2-7	Panels O14 and O15	2-12
2-8	Panel O16	2-13
2-9	OVERRIDE display (SPEC 51)	2-15
2-10	IMU ALIGN display (SPEC 21)	2-15
2-11	GNC SYS SUMM 1 display (DISP 18)	2-18
2-12	ENVIRONMENT display (DISP 66)	2-19
2-13	SM SYS SUMM 1 display (DISP 78)	2-20
2-14	GND IMU CNTL/MON display (SPEC 104)	2-21
3-1	Orbit Ops checklist, IMU ALIGN-S TRK procedure	3-5
3-2	Orbit Ops checklist, IMU ALIGNMENT-IMU/IMU	3-8
4-1	IMU three-level attitude selection filter	4-2
4-2	IMU two-level attitude selection filter	4-3
4-3	Typical attitude FD thresholds, time from any on-orbit alignment	4-4
4-4	IMU three-level velocity selection filter	4-6
4-5	Typical velocity fault detection threshold	4-7
4-6	GPC/FF MDM/IMU data path	4-8
5-1	BFS OVERRIDE display (SPEC 51)	5-3
5-2	BFS GNC SYS SUMM 1 display (DISP 18)	5-3

Section 1

Introduction

Performance Objectives

As a result of studying this section, you should be able to do the following:

- Explain what the Inertial Measurement Unit (IMU) provides
- Describe how many IMUs are installed onboard the orbiter

The IMU provides inertial attitude and velocity data to the Guidance, Navigation, and Control (GNC) software functions. Navigation (NAV) software uses the processed IMU velocity data to propagate the orbiter state vector. Guidance uses the attitude data, along with the state vector from the NAV software, to develop steering commands for flight control. Flight control uses the IMU attitude data to convert the steering commands into control surface, engine gimbal, and Reaction Control System (RCS) thruster fire commands.

For redundancy, three IMUs are installed onboard the orbiter, although flight could be accomplished with only one. They are mounted on the NAV base, which is located inside the pressurized flight deck forward of the main instrument panels. The NAV base mounting platform is pitched down 10.6° from the orbiter +X body axis (see Figure 1-1). The purpose of the NAV base is to provide a platform to which the IMUs can be repeatedly mounted with great accuracy. This accuracy enables transformations to be defined that relate IMU reference frame measurements to any other reference frame.

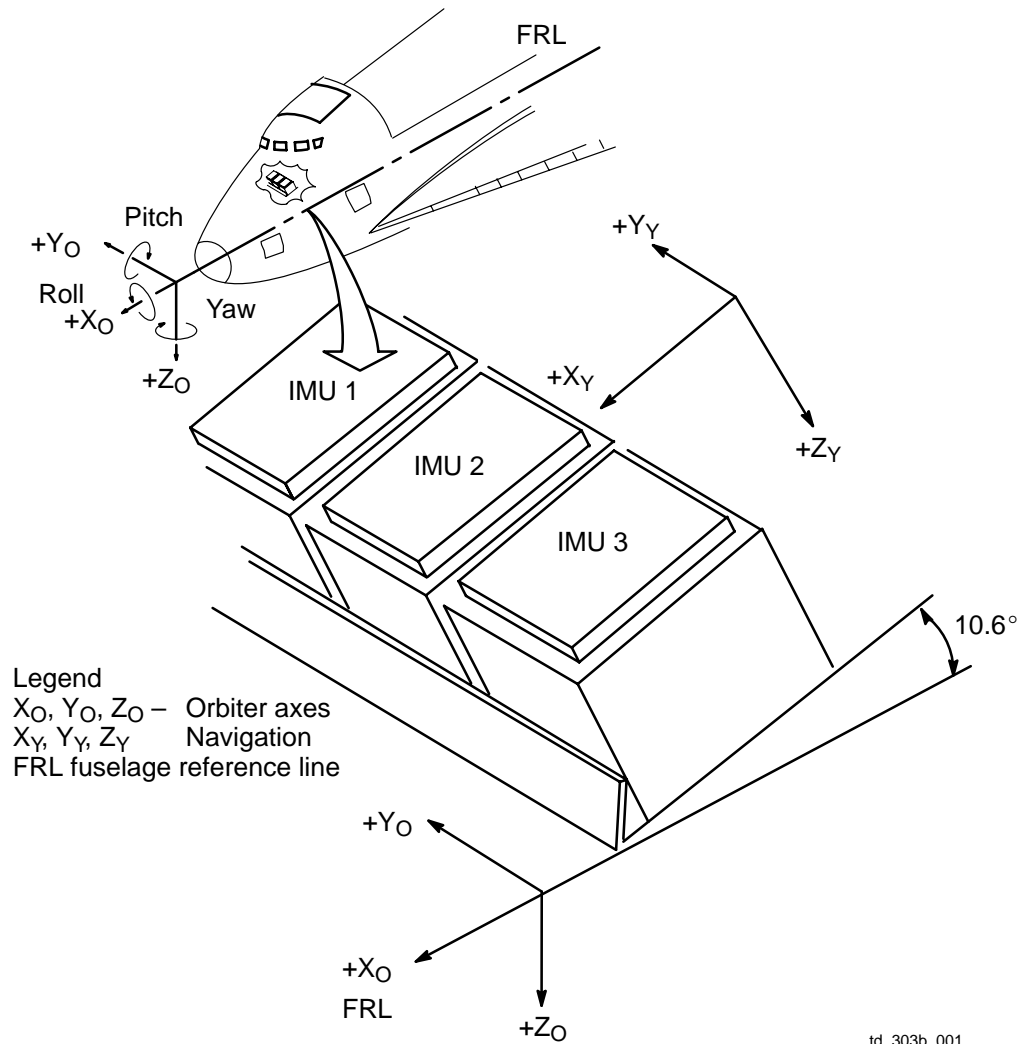
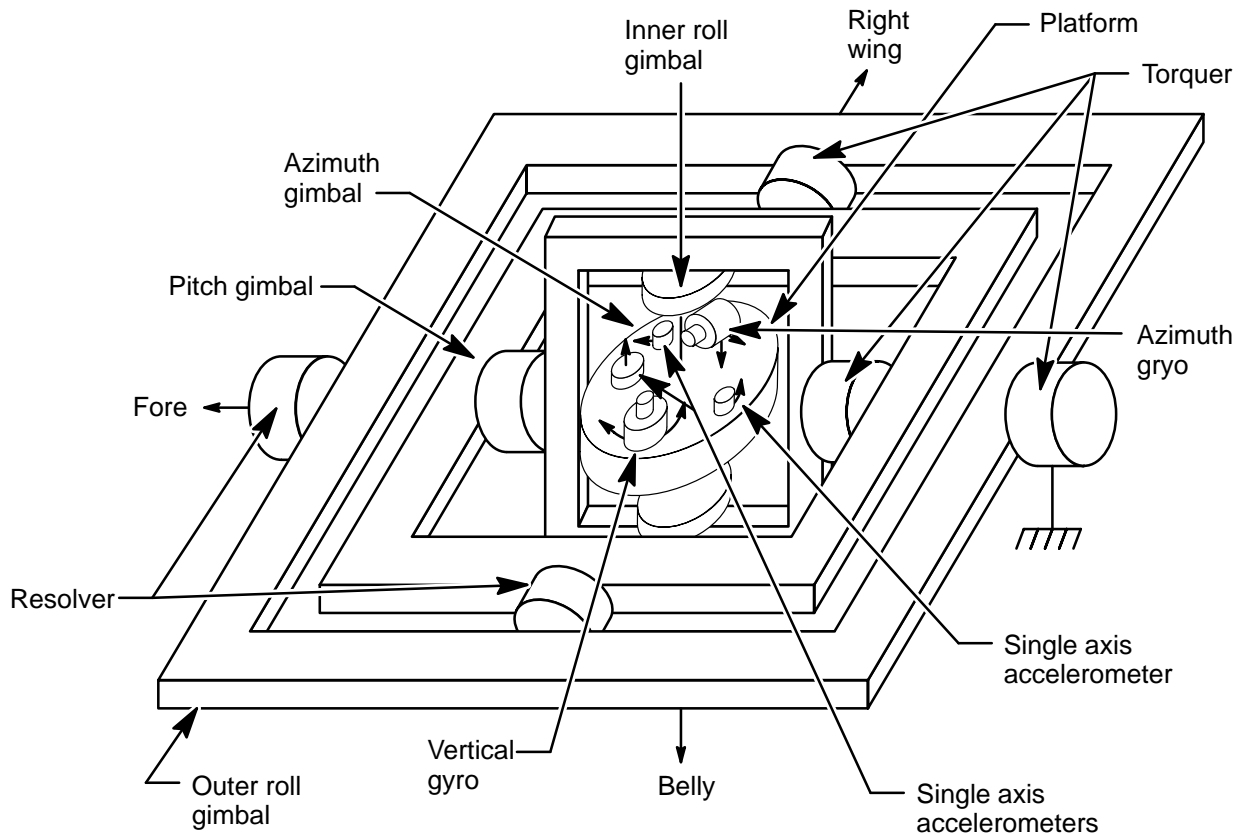


Figure 1-1. The IMU location

The IMU consists of a platform that is isolated from vehicle rotations by four gimbals (see Figure 1-2). Since the platform does not rotate with the vehicle, its orientation remains fixed in space; that is, an inertial orientation. Mounted upon the platform are the sensors and some of the interface hardware. The inertial sensors consist of two gyros, each having two degrees of freedom and three single-axis accelerometers.

The gyros are used to maintain an inertial orientation of the platform by sensing rotations of the platform due to vehicle rotations. The gyros output a signal proportional to the motion, which is then used by gimbal electronics to drive the appropriate gimbals to null the gyro output. The design of the system is such that this happens almost instantaneously and the platform remains essentially undisturbed, thereby maintaining its inertial orientation while the gimbals respond to the vehicle motion.



td_303b_002

Figure 1-2. IMU platform assembly and coordinate system

The accelerometers measure linear vehicle accelerations in the IMU inertial reference frame. The input axes of the accelerometers form an orthogonal right-handed coordinate system. The accelerometers output a signal when they are subjected to an acceleration along their input axes. This signal, which is proportional to the acceleration, is then used by the velocity electronics to compute the IMU velocity components.

The resolvers are used to measure vehicle attitude. There are four resolvers in an IMU. A resolver is located at one of the two pivot points between adjacent gimbals. The resolvers electrically measure the angle between the two gimbals. This electrical signal is transformed into a mechanical angle by the IMU electronics. The attitude processors in the Primary Avionics Software System (PASS) GNC General Purpose Computers (GPCs) and the Backup Flight System (BFS) GPC use these measured angles to determine the orbiter Mean of 1950 (M50) attitude. (Reference appendix C for M50 description.)

The velocity data measured by the IMUs are the main source in propagating the orbiter state vector during ascent and entry. On orbit, a sophisticated drag model is substituted for IMU velocity information, except during large vehicle accelerations. During these large accelerations, IMU velocity data are again used in NAV calculations.

The attitude data provided by the IMUs are always used for attitude control during all phases of flight.

Each IMU interfaces with the five onboard GPCs through a different Flight Forward Multiplexer/Demultiplexer (FF MDM) of the Data Bus Network (DBN). Under the control of the GPCs, each IMU has the capability of orienting its platform to any attitude, determining platform alignment relative to a reference, and providing velocity and attitude data for flight operations.

The IMU and its software are designed to minimize crew interaction. In the optimum case, the crew should need to interface with the IMUs only during on-orbit alignments.

Questions

1. What does the IMU provide?
2. How many IMUs are installed onboard the orbiter?

Section 2

System Description

In this section of the workbook a more detailed description of the IMU hardware is presented. Also, the IMU thermal control system, electrical power supply, and Data Processing System (DPS) interfaces, displays, and controls are discussed.

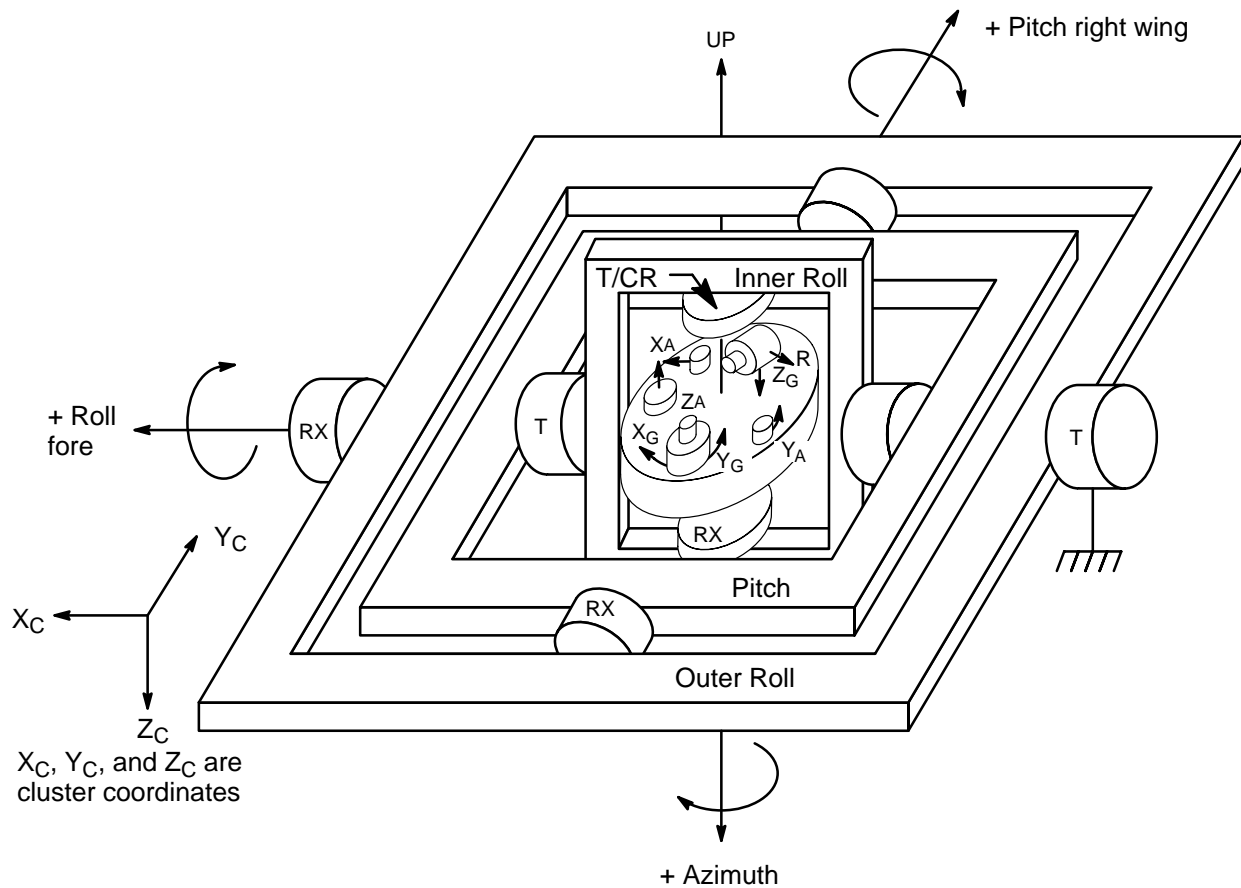
Performance Objectives

As a result of studying this section, you should be able to do the following:

- List the gimbals from outermost to innermost
- Describe the IMU resolver
- Explain what an accelerometer is
- Explain how the IMU fans are used
- Describe how the IMUs are powered

Gimbals

The IMU contains four gimbals that isolate the platform from vehicle rotations (see Figure 2–1). The gimbal order from outermost to innermost is outer roll, pitch, inner roll, and azimuth. The platform is attached to the azimuth gimbal. The inner roll gimbal is a redundant gimbal that is used to provide an all-attitude IMU while preventing the possibility of gimbal lock (a condition that can occur with a three-gimbal system causing the inertial platform to lose its reference). The outer roll gimbal is driven from error signals generated from disturbances to the inner roll gimbal. Thus, the inner roll gimbal will remain at its null position and orthogonal to the pitch gimbal.



X_C , Y_C , and Z_C are cluster coordinates

Notes:

- X_G = X gyro input axis
- Y_G = Y gyro input axis
- Z_G = Z gyro input axis
- R_G = red. gyro input axis
- Z_A = Z accel sens. axis
- X_A = X accel sens. axis
- Y_A = Y accel sens. axis
- (T) = gimbal torquer
- (RX) = gimbal angle resolver
- CR = coordinate resolver

td_303b_003

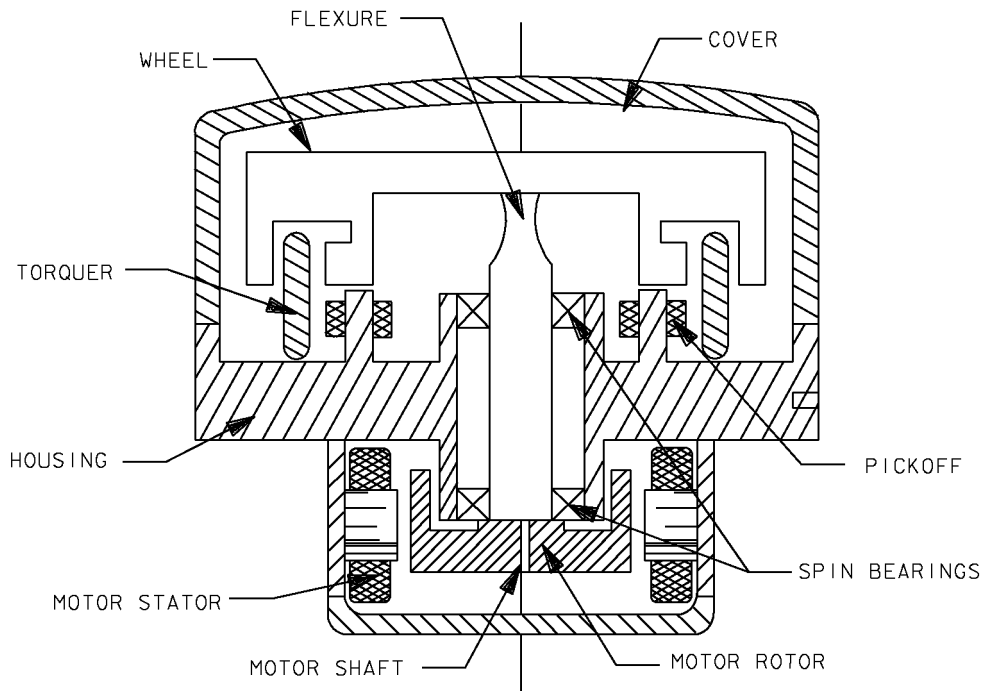
Figure 2-1. IMU gimbal-mounted platform

Gyros

The IMU contains two gyros, each having two degrees of freedom, which are used for platform stabilization (see Figure 2-1). One gyro is oriented such that its input axes are aligned with the X and Y platform axes. This gyro, called the vertical gyro, provides the IMU roll and pitch stabilization. The second gyro is orientated such that one input axis lies along the platform Z-axis and the other lies in the X-Y plane. This gyro, called the azimuth gyro, provides yaw

stabilization with the Z input axis while the second input axis is used as a platform rate detector for Built-In Test Equipment (BITE).

Each gyro contains a two-axis pickoff that senses deflections of the rotating wheel (see Figure 2-2). The gyro also contains two torquers, each having two axes, that provide compensation torquing for gyro drift and a means to reposition the platform. The use of these will become clearer after the discussion of the IMU stabilization loops.



TD3030202. ART 1
td_303b_004

Figure 2-2. Two-degrees-of-freedom gyro

Resolvers

The IMU resolvers are electromechanical devices that use the principle of magnetic induction to electrically measure the angle between two adjacent gimbals. There are two resolvers on each gimbal, the one-speed (1X) and the eight-speed (8X). The 1X electrical output represents a course measurement of the true gimbal mechanical angle while, for greater resolution, the 8X electrical output represents a measurement eight times the true angle. These outputs are converted to an angle measurement in the IMU electronics and are sent to the GPCs. The outputs are combined into a single measurement of the gimbal angle and used for vehicle attitude determination.

Accelerometers

The IMUs have three accelerometers, one to measure accelerations along each axis. The accelerometer is basically a force rebalance type instrument. When the accelerometer experiences an acceleration along its input axes, it causes a pendulum mass displacement. This

displacement is measured by a pickoff device that generates an electrical signal. This signal, which is proportional to the sensed acceleration, is amplified and returned to a torquer within the accelerometer, which attempts to reposition the proof mass to its null (no output) position.

Each accelerometer has its own Digital Accelerometer Loop (DAL). The DAL is a terminal pulse rebalance loop that produces accurate current pulses to restore the pendulum to null and provides an incremental velocity pulse train to the IMU's internal computer.

Stabilization Loops

The stabilization loops are used to maintain the inertial orientation of the platform. There is one stabilization loop for each axis of rotation.

The spin axis of a gyro is its axis of rotation. A property of gyroscopes is the inertial stability of the spin axis. This property is used in the stabilization loops.

The stabilization loops consist of the gyro pickoff, the gimbals, and the gimbal torquers. When the vehicle goes through a rotation, the platform tends to rotate because of friction at the gimbal pivot points. Since the gyro casing is rigidly mounted to the platform, it will also rotate. The gyro resists this rotation because of its tendency to remain inertial, but the resistance is overcome by friction. This rotation is detected by the pickoffs as a deflection of the rotating gyro wheel. A signal proportional to this deflection is sent to the gimbal electronics, which routes the signals to the appropriate torquers. The torquers, in turn, rotate their gimbals to null the pickoff output. When the output is nulled the loop is closed.

The vertical gyro provides platform roll and pitch stabilization, whereas the azimuth gyro provides platform yaw stabilization.

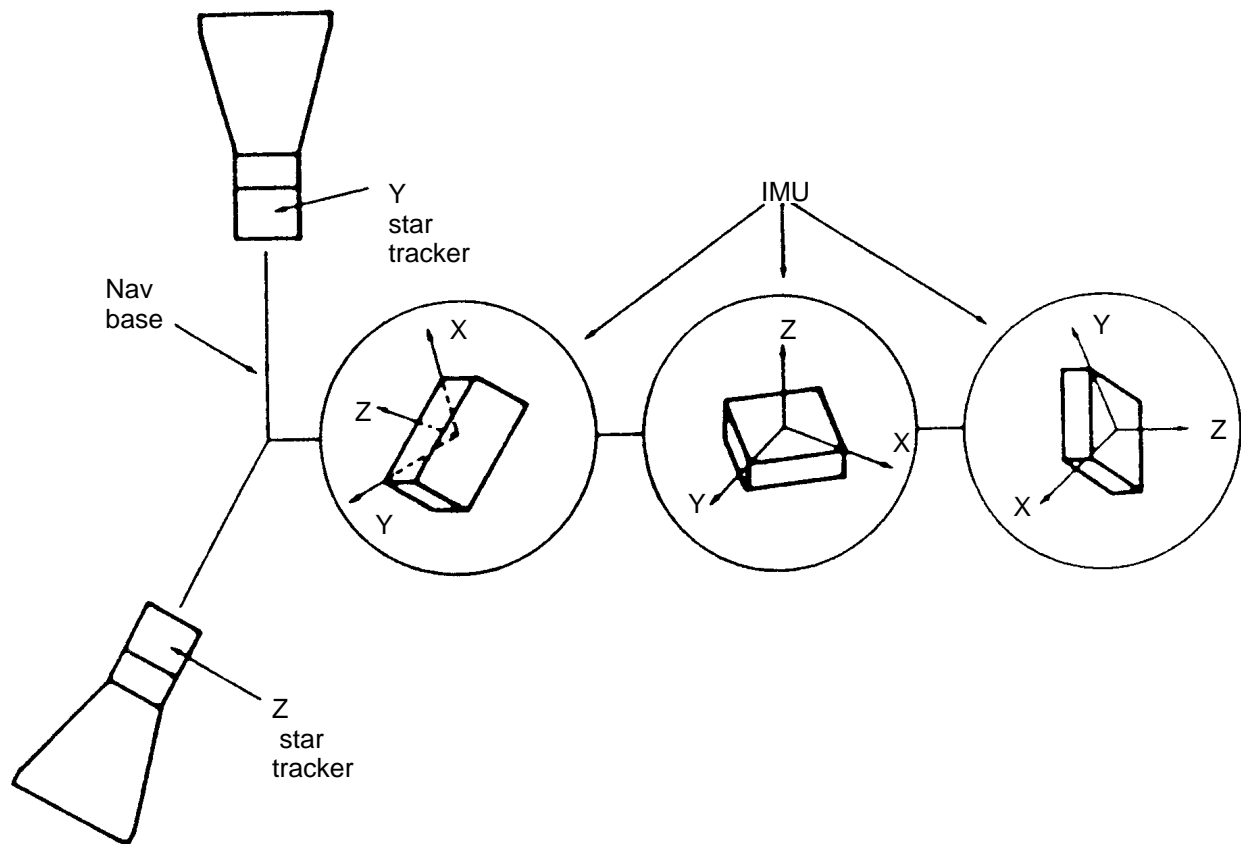
Platform Reorientation

The platform attitude can be reoriented by two methods, slewing or pulse torquing. Slewing rotates the platform at a high rate of 1.2 deg/sec. Pulse torquing rotates the platform very slowly (0.007 deg/sec).

Platform reorientation uses another property of gyroscopes. If a force is applied to a spinning gyroscope, the induced motion is 90° from the input force. This is called precession. In the IMU, a two-axes torquer is located along the input axes of both gyros. Commands are sent to the torquers from the GPC to apply a force along the input axes. The result is a deflection of the gyro spin axis that is detected and nulled by the stabilization loops. Since the gyro spin axis is forced to point in a new direction, the platform will have to rotate to null the gyro outputs.

Skew

Skew is the orientation of the platform of each IMU such that none of the principal axes of the IMUs are parallel (see Figure 2–3). The IMUs are skewed to enable optimum fault detection and isolation and to avoid more than one IMU reaching its gimbal flip condition at the same time. Skew allows single-axis failures on one IMU to be resolved by multiple axes on another IMU, since the possibility of a multiple-axis failure is more remote. The $\sqrt{6}$ skew has been defined as optimal and was named for the recurring factor in the transformation matrix.



td_303b_005

Figure 2–3. IMU skew

Built-In Test Equipment

Each IMU has an extensive self-monitoring capability called BITE. BITE is divided into two categories: hardware- and software-aided. The information provided by BITE is used by IMU Redundancy Management (RM) software to determine the health of an IMU.

Upon detection of a BITE failure, the PASS IMU RM software will annunciate a class 3 alarm Systems Management (SM) alert and generate an IMU BITE/T X fault message. Status fields on the GND IMU CNTL/MON display SPEC 100 in GNC OPS 9; OVERRIDE display SPEC 051 in GNC OPS 1, 3, and 6; and the IMU ALIGN display SPEC 021 in GNC OPS 2, 3, and 8 will display BITE for the pertinent IMU.

Hardware BITE indications, which are found on the mode status word, are as follows:

1. SYNC
2. SYNC
3. SYNC
4. HAINS GOOD
5. MUX FAIL
6. A/D FAIL
7. PLATFORM FAIL
8. DIGITAL SUBSYSTEM FAIL
9. DC/DC FAIL
10. DISCRETE POWER SUPPLY FAIL
11. RX FAIL
12. CIRCUIT CARD OVERTEMP
13. TRANSMISSION WORD 1 FAIL
14. TRANSMISSION WORD 2 FAIL
15. D1 + D8 SEQUENCER DISCRETE
16. D2 SEQUENCER DISCRETE
17. D3 SEQUENCER DISCRETE
18. D4 SEQUENCER DISCRETE
19. D5 SEQUENCER DISCRETE
20. PARITY

Limit checks in any of these areas that detect failures will cause BITE to be issued within the IMU. This action also sets certain bits in the IMU output data words that the GPC IMU software reads, and, as a result, the GPC annunciates a BITE message against the pertinent IMU.

The information transmitted to the GPC by the IMU is used not only for attitude and acceleration data, but also to perform certain tests indicating the health of the IMU. The software uses these tests in conjunction with the above hardware BITE to provide assurance that greater than 95 percent of the hardware failures are covered by BITE. IMUs also have an extensive internal BITE/history storage that is accessible only via special ground test software postflight.

Software-aided BITE consists of seven separate signals, which are listed as follows:

- Accelerometer scale factor fail
- Echo one fail
- Echo two fail
- Velocity limit fail
- Resolver limit fail
- Redundant rate fail
- Inner roll null fail

Two temperature discretes are relayed to the GPC software in the IMU output data words. These discretes give the temperature status of the IMU and provide software with the capability to monitor the IMU operating temperature. The limits that set the discretes are listed as follows:

- PLAT TEMP SAFE - If the platform temperature is $<156.5^{\circ}$ F, then it is SAFE.
- PLAT TEMP RDY - If the platform temperature is $>146.5^{\circ}$ F, then it is READY.

The listed hardware and software BITE detections plus the temperature limit indications make up the total IMU BITE indication from the GPC. The IMU BITE word consisting of these parameters is a 16-bit word within the software. The IMU BITE/T X fault message described on page 2–6 is annunciated when any bit within this word is set true.

It is possible for an IMU to annunciate an IMU BITE while having no error condition. This is referred to as a “False BITE.”

The Mission Control Center (MCC) has the capability to detect false BITEs by monitoring IMU performance through GNC telemetry. Each IMU BITE has characteristic performance problems. If no degradation occurs, the IMU BITE may be false, and MCC may wish to mask the BITE in the GPC software to avoid reannunciation of the message and to preclude the software from using this indication in determining IMU failures.

Thermal Controls

Because of the temperature sensitivity of the platform inertial components, a very precise thermal control system is necessary for the IMUs to meet performance requirements. The IMU thermal control system consists of two major components, an internal heater system and a forced-air cooling system.

The internal heater system is completely automatic. It is powered on when power is initially applied to the IMU and will continue to operate until the IMU is powered off. It is used to maintain critical IMU component temperatures within tight tolerances.

The forced-air cooling system is required to ensure that the internal heaters can do their job. It consists of three fans, which serve all three IMUs (see Figure 2–4). The fans pull cabin air through the casing of each IMU. The air is then cooled in a heat exchanger and returned to the cabin. Only one fan is necessary to provide adequate air flow. Each IMU fan is powered by a different ac power supply. The IMU fan power switches are located on panel L1, and their corresponding circuit breakers are on panel L4 (see Figure 2–5).

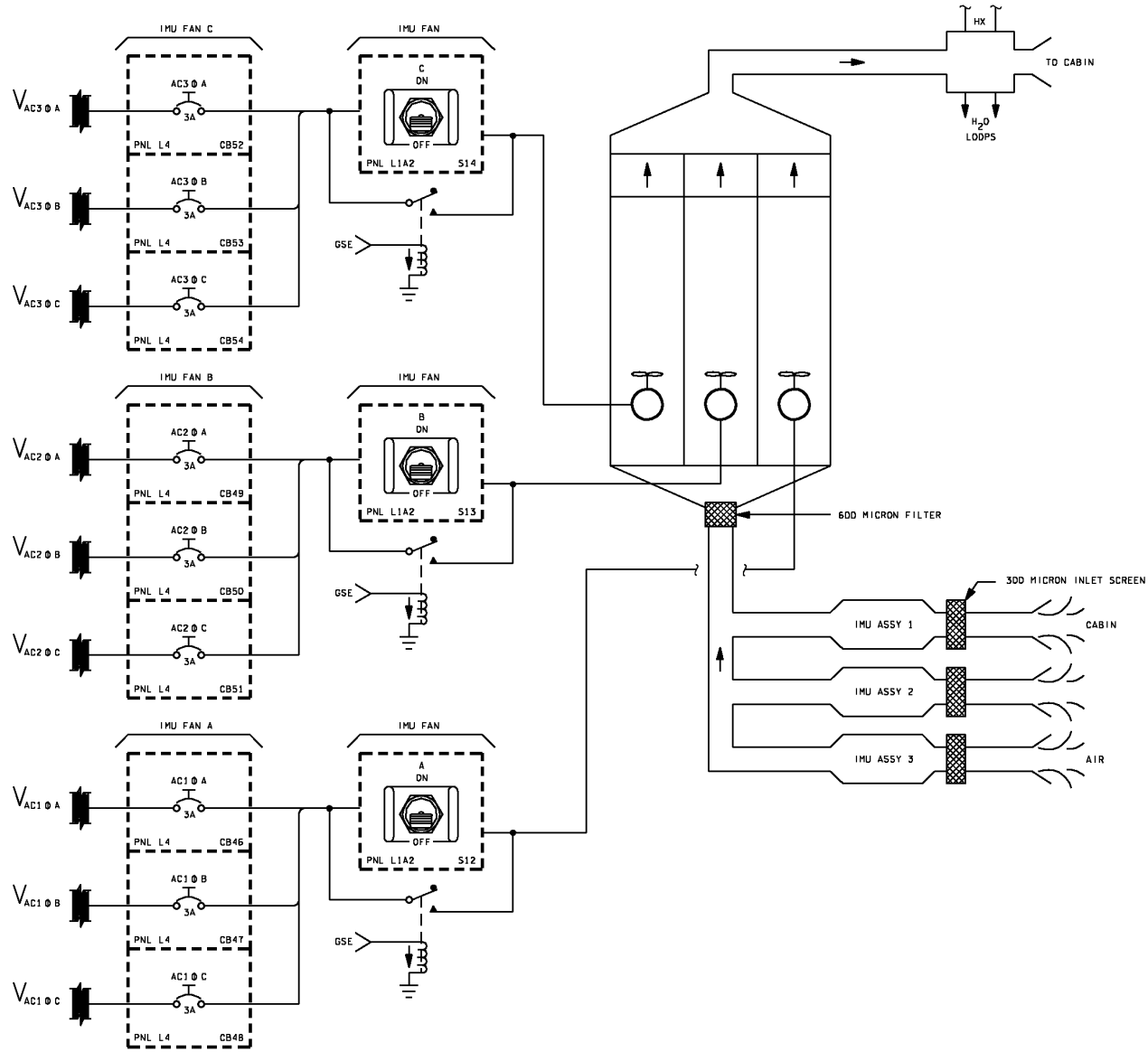


Figure 2-4. IMU air circulation

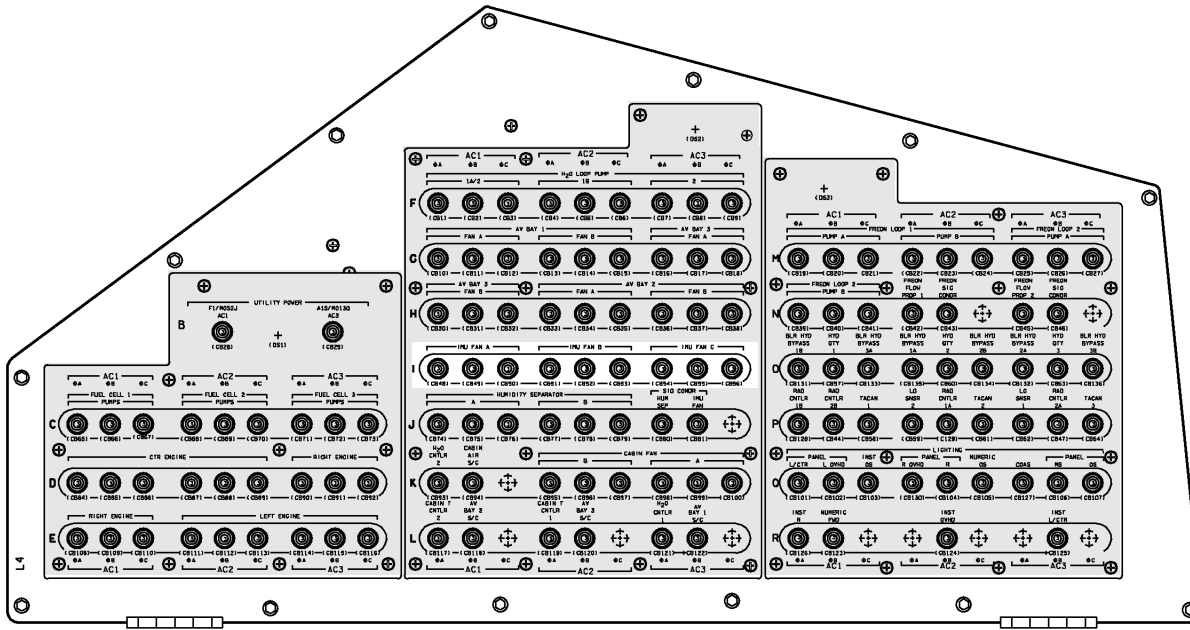
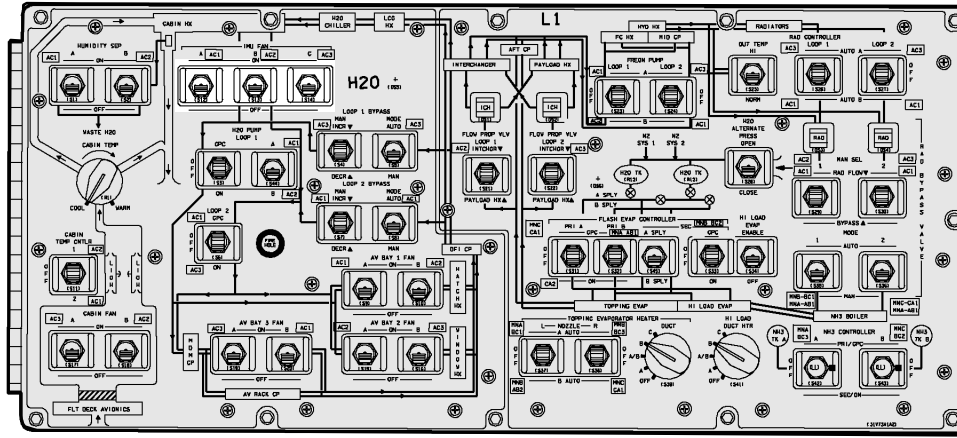


Figure 2-5. Panels L1 and L4

td_303b_007

753030206, APP 1

IMU operating temperature indications are available only on the IMU ALIGN display (SPEC 21). Two temperature discretes are sent from each IMU to be processed and displayed as a single temperature indication. One of the three different temperature indications (LO, OK, and HI) will be present. When an IMU temperature exceeds limits, a class 3 alarm (SM ALERT) will be annunciated as well as an IMU BITE/T X fault message.

IMU fan status can be found on the PASS ENVIRONMENT display (DISP 66) in SM OPS 2, the PASS SM SYS SUMM 1 display (DISP 78), and the BFS SM SYS SUMM 1 display (DISP 78). Each display shows which fan is presently operating (an asterisk present next to or below the particular IMU fan) and a status indication (to the right of the asterisk). Status indications are present only for operating IMU fans. If the status indication field is blank, then there is no problem with the operation of that particular fan. If an “M” is displayed, this indicates that no data are available on the fan indicated. A “↓” denotes that the fan has been operating but its speed has dropped below a predetermined limit.

Electrical Power

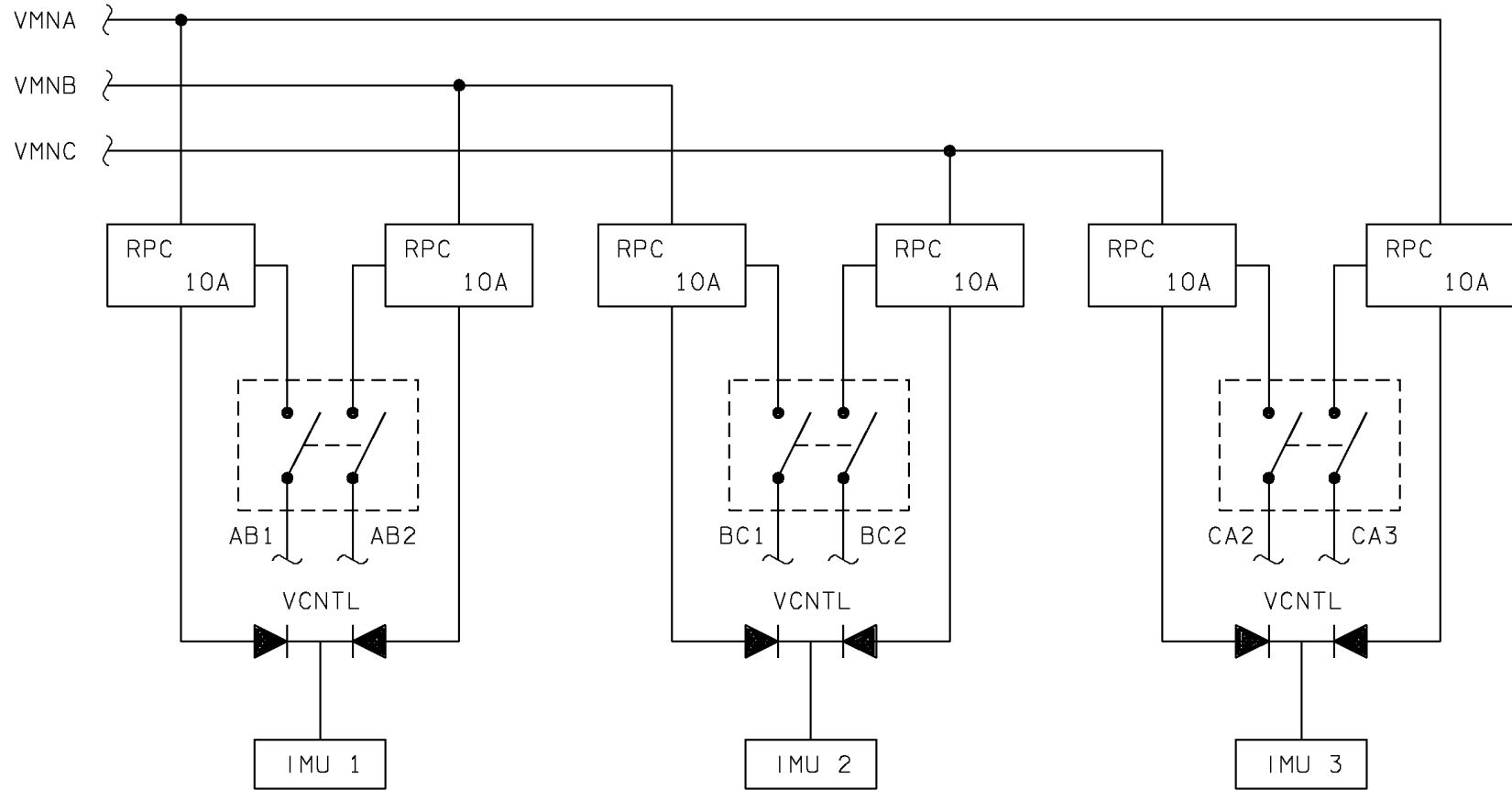
Each IMU is supplied with redundant 28 V dc power. This power is fed to the IMU through separate Remote Power Controllers (RPCs) when control bus power is applied to the RPC by the IMU power switch (see Figure 2–6). The IMU power switches are located on the overhead panels O14, O15, and O16 in row A (see Figures 2–7 and 2–8). Note that the loss of one main bus or any one control bus will not cause loss of an IMU.

IMU operating temperature indications are available only on the IMU ALIGN display (SPEC 21). Two temperature discretes are sent from each IMU to be processed and displayed as a single temperature indication. One of the three different temperature indications (LO, OK, and HI) will be present. When an IMU temperature exceeds limits, a class 3 alarm (SM ALERT) will be annunciated as well as an IMU BITE/T X fault message.

IMU fan status can be found on the PASS ENVIRONMENT display (DISP 66) in SM OPS 2, the PASS SM SYS SUMM 1 display (DISP 78), and the BFS SM SYS SUMM 1 display (DISP 78). Each display shows which fan is presently operating (an asterisk present next to or below the particular IMU fan) and a status indication (to the right of the asterisk). Status indications are present only for operating IMU fans. If the status indication field is blank, then there is no problem with the operation of that particular fan. If an “M” is displayed, this indicates that no data are available on the fan indicated. A “↓” denotes that the fan has been operating but its speed has dropped below a predetermined limit.

Electrical Power

Each IMU is supplied with redundant 28 V dc power. This power is fed to the IMU through separate Remote Power Controllers (RPCs) when control bus power is applied to the RPC by the IMU power switch (see Figure 2–6). The IMU power switches are located on the overhead panels O14, O15, and O16 in row A (see Figures 2–7 and 2–8). Note that the loss of one main bus or any one control bus will not cause loss of an IMU.



TD3030207. ART# 1

td_303b_008

Figure 2-6. IMU electrical power interface

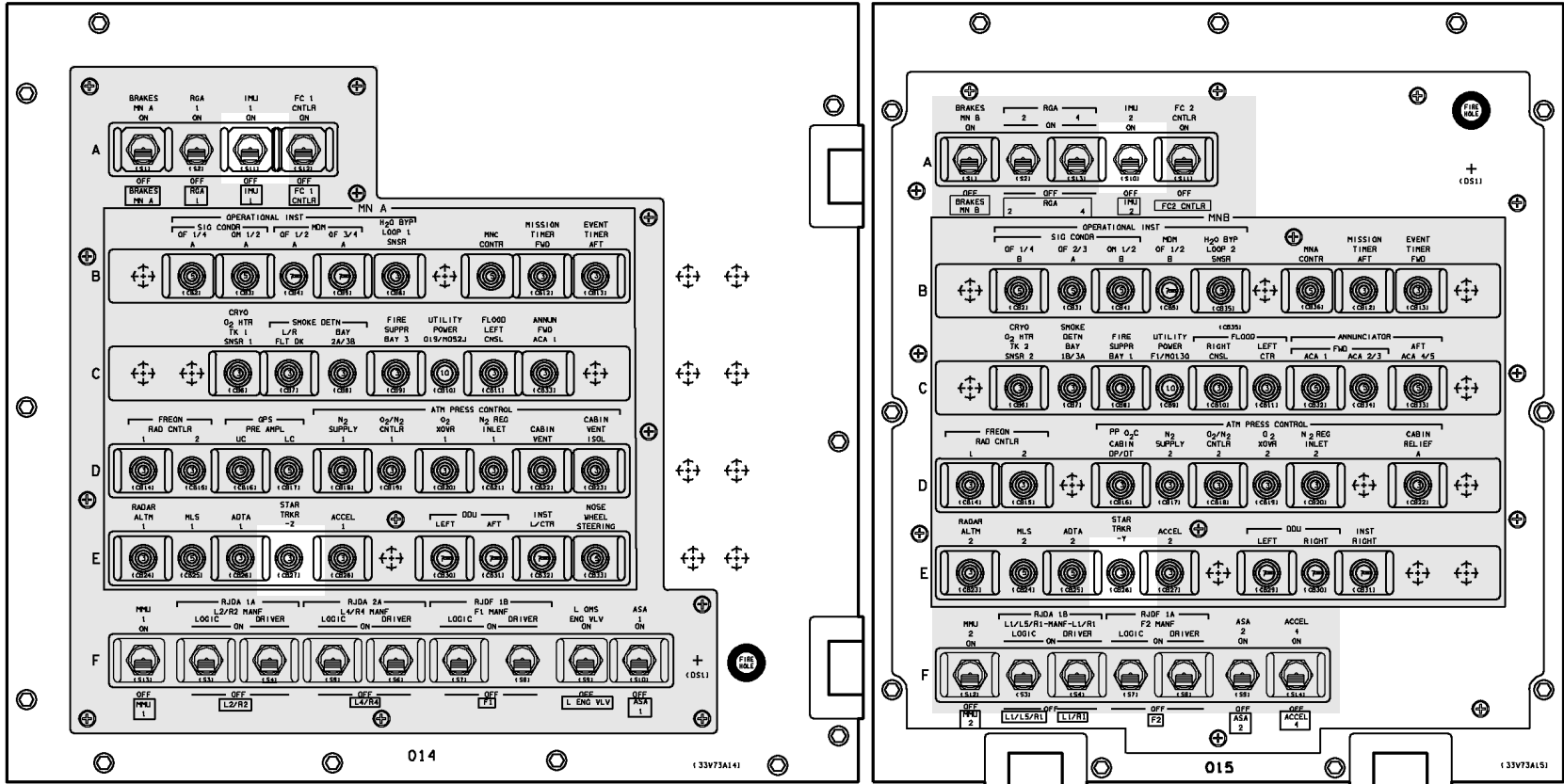


Figure 2-7. Panels 014 and 015

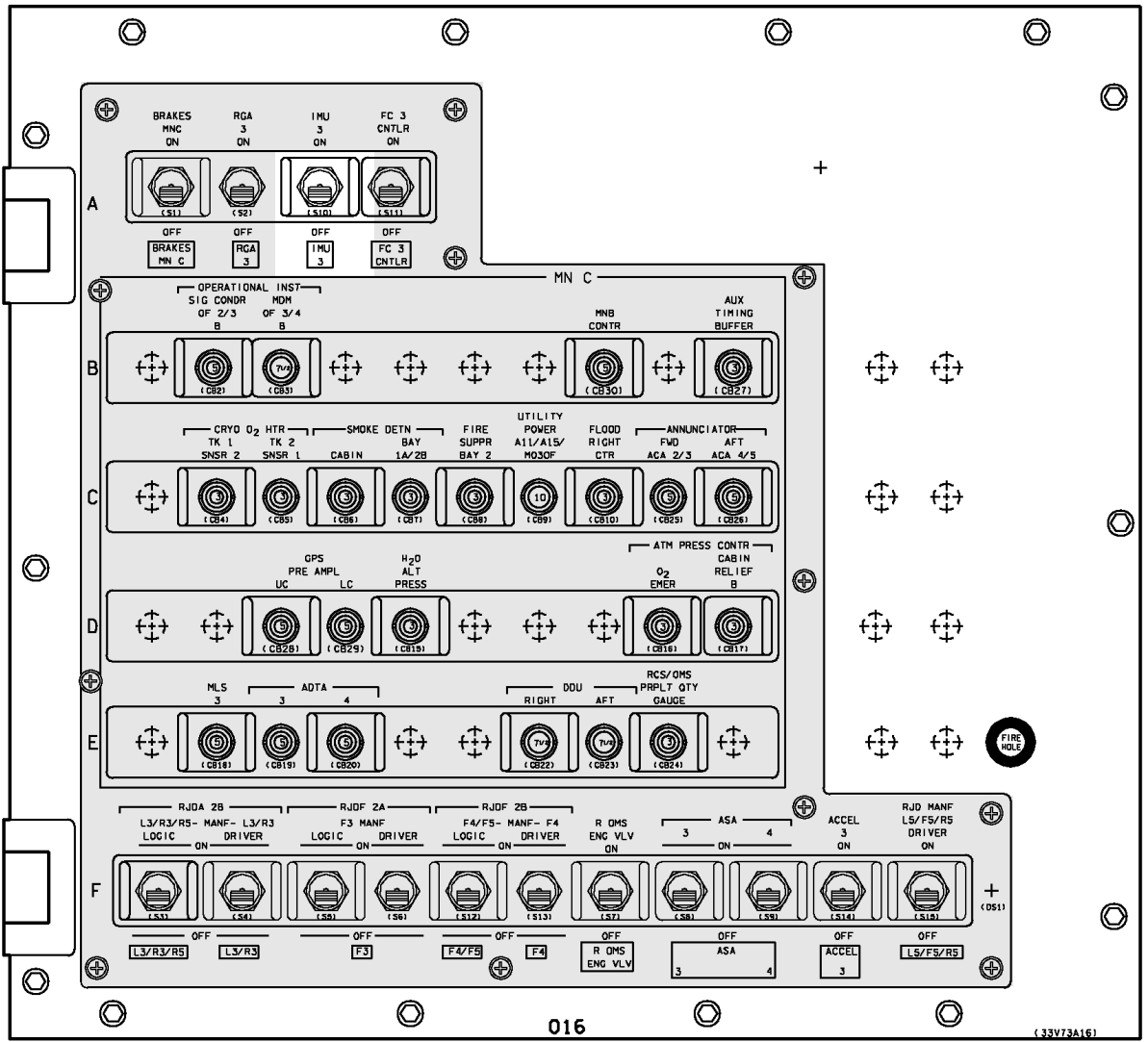


Figure 2-8. Panel 016

2086, PNL 1
td_303b_010

GPC Interface

The IMUs interface with the GPCs through the FF MDMs. IMUs 1, 2, and 3 are connected to FF MDMs 1, 2, and 3, respectively. The interface consists of several discrete wires and a serial data bus.

Displays

In this section a brief review of IMU switch locations is presented along with descriptions of the PASS displays where IMU information can be found.

OVERRIDE Display (SPEC 51)

The OVERRIDE display is available in GNC OPS 1, 3, and 6. This display provides the crew with information on IMU operations during ascent and entry (see Figure 2–9). It also gives them the ability to manually deselect an IMU from RM and the data selection filter (both of which are described in Section 4). All IMU information is located in the center of the display.

- To the right of the IMU number is the IMU RM status column. The column is blank for normal IMU operations, displays a “↓” for a deselection by RM or the crew, a “?” for an RM dilemma, or an “M” for missing IMU data.
- To the right of the RM status column is the Status (STAT) column. This column is either blank for normal IMU operations or displays BITE for a BITE–detected problem.
- The field just below Attitude (ATT) indicates the IMU presently being selected as a source for attitude data. “RGA” will be displayed below the IMU attitude source number if the IMU attitude data is declared invalid for use by the attitude processor.
- Item numbers 25, 26, and 27 allow manual deselection of an IMU from RM and the selection filter. A subsequent reexecution of the item number reselects the IMU, and the asterisk will be removed.

```

1011/051/          OVERRIDE          DDD/HH: MM: SS
                                DDD/HH: MM: SS
ABORT MODE          ENTRY FCS
TAL/AOA 1          ELEVON          FILTER          ATMOSPHERE
ATO 2              NOM 17*         NOM 20*         NOM 22*
ABORT 3            ALT 18          ALT 21          N POLE 23
MAX THROT 4       S POLE 24
PROPLT DUMP
OMS DUMP TTG 0
ENA ICNCT 5
CONT CENT
ABT 6              9
ARM 7              10
START 8*           11
INERT 9            12
STOP 10            13
AFT RCS 13
14 TIME ---
FWD RCS 15
16 TIME ---
IMU STAT ATT DES          PRL
1 3 25          SYS AUT DES
2 26          1 28* 31
3 27          2 29* 32
3 30* 33
ADTA H α M DES
L 1 0 0.0 0.00 34
3 0 0.0 0.00 35
R 2 0 0.0 0.00 36
4 0 0.0 0.00 37
ET SEP          ROLL MODE
AUTO 38        AUTO SEL 42
SEP 39
ET UMB DR          VENT DOOR CNTL
CLOSE 40        OPEN 43*
RCS RM MANF        CLOSE 44
CL OVRD 41

```

TD3030209. ART# 3
td_303b_011

Figure 2-9. *OVERRIDE display (SPEC 51)*

IMU ALIGN Display (SPEC 21)

This display, which is available in GNC OPS 2 and 3, provides IMU alignment capability as well as status and controls. See Figure 2-10.

```

XXXX/021/          IMU ALIGN          XX X DDD/HH: MM: SS
IMU                DDD/HH: MM: SS
1S 2S 3S
STAT XXXX XXXX XXXX          ALIGN XXX
TEMP XX XX XX          IMU 1 10X STAR ALIGN 13X
STBY 21X 22X 23X          2 11X 14 IMU/IMU X
OPER 4X 5X 6X          3 12X MATRIX 15X
DES 7X 8X 9X
EXEC 16X
TERM 17
ACC
1 2 3
X ±X.XX ±X.XX ±X.XX          IMU BITE MASK
Y ±X.XX ±X.XX ±X.XX          1 XXXX 24X
Z ±X.XX ±X.XX ±X.XX          2 XXXX 25X
3 XXXX 26X
ANG
1 1 1
X XXX.XX XXX.XX XXX.XX
Y XXX.XX XXX.XX XXX.XX
Z XXX.XX XXX.XX XXX.XX
NAV ΔV THRESH
18 XXXXXXXX
MM READ 19X
(XX)

```

TD3030210. CRT# 2
td_303b_012

Figure 2-10. *IMU ALIGN display (SPEC 21)*

The upper left portion of the display contains the status and controls for each IMU.

- Beside the IMU number will be displayed an “M” for missing data (comm fault), a “↓” for a deselection by RM or the crew input, or a “?” for an RM dilemma. Blank indicates nominal operation.
- STAT will indicate “BITE” for the particular IMU with a BITE condition or “OFF” when power is removed. Blank indicates a nominal condition.
- TEMP) will indicate the current condition of the IMU by displaying one of the following: LO, OK, or HI.
- Items 21, 22, and 23 command the Standby (STBY) mode of the IMU. An asterisk beside the number indicates the current mode.
- Items 4, 5, and 6 command the Operate (OPER) mode of the IMU. An asterisk beside the number indicates the current mode. The STBY and OPER mode asterisks are mutually exclusive.
- Items 7, 8, and 9 allow the crew to manually select/deselect the IMU as a candidate for the selection filter. An asterisk indicates deselection. This is a toggle item number. Subsequent executions will alternately remove or replace the asterisk. If RM deselects an IMU upon detection of a failure, an asterisk will be placed in the given column.

The lower left portion of SPEC 21 provides attitude and accelerometer data. These data are useful for comparing the data output between IMUs.

- Each IMU’s data has been transformed to the M50 coordinate system.
- The acceleration (ACC) data is a measure of the acceleration output of the IMU in feet per second squared. These data provide a means for the crew to compare IMU accelerometer data output for troubleshooting purposes, despite skew.
- Angle (ANG) provides attitude data for each IMU in degrees. X, Y, and Z correspond to pitch, roll, and yaw, respectively. As with ACC data, the attitude data allow comparison of IMUs for troubleshooting purposes, despite skew.
- Below the attitude data, IMU torquing (or misalignment) angles are displayed (ΔX , ΔY , and ΔZ). These data indicate the angle through which each axis of each IMU will have to be rotated (or torqued) to be realigned. These angles will decrease to zero at the display update rate as an alignment progresses. The units are degrees. These angles are computed cyclically (once per minute) prior to alignment initiation.

The upper right portion of the display contains various alignment controls and options.

- The three–space field beside ALIGN indicates that there are stars in the star table (S TABLE) on SPEC 22 that meet the criteria for selection for an IMU alignment. This condition is represented by ENA (Enable) in the field. A blank field indicates that there are no stars in the table or that the stars in the table do not meet criteria for auto selection.
- Items 10, 11, and 12 allow selection of the IMUs that are to be aligned. This action is done by executing the item number to toggle the asterisk. An asterisk indicates that the IMU is selected for alignment.

- Item 13 (STAR ALIGN) is the alignment option selected when the IMUs are to be aligned using star data. This option is the default option when the display is first called (asterisk will be beside it).
- Item 14 is the alignment option selected when one or more IMUs is to be aligned using another IMU as a reference (IMU/IMU alignment). This option is selected by entering the number of the reference IMU.
- Item 15 (MATRIX) is an IMU alignment option that aligns the IMU by computing a new matrix (instead of reorienting the IMU physically).
- Item 16 (EXEC) initiates an alignment. An asterisk appears and remains beside the item number while the alignment is progressing.
- Item 17 (TERM) allows manual termination of an alignment, although any alignment will terminate automatically, given time to complete. There will never be an asterisk beside this item number.
- Item 18 (NAV ΔV THRESH) provides a means by which the NAV IMU velocity threshold may be changed (only in OPS 2).
- Item 19 (Mass Memory (MM) READ) allows transfer of IMU calibration parameters from MM to GPC memory.
- Items 24, 25, and 26 allow the crew to mask any BITEs present on IMUs 1, 2, and 3. An “*” is driven next to the item number selected. Execution of these items masks only those BITEs already present; in order to mask any new BITEs, masking must be terminated and then reactivated. The data displayed under BITE reflect the current BITE status, not the mask status. (The REF Data Flight Supplement contains a table which decodes the hexadecimal data into individual BITEs.)

GNC SYS SUMM 1 Display

The GNC SYS SUMM 1 display (DISP 18) is available in GNC OPS 1, 2, 3, 6, and 8. This display provides an overview of critical GNC hardware operations (see Figure 2–11). The IMU data are located in the NAV subsystem area in the lower right corner of the display. The same status parameters available on the OVERRIDE display are shown here.

1031/051/018		GNC SYS SUMM 1		4/000/00:04:04		000/00:04:04				
<u>RCS</u>	<u>JET ISOL</u>	<u>SURF</u>	<u>POS</u>	<u>MOM</u>	<u>DPS</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
MAN	FFAIL	L	OB		GPC					
F1	OP	R	IB		MDM	FF				
2	CLM		OB		FA					
3	OP									
4	OP									
5										
<u>L1</u>	<u>OP</u>	<u>AIL</u>			<u>FCS</u>	<u>CH</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
2	OP	RUD								
3	OP	SPD BRK								
3	CLM	BDY FLP								
4	OP									
5										
<u>R1</u>	<u>OP</u>	<u>CNTLR</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>NAV</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
2	OP	RHC	L			IMU				
3	CLM		R			ACC				
4	OP		A			RGA				
5			L			TAC				
			A			MLS				
			L			ADTA				
			R							
			A							
			L							
			R							

1475. CRT# 11

td_303b_013

Figure 2–11. GNC SYS SUMM 1 display (DISP 18)

ENVIRONMENT Display

The ENVIRONMENT display (DISP 66) is available in SM OPS 2 (see Figure 2–12). IMU FAN and ΔP data are available in the lower left corner of this display. This information is discussed in the thermal control system description.

XXXX/XXX/066				ENVIRONMENT				XX X DDD/HH: MM: SS		
				DDD/HH: MM: SS						
CABIN				AV BAY			1 2 3			
dP/dT	±.XXS	CABIN P	XX.XS	TEMP	XXXXS	XXXXS	XXXXS	XXXXS	XXXXS	XXXXS
PP02		AIRLK P	XX.XS	FAN ΔP	X.XXS	X.XXS	X.XXS	X.XXS		
A	X.XXS	FAN ΔP	X.XXS	SUPPLY H2O						
B	X.XXS	HX OUT T	XXXXS	QTY A	XXXXS	PRESS		XXXXS		
C	X.XXS	CABIN T	XXXXS	B	XXXXS	DMP LN T		XXXXS		
PPC02	XX.XS			C	XXXXS	NOZ T A		XXXXS		
				D	XXXXS			B	XXXXS	
				WASTE H2O						
02 FLOW	X.XS	1	X.XS	QTY 1	XXXXS	PRESS		XXXXS		
REG P	XXXXS	2	XXXXS			DMP LN T		XXXXS		
N2 FLOW	X.XS		X.XS			NOZ T A		XXXXS		
REG P	XXXXS		XXXXS					B	XXXXS	
02/N2 CNTL VLV	XXS		XXS	VAC VT NOZ T XXXXS						
H2O TK N2 P	XXXXS		XXXXS	CO2 CNTLR		1XS		2XS		
N2 QTY	XXXXS		XXXXS	FILTER ΔP		X.XXS				
EMER 02 QTY	XXXXS		XXXXS	PPC02		XX.XS				
REG P	XXXXS			TEMP		XXX.XS				
				BED A	PRESS	XX.XS	XX.XS	XX.XS		
IMU FAN	XS XS XS	A B C	ΔP	B	PRESS	XX.XS	XX.XS	XX.XS		
HUMID SEP	XS XS		X.XS	ΔP		X.XXS	X.XXS			
				VAC PRESS		X.XS				(XX)

4947. CRT 3
td_303b_014

Figure 2–12. ENVIRONMENT display (DISP 66)

SM SYS SUMM 1 Display

The SM SYS SUMM 1 display (DISP 78) is available in SM OPS 2 (see Figure 2-13). IMU FAN data are available near the lower left corner of this display. This information is discussed in the thermal control system description.

XXXX/XXX/078				SM SYS SUMM 1			XX X DDD/HH: MM: SS		
EMERGENCY				DDD/HH: MM: SS					
SMOKE	1/A	2/B		DC VOLTS	1/A	2/B	3/C		
AV BAY	1	XX.XS	XX.XS	FC	XX.XS	XX.XS	XX.XS		
	2	XX.XS	XX.XS	MAIN	XX.XS	XX.XS	XX.XS		
	3	XX.XS	XX.XS	CNTL	AB	XX.XS	XX.XS	XX.XS	
dP/dT	±.XXS				BC	XX.XS	XX.XS	XX.XS	
					CA	XX.XS	XX.XS	XX.XS	
CABIN				ESS	XX.XS	XX.XS	XX.XS		
PRESS	XX.XS			AC					
dP/dT-EQ	±.XXS±X.XXS			VOLT	Φ A	XXXX	XXXX	XXXX	
O2 CONC	XXX.XS				Φ B	XXXX	XXXX	XXXX	
PPO2	X.XXS	X.XXS			Φ C	XXXX	XXXX	XXXX	
FAN ΔP	X.XXS			AMP	Φ A	XX.XS	XX.XS	XX.XS	
HX OUT T	XXXX				Φ B	XX.XS	XX.XS	XX.XS	
O2 FLOW	XX.XS	XX.XS			Φ C	XX.XS	XX.XS	XX.XS	
N2 FLOW	XX.XS	XX.XS		FUEL CELL					
IMU FAN	AXS	BXS	CXS	AMPS	XXXX	XXXX	XXXX		
ΔV	FC1	FC2	FC3	REAC VLV	XXS	XXS	XXS		
SS1	XXXX	XXXX	XXXX	STACK T	±XXXX	±XXXX	±XXXX		
SS2	XXXX	XXXX	XXXX	EXIT T	XXXX	XXXX	XXXX		
SS3	XXXX	XXXX	XXXX	COOL P	XXXX	XXXX	XXXX		
TOTAL AMPS	XXXXX			PUMP	XXS	XXS	XXS		
	KW		XXS						
(XX)									

TD3030213. CRT# 2
td_303b_015

Figure 2-13. SM SYS SUMM 1 display (DISP 78)

GND IMU CNTL/MON Display

The GND IMU CNTL/MON display (SPEC 104) is available in GNC OPS 9. This display provides monitoring and control of the preflight IMU calibrations and alignment (see Figure 2-14). Procedurally, the crewmembers never interface with this display. Therefore, it will not be discussed in detail.

XXXX/104/		GND IMU CNTL/MON			XX X	DDD/HH:MM:SS	DDD/HH:MM:SS
IMU	1	2	3				
X	1 XXX.XX	4 XXX.XX	7 XXX.XX		SEL IMU 1	16X	
Y	2 XXX.XX	5 XXX.XX	8 XXX.XX			2 17X	
Z	3 XXX.XX	6 XXX.XX	9 XXX.XX			3 18X	
	0 XXX.XX	XXX.XX	XXX.XX		ATT DET	19X	
M	XXX.XX	XXX.XX	XXX.XX		HNGR CAL A	20X	
I	XXX.XX	XXX.XX	XXX.XX			B 21X	
IR	XXX.XX	XXX.XX	XXX.XX			C 22X	
V X	±XX.XX	±XX.XX	±XX.XX		PREFLT CAL	23X	
Y	±XX.XX	±XX.XX	±XX.XX		GYROCOMP	24X	
Z	±XX.XX	±XX.XX	±XX.XX		XXXX XXXX		
VRSS	XX.XX	XX.XX	XX.XX		INERTIAL	25X	
B HWD	XXXX	XXXX	XXXX		PLAT POS	26X	
I S/W	XX	XX	XX		TERM/IDLE	27X	
TSTAT	XX	XX	XX		28 MM WRITE	X	
					READ	29X	
PWR ON	X	X	X		MM STATUS	XXXX	
I/O	S	S	S				
STBY	10X	11X	12X		30 SITE SEL	X	
OPER	13X	14X	15X		ACTUAL	XXX	
						(XX)	

TD3030214. CRT: 1

td_303b_016

Figure 2-14. GND IMU CNTL/MON display (SPEC 104)

Questions

1. What is the order of the gimbals from outermost to innermost?
2. What is the IMU resolver?
3. What is an accelerometer?
4. How many IMU fans are used to cool the IMUs?
5. True or false. The IMUs are powered by three power sources.

Section 3

System Operations

Performance Objectives

As a result of studying this section, you should be able to do the following:

- Name the two IMU modes of operation
- Explain Reference Stable Member Matrix (REFSMMAT)
- Name the three types of IMU alignments
- Explain when the three types of alignments are available

Modes of Operation

An IMU has two modes of operation, the warmup/standby mode and the operate mode. At powerup, an IMU enters the warmup/standby mode. In this mode, power is applied only to the heater circuits.

Upon achieving its operating temperature, the IMU is in standby. An asterisk will appear next to the standby item number for the IMU on the GND IMU CNTL/MON display (SPEC 104) in GNC OPS 9 or the IMU ALIGN display (SPEC 21) in GNC OPS 2 or 3. Upon reaching the standby mode, the IMU can be moded to operate. Moding to operate by crew command can occur only in GNC OPS 2, 3, or 9 when the displays mentioned above are available.

The IMUs are in operate mode by the time the crew enters the vehicle prelaunch and remain in that state for the duration of the flight, unless taken to standby to help minimize power consumption. While in the operate mode, the IMU maintains its inertial orientation and is used for calibrations, preflight alignment, flight, and on-orbit alignments.

To mode the IMU to operate, the controlling GPC sends the operate discrete to the IMU through the FF MDM. The IMU, upon receiving this command, initiates its startup sequence.

The startup sequence first cages the IMU. Caging refers to the process of reorienting the IMU gimbals and then mechanically locking them into place so that the gyros may begin to spin. By caging the IMU, its platform orientation will be known when it becomes inertial. The IMU-caged orientation is defined as the point at which all resolver outputs are zero. Physically this causes the IMU platform to lie parallel to the NAV base plane with its coordinate axes lying parallel to the NAV base coordinate axes.

Once the IMU gimbals are caged, the gyros begin to spin and power is applied to the remaining IMU components. When the gyros have reached the correct spin rate, the stabilization loops are powered and the IMU becomes inertial. At this time, the IMU returns an “in operate” mode discrete to the GPC, indicating that it has completed the startup sequence. An asterisk will appear next to the OPER ITEM number for the IMU on the GND IMU CNTL/MON display or the IMU ALIGN display. The startup sequence takes approximately 85 seconds.

The IMU can be safely powered off from either the warmup/standby mode or the operate mode. The IMU has a built-in dynamic braking circuit to ensure that caging of the platform gimbals will not occur unless both gyro motors are at zero speed. The time needed to slow the gyro motors with the braking circuit is incorporated in the 85-second startup sequence.

Preflight

The IMUs are taken through three levels of calibration to correct for hardware inaccuracies: factory calibration, hangar calibration, and preflight calibration. Sixty-one IMU parameters are developed during this extensive calibration period. At the completion of the factory calibration, this set of calibration parameters is written to a region of the IMU internal hardware memory, called EEPROM, for internal compensation. Following the storage of calibration parameters to EEPROM, any subsequent testing will result in delta compensation, which is the difference between the whole error and the internally compensated value. These delta compensation terms would then have to be compensated by the GPC and stored in the GPC Mass Memory Units (MMUs). These data can be placed in the GNC major function base (GPC software) by executing the MM READ item number on the GND IMU CNTL/MON display or the IMU ALIGN display.

Prelaunch

About 10 hours before lift-off, the IMUs are taken to the operate mode. They must be aligned preflight and attitude determination has to be accomplished prior to the alignment. Attitude determination is done by using resolver and velocity information to determine the orientation of the NAV base with respect to the North-West-Up (NWU) coordinate frame. The attitude determination submode takes about 4 minutes. The IMUs are aligned first to the local vertical. Then the azimuth is aligned. This alignment takes 38 minutes. Once it is complete, the IMUs go into a continuous align mode. The continuous alignment runs in 8-minute cycles, which is done by measuring the drift for 7 minutes 50.4 seconds and then torquing out the measured errors for 9.6 seconds. Attitude determination, alignment, and continuous alignment make up a three-step sequence that is nominally performed three times prior to launch.

Seven and a half hours before launch, the preflight calibration (cal) of the IMUs is accomplished. The IMUs have been calibrated earlier in the hangar and at the factory, but this cal is used to update the parameters computed in the previous cal. The final cal data is written onto the MMUs.

Once the cal is complete, the IMUs go through the attitude determination, the alignment, and the continuous alignment sequence two more times. Once the last continuous align starts, the IMUs stay in this mode until T-4 min. when the platforms are released and the IMUs enter the inertial mode. At this point the Attitude Direction Indicator (ADI) will flip around since it is now using the IMU data. Once the IMUs are in the free inertial mode, they are flight ready and all IMU functions stay the same throughout the flight.

Note: This is a very simplified explanation. For a detailed explanation refer to the GNC Systems Briefs, Sections 6.3.2.2 and 6.3.2.3.

Ascent

During ascent the IMUs provide accelerometer and resolver data to the GNC software for use in propagating the state vector and determining attitude. There is little IMU data available for crew viewing in the OPS1 software, but two displays provide status indications and selection filter controls. The PASS GNC SYS SUMM 1 display indicates any RM action or commfaults for each IMU. PASS GNC OVERRIDE (SPEC 51) allows crew selection/deselection of each IMU and displays the following: RM action (fail or dilemma), commfault, BITE, IMU currently selected for attitude data, and, in the case where no IMU is selected for attitude (three IMUs failed), display of “RGA,” to indicate that Rate Gyro Assembly (RGA) output data are being used to determine attitude.

Orbit

During the orbital phase of flight, the IMUs continue to provide GNC software with attitude and accelerometer data, but use of the accelerometer data for propagating the NAV state vector depends on two criteria.

First, the use of IMU accelerometer data can be manually controlled by a software “switch” available on two displays. This “switch” is labeled AVG G ON and may be enabled or disabled, thereby allowing NAV software to use or not to use, respectively, IMU accelerometer data. AVG G ON is located on the REL NAV display (Major Mode (MM) 201, SPEC 33) and on the FCS/DED DIS C/O display (MM 801, OPS display) and is nominally always enabled. In MM 202, AVG G ON is always enabled, thereby ensuring that a targeted maneuver cannot be done without NAV knowing about it.

Secondly, IMU accelerometer data must exceed a threshold before it will be used to propagate the NAV state. This threshold is called the NAV ΔV THRESH and is an I-loaded value displayed on the IMU ALIGN display (SPEC 21). The displayed value uses units of micro-g’s over a NAV cycle (one NAV cycle is a software execution time of 3.84 seconds). The current I-loaded value is 3840, which is 1000 micro-g’s, since a NAV cycle is 3.84 seconds.

On-orbit alignments are necessary to correct platform misalignment caused by uncompensated gyro drift. Recall that the GPC will compensate the predicted drift of the IMU by continuously pulse-torquing the IMU. However, there will still be a small amount of drift. We will correct the misalignment caused by this drift by performing an IMU alignment. These are usually performed once a day to ensure minimal misalignment of the IMUs. Three options are available to align the IMUs. Before these options are discussed, an understanding of REFSMMAT is needed.

Reference Stable Member Matrix

A REFSMMAT is simply a 3 by 3 transformation matrix that enables measurements from one coordinate system to be expressed in another. For the orbiter, this transformation allows attitude measurements in the platform coordinate system to be expressed in the M50 coordinate system. In equation form it looks like this:

$$\begin{bmatrix} \bar{X} \\ \bar{Y} \\ \bar{Z} \end{bmatrix}_{\text{M50}} = \text{REFSMMAT} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{PLATFORM}}$$

Three REFSMMATs are defined for each IMU. Two are always present in GPC memory, while the third is computed to support IMU alignments.

The **current** REFSMMAT defines the orientation of the IMU platform at the end of the previous alignment. It resides in the GPC Common Datapool (COMPOOL) and is used by GNC software for determining attitude, velocity, instrument Line-of-Sight (LOS), and other pointing computations. The IMU software always assumes that the IMU platform is aligned to this orientation despite uncompensated drift. The initial **current** REFSMMAT is computed at the end of the velocity/tilt initialization just prior to the platform release to inertial operation during the prelaunch phase.

The **desired** REFSMMAT defines the preferred IMU platform orientation at the end of the next star alignment or IMU/IMU alignment. It is resident in the IMU alignment software and may be changed by uplink.

The **present** REFSMMAT relates the present orientation of the IMU to a reference, which is determined by the align option selected. If STAR ALIGN or a MATRIX align option is selected, the **present** REFSMMAT is computed relative to the stars acquired for the alignment. If IMU/IMU alignment is selected, this REFSMMAT is computed relative to the selected reference IMU.

IMU Alignment Options

STAR ALIGN

The IMUs are normally aligned using this mode. Data are normally collected on two stars by the star trackers. The data can be obtained by maneuvering the orbiter to an attitude such that a known star appears in each star tracker. It is usually obtained by allowing the star trackers to randomly select “stars of opportunity” to be used for IMU alignments. If the star trackers are unavailable, data can be collected by manually sighting on stars through the Head Up Display (HUD) or Crew Optical Alignment Sight (COAS).

These data are used to compute the measured LOS vectors to the two sighted stars with respect to the **current** REFSMMAT of each IMU. These vectors and the ideal LOS vectors stored in software are then used to compute the **present** REFSMMAT for each IMU to be aligned. The **present** REFSMMAT and the **desired** REFSMMAT are then used to compute the torquing angles displayed on the IMU ALIGN display. These angles update every 60 seconds if the alignment has not been initiated. When the alignment is initiated, the gyros are pulse-torqued,

causing the platform to move at a slow rate (.007deg/sec) to remove the misalignment. Once this is completed, the **current** REFSMMAT is set equal to the **desired** REFSMMAT.

The crew procedure for executing this type of alignment is located in the Orbit Ops Checklist of the Flight Data File (FDF), GNC Section, titled IMU ALIGN – S TRK. An example of this procedure is given in Figure 3–1.

IMU ALIGN – S TRK, GNC 201, 301

1. COLLECT STAR DATA
 √DAP: A1/AUTO/VERN (PRI)
GNC 22 S TRK/COAS CNTL
 CRT √S TRK –Y,–Z: STATUS – (no BITE)
 SHUTTER – OP

 * If SHUTTER – CL: *
 * √Att,MET – correct *
 * Visually verify no bright object in FOV *
 * After data collected and before changing *
 * attitude return shutter to AUTO *
 * To open shutter: *
 * MAN OP – ITEM 15(16) EXEC (*) *
 * To return shutter to AUTO: *
 * MAN OP – ITEM 15(16) EXEC (no *) *
 If reqd ID – other than 0:
 STAR TRK – ITEM 3,4 EXEC (*)
 Wait for TERM/IDLE (*), then:
 S TABLE CLR – ITEM 20 EXEC
 √STAR TRK – ITEM 3,4 EXEC (*)

2. VERIFY STAR DATA
 √S TABLE: TRK ID 1,2 – (correct #s)
 ANG ERR 1 – ≤ .08, Rcd ____ . ____ ____
 SEL, ITEM 17,18 – (*)
 Wait approx 1 min for new IMU ΔANGs

 * If no data after 3 min or bad data: *
 * √Att,stars,MET – correct *
 * √Rot Rate – ≤.5 deg/sec *
 * √S TRK –Y,–Z: TRK ID – (correct #s) *
 * ΔANG – <1.0 *
 * If preceding checks are good: *
 * Perform S TRK SELF–TEST, then; *
 * If both STATUS – ST FAIL: *
 * | Inform MCC before proceeding *
 * If both STATUS – ST PASS: *
 * | Repeat step 1 at new att, stars *
 * If one STATUS – ST PASS: *

Cont next page

Figure 3–1. Orbit Ops checklist, IMU ALIGN–S TRK procedure

- * √TERM/IDLE, ITEM 9(10) – (*) *
- * STAR TRK, GOOD S TRK – ITEM 3(4) EXEC (*) *
- * S TABLE CLR – ITEM 20 EXEC *
- * √S TABLE: TRK ID 1 – (correct #) *
- * TERM/IDLE, GOOD S TRK – ITEM 9(10) EXEC (*) *
- * Mnv to 2nd att, star *
- * STAR TRK, GOOD S TRK – ITEM 3(4) EXEC (*) *
- * Repeat step 2 with good S TRK only *

3. CHECK IMU ΔANGs

GNC 21 IMU ALIGN

CRT

- √ IMU 1,2,3: STAT – blank
- √ STAR ALIGN, ITEM 13 – (*)
- √ ANG 1,2,3: ΔX,ΔY,ΔZ – ≤ .80

Rcd ANG	1	2	3
ΔX()	_____	_____	_____
ΔY()	_____	_____	_____
ΔZ()	_____	_____	_____

- * If ANG ΔX, ΔY or ΔZ > .80 for two or *
- * more IMUs, repeat steps 1,2,3 *

CAUTION

If ANG ΔX, ΔY or ΔZ still >.80 for 2 or more IMUs:
DO NOT TORQUE PLATFORMS
EXCEPT UNDER MCC INSTRUCTIONS

4. ALIGN IMUs

- ALIGN IMU 1(2,3) – ITEM 10(11,12) EXEC (*)
- EXEC – ITEM 16 EXEC (*), Rcd MET ___/___:___
- √ EXEC, ITEM 16 – (no *)

5. S TRK CONFIG VERIFICATION

GNC 22 TRK/COAS CNTL

CRT

- √S TRK –Y(–Z): Reqd ID, ITEM 11(12) – 0
- √Shutter not MAN OP, ITEM 15,16 – (no *)

6. Report IMU align results

Figure 3–1. Concluded

IMU/IMU ALIGN

The IMU/IMU alignment mode uses an IMU as a reference in place of LOS vectors to stars (as in STAR ALIGN). The IMUs to be aligned use the reference IMU to compute a **present** REFSMMAT. The **present** REFSMMAT and the **desired** REFSMMAT of each IMU are used to compute the torquing angles on the IMU ALIGN display. When the alignment is initiated, the platform is slewed and/or pulse–torqued to remove the misalignment.

If the misalignment is greater than 1°, the IMU platform is slewed to within 1° of its desired orientation. Once it reaches this point, it continues to slew for 19.84 seconds in one direction and then 19.84 seconds in the reverse direction. This is done to remove any directional sensitivity. When slewing is complete, the platform is pulse-torqued until the misalignment is nulled, and again, the **current** REFSMMAT is set equal to the **desired** REFSMMAT.

If the misalignment is less than 1°, the platform is pulse torqued to remove the misalignment. When completed, the **current** REFSMMAT is set equal to the **desired** REFSMMAT.

If the reference IMU is to be aligned, it is done after the alignment of the other IMUs. It is accomplished in the same manner, with the lowest numbered nonreference IMU in the operate mode acting as the next reference while alignment of the previous reference occurs. Usually the reference IMU will not require alignment (since declaring it as a reference implies it is correctly aligned). However, if the **desired** REFSMMAT has been updated, all three IMUs will be reoriented by the new REFSMMAT; therefore, all three should be selected for alignment.

Since this alignment mode is the only one that uses the IMU slew capability, it will be used when applicable to remove large misalignments. The procedure for performing this type of alignment is also located in the Orbit Ops Checklist, GNC section. It is titled IMU ALIGNMENT – IMU/IMU. An example is given in Figure 3–2.

MATRIX ALIGN

The MATRIX ALIGN gives the crew the capability to use star data collected by the star trackers, HUD, or COAS to update the **current** REFSMMAT instead of physically realigning the platform. In this case the **present** REFSMMAT is determined in the same manner as during a star alignment. The torquing angles displayed are computed from the **current** and **present** REFSMMAT of each IMU instead of the **desired** and **present** REFSMMAT. When the alignment is initiated, the **current** REFSMMAT is set equal to the **present** REFSMMAT. Since there is no platform movement, this alignment is instantaneous. However, since the **desired** REFSMMAT is not used, the relative skew is not optimum for RM purposes. The IMUs are still completely usable and an IMU/IMU alignment or star alignment may be used later to reinstate the **desired** REFSMMAT.

This type of alignment is not performed in nominal operations. Therefore, it is located only in the Systems Malfunction Procedures Volume of the FDF, GNC Section.

IMU ALIGNMENT – IMU/IMU

NOTE

Procedure must be accomplished
in GNC OPS 2 or MM301

GNC 21 IMU ALIGN

IMU/IMU – ITEM 14 + __ EXEC

ΔX ()¹____()²____()³____

ΔY ()____()____()____

ΔZ ()____()____()____

ALIGN IMU 1(2,3) – ITEM 10(11,12) EXEC (*)

EXEC – ITEM 16 EXEC (*),

Rcd MET ____/____:____

NOTE

Align will require 3–6 min

Report IMU align results

VERIFY GOOD IMU/IMU ALIGNMENT

- √ EXEC, ITEM 16 – (no *)
- IMU/IMU – ITEM 14 + (SAME REF IMU) EXEC
- √ IMU 1,2,3 ANG ΔX , ΔY , ΔZ < 0.13
 - * If ANG ΔX , ΔY , ΔZ \geq 0.13, *
 - * Report to MCC *

If in GNC OPS 2 or MM 301,
STAR ALIGN – ITEM 13 EXEC (*)

Figure 3–2. Orbit Ops checklist, IMU ALIGNMENT–IMU/IMU

Entry

During entry, IMU operation differs only in the manner in which accelerometer data are used by NAV. This is discussed in the Navigation Workbook.

As stated previously, SPEC 21 is available throughout OPS 3. However, all IMU alignment options are not. STAR ALIGN and MATRIX ALIGN are available only in major mode 301. IMU/IMU ALIGN is available in all OPS 3 major modes.

Questions

1. List the two IMU modes of operation.
2. What is a REFSMMAT?
3. Name the three types of IMU alignments. Which one is normally used?
4. All three alignment types are available in all of OPS 3. True or false.

Section 4

System Malfunctions

The IMUs, like all redundant sensor systems, have a software scheme designed to select the best data for use by the GPCs and to detect system failures. This scheme is called IMU RM.

Performance Objectives

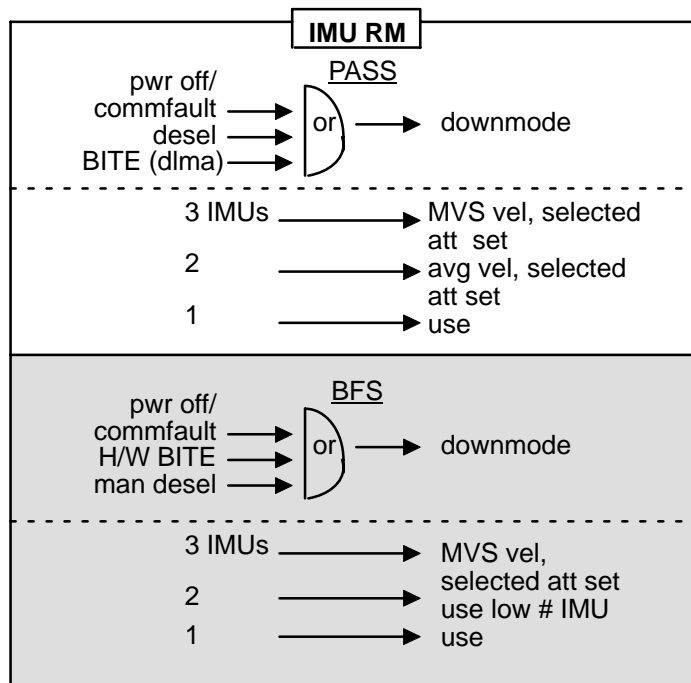
As a result of studying this section, you should be able to do the following:

- Describe the IMU RM scheme
- Explain the purpose of the attitude Selection Filter (SF) and the velocity SF
- Explain the purpose of the Fault Detection, Identification, and Reconfiguration (FDIR)

Redundancy Management Scheme

The IMU RM scheme consists of an SF and FDIR software. The SF selects the best data from the available IMUs. FDIR searches for faulty data, attempts to identify the IMU producing this data, and if successful, reconfigures the SF to exclude data from the faulty IMU.

The following diagram from the Ascent Pocket Checklist shows an overview of IMU RM. The top block indicates the requirements for an IMU to be available for use. The second block shows how they are used based on the number of IMUs available. The remainder of this section is a more detailed explanation of RM.



The IMU RM software is divided into two distinct areas, attitude RM and velocity RM.

The first step in both attitude and velocity RM is to determine which IMUs are candidates for RM processing. Candidacy is determined from the following criteria:

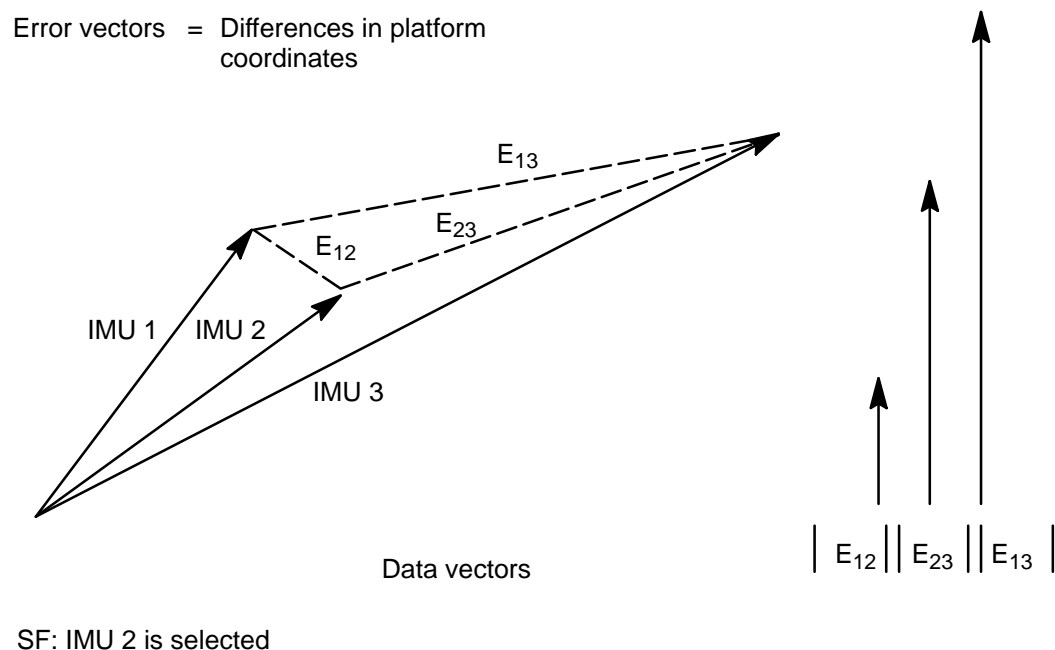
- No manual deselection – The IMU has not been deselected by the crew.
- No commfault – The GPC has not bypassed IMU data.
- No current failure – The IMU has not been previously failed by RM (i.e., automatically deselected).
- No slewing – The IMU is not being slewed during an IMU/IMU alignment.

If all of the above criteria apply, the IMU is a candidate for use by RM.

There is no FDIR software processing if only one IMU is available. Any IMU will continue to operate if it is deselected manually or declared failed by RM.

Attitude Redundancy Management

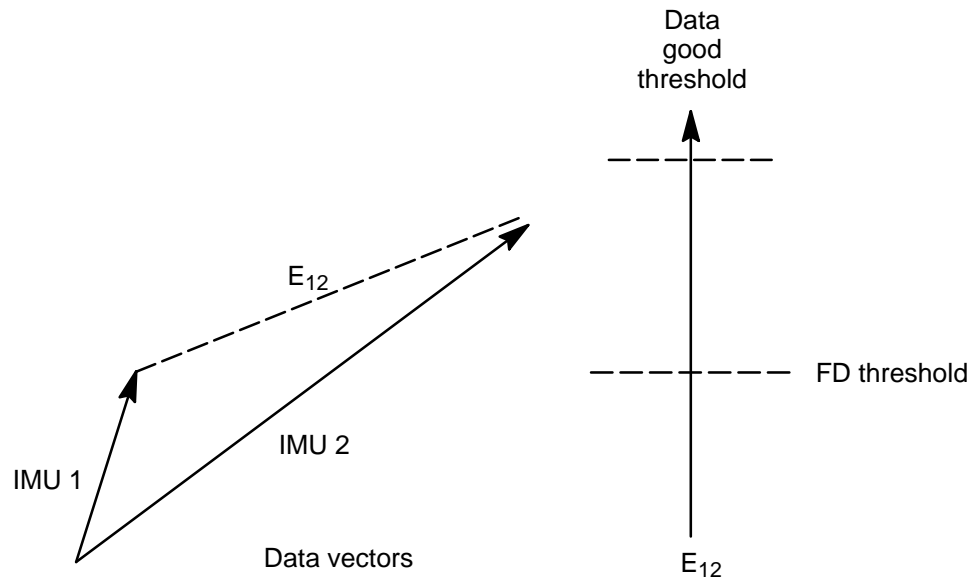
The purpose of the attitude SF is to select one IMU as the attitude source for the GNC software. If there are three candidate IMUs, the SF uses a Midvalue Select (MVS) scheme (see Figure 4–1). The SF calculates the misalignment between each pair of IMUs. It then finds the largest of these values. The IMUs that produced this misalignment are obviously the farthest apart, so the IMU that is not part of this maximum value is the middle value IMU and is used as the attitude source.



td_303b_017

Figure 4–1. IMU three-level attitude selection filter

If only two IMUs are candidates, the SF calculates the misalignment between the two IMUs (see Figure 4–2). This value is compared to the I-loaded attitude data good threshold. This value is 1° for ascent and orbit operations and 2.5° for entry.



SF: The selected IMU is left unchanged from its previous value if this IMU is a candidate; otherwise, the selected IMU is set equal to the lowest-numbered candidate IMU

td_303b_018

Figure 4–2. IMU two-level attitude selection filter

If the misalignment is greater than the attitude data good threshold, the attitude data good flag is set bad, causing the attitude processor to exclude IMU data in its attitude computations. Also, if this threshold is violated, FDIR processing increases from 1/16 Hz to 1 Hz to try to isolate which of the two IMUs has the failure. On orbit, this causes the Digital Autopilot (DAP) to downmode to free drift, since no attitude data are available to the GNC software.

During ascent and entry, the attitude processor will use RGA data to maintain attitude control. When this is the case, “RGA” will be displayed under the IMU attitude source on the GNC OVERRIDE display.

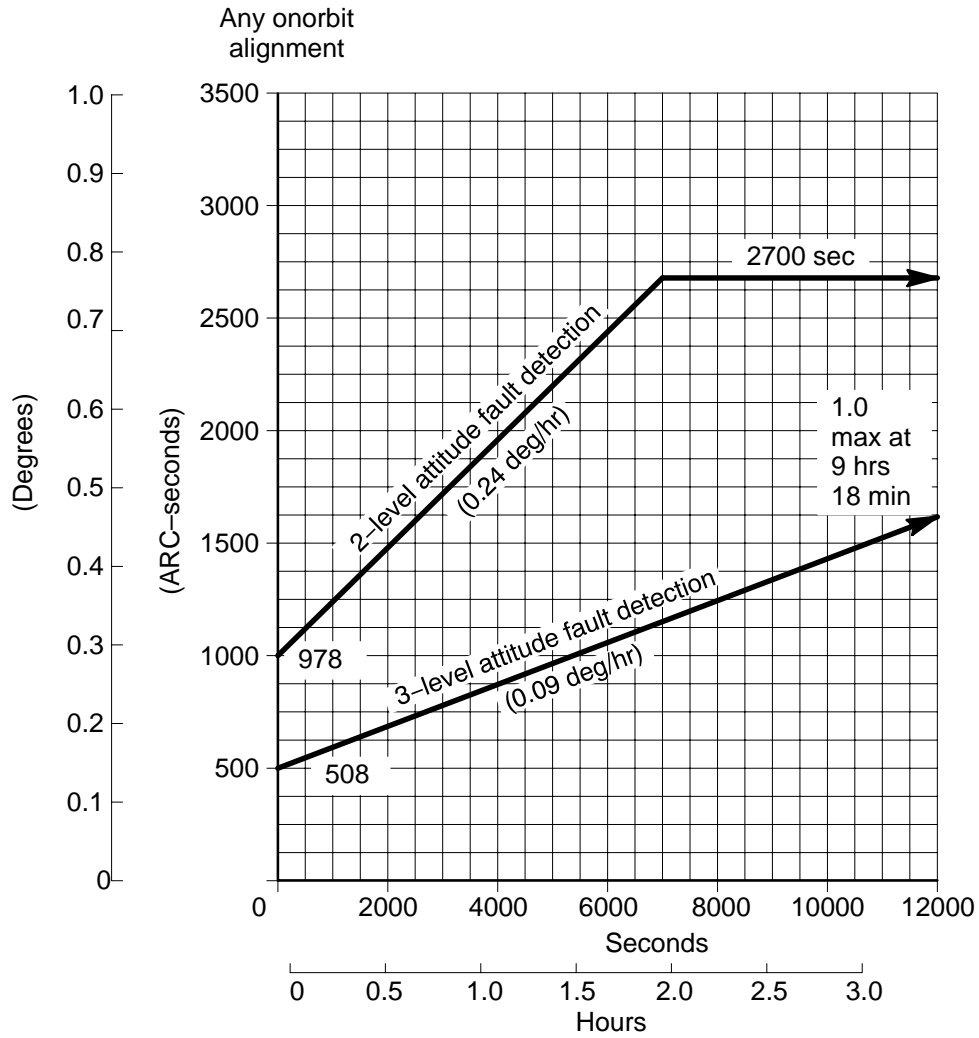
If the misalignment is less than the attitude data good threshold, the IMU used as the last attitude source is selected. If it is not available, the lowest numbered available IMU is chosen.

If only one IMU is a candidate, its data is used, unless during OPS 2 or 8 it has a BITE indication. If this is the case, the attitude data good flag is set bad. In OPS 1 or 3, with a BITE against the one IMU, its data continue to be used.

If no IMUs are candidates, the attitude data good flag is set bad.

Once an attitude source has been selected, the FDIR starts processing. If three IMUs are candidates, the misalignments computed in the SF are compared to the three-level Fault Detection (FD) threshold. This threshold is reinitialized at the end of any IMU alignment and increases with time to a maximum, at which point it remains constant. Figure 4–3 is a typical

FD threshold chart for attitude. If the misalignment for a given IMU pair exceeds the threshold, a miscompare flag is set that is sent to the fault identification software.



td_303b_019

Figure 4-3. Typical attitude FD thresholds, time from any on-orbit alignment

The three-level FDIR software checks the number of miscompare flags. If only two flags are present, the software records the number of the IMUs that are common to the two flags and starts a counter. No failure is annunciated unless there are three consecutive execution cycles through the FDIR software that identify the same IMU as the cause of the miscompares. If this is the case, IMU RM declares the IMU failed and deselects it from the SF. A class 3 SM alert will be annunciated along with an RM FAIL IMU fault message. The FDIR software runs at a 1/16 Hz rate, so an attitude failure will require 48 seconds to be isolated.

If two IMUs are candidates, a new FD threshold is computed. The misalignment between the two IMUs is recomputed using a different equation, and the two are compared. If the misalignment exceeds the threshold, a miscompare flag is sent to FDIR software.

If a miscompare flag is present, the two-level FDIR software checks for a BITE failure on both IMUs. If a BITE is present on only one IMU, it is recorded in the counter. Again, three consecutive passes with the BITE indication present will cause the IMU to fail. If both IMUs, or neither IMU, have a BITE, the software looks for failures in the gyros. It will attempt to isolate the misalignment to the drift of a single gyro. After three cycles if the problem cannot be identified, FDIR will issue an RM Dilemma (DLMA). The redundant gyro monitor is then used to solve the dilemma. FDIR will solve an attitude DLMA by identifying the IMU with the highest rate on the redundant gyro.

Velocity RM

The purpose of the velocity SF is to select the best available data from the IMUs for use in propagating the orbiter State Vector (SV). To minimize velocity errors sent to nav, a rectification cycle is present. Rectification causes the velocity of each IMU to be set equal to the total velocity used by NAV every 8 seconds. This rectification is done by computing a bias which is added to the IMU sensed velocity, allowing IMUs that were temporarily out of the RM scheme to be reselected without causing bad data to be used in propagating the SV.

If three IMUs are candidates, the SF midvalue selects the total velocity vector from the three biased IMU velocity vectors (see Figure 4-4). The MVS scheme is done on a component-by-component basis, which could result in selection of one component from each IMU. If two IMUs are candidates, the SF computes a velocity error vector between the two IMUs, based on the current and the previous cycle measurements. This error vector is compared to the velocity data good threshold.

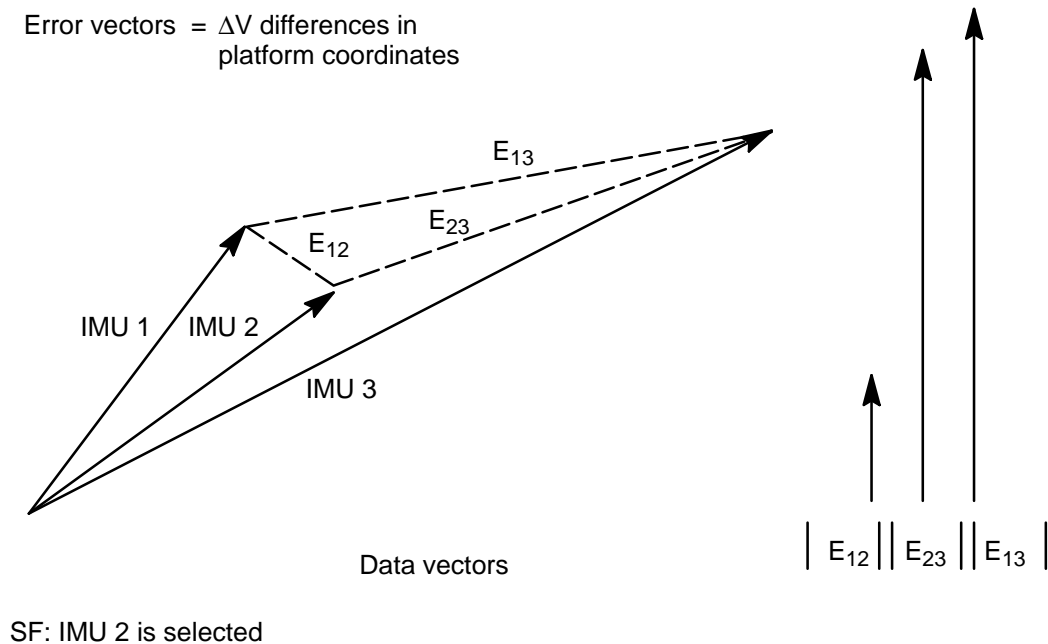
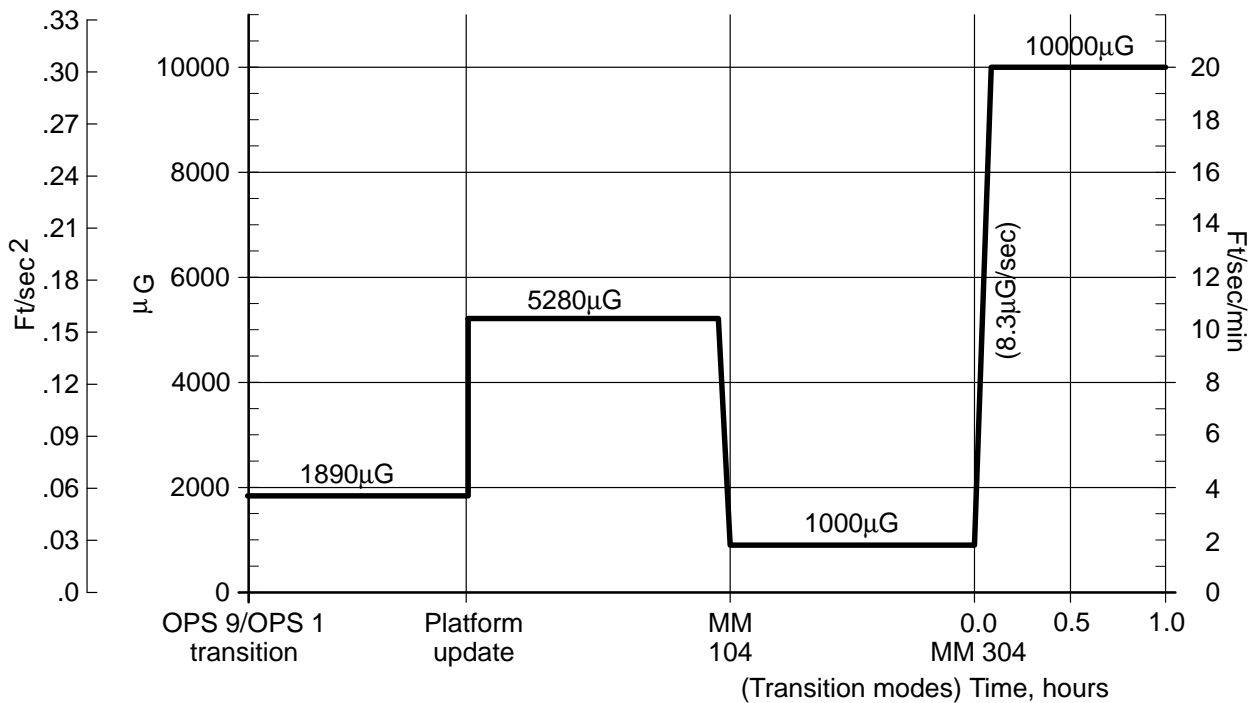


Figure 4-4. IMU three-level velocity selection filter

If the error vector is greater than the threshold, the SF looks for a BITE indication on both IMUs. If only one IMU has a BITE indication, the SF downmodes to one good IMU (the IMU without the BITE) and it is used as the velocity source for nav. If no BITE indication is present, the RM software attempts to isolate the problem to one of the accelerometers. If it can be isolated, a downmoding again occurs. If not, or if both IMUs have BITE indications, or if the error vector is less than the threshold, the velocities of the two IMUs are averaged to compute the total velocity.

If only one IMU is a candidate, its data are used. If no IMUs are candidates, the last sample of data from the previously selected IMU is used.

The velocity FDIR software uses the same logic as the attitude FDIR software, except only two consecutive passes are required to fail an IMU or annunciate a dilemma. Also, no redundant gyro monitor is available to solve velocity DLMA's, and the data will continue to be averaged until the crew deselects one of the two IMUs. (Figure 4-5 is a typical FD threshold chart for velocity.)



td_303b_021

Figure 4-5. Typical velocity fault detection threshold

Thermal Control System

Two types of failures can affect the thermal control system, fan failures and internal heater failures. Fan failures are not as critical since the fan system is a triply redundant system. If a fan fails, either of the other two fans can be powered up to support IMU cooling. A heater system failure is more critical, but it should not cause loss of the IMU.

Since the IMU electronics are highly temperature sensitive, a failed-on or -off heater will cause degraded IMU performance, since the IMU will not be operating at its design temperature. Through GNC telemetry, the MCC should see a heater failure problem well in advance of failure annunciation (depending on telemetry availability) in the form of off-nominal gyro drifts and accelerometer biases. If the problem is a heater failed on, a backup thermostat will open at a higher temperature and the IMU temperature will stabilize at that point; therefore, the gyro drifts and accelerometer biases will stabilize, enabling the MCC to compute and uplink (into IMU software) compensation for each, thereby making the IMU usable. Likewise, if the heater fails off, the same results will be attained and the same actions can be taken.

Data Path Failures

As stated before, IMUs are linked to GPCs through FF MDMs (see Figure 4-6). For an IMU in the OPER mode, GPC IMU software sends torquing commands, gyro bias compensation, slew commands, and an accelerometer scale factor in the form of two input data words. The IMU returns BITE status, resolver data, and velocity data to the GPC in the form of 14 output data words.

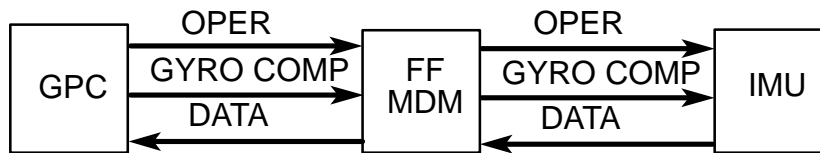


Figure 4-6. GPC/FF MDM/IMU data path

Failures in this data path between the IMU and GPC necessitate the execution of procedures in an attempt to regain the data path. Some procedures contain a step in which the affected IMU is deselected from RM.

This is done because of the possibility that velocity data from that IMU that has not been rectified might be selected for navigation. Rectification is explained as follows: The SF provides a selected total velocity to NAV in M50 coordinates. These total velocities are rectified every 8 seconds to limit the errors sent to NAV. Rectification involves calculating the difference between the total velocities from each IMU and the selected total velocity. This difference for each IMU is then added to the total velocities for each IMU every 8 seconds. This results in agreement between the total velocities from each IMU and the selected total velocity every 8 seconds. The bias computed at a given rectification cycle is applied to each IMU total velocity until the new computation on the next rectification cycle.

Therefore, if the IMU is deselected while the data path is being recovered, by the time it is reselected after data path recovery, its velocity data will have been rectified.

At the three-level (i.e., all three IMUs are being used by RM), failure to deselect an IMU presents no problem since RM uses MVS to determine the total velocity vector. It does become a problem when one or two IMUs have failed or have been deselected.

The scheme used here to compute the total velocity vector is either averaging the two remaining IMU velocity vectors or using that of the lone IMU. It can be seen how a bad velocity vector in one of the remaining IMUs or the lone IMU will cause SV problems.

The IMU OPER discrettes are channeled through FF1, 2, and 3 MDMs to IMUs 1, 2, and 3, respectively. They are normally in the ON or "1" state. A loss of this discrete for 8–14 seconds causes an IMU to go to standby, which makes it useless (it will cage when moded to operate) until it is realigned.

In the case of a GPC failure, the OPER discrete output from the GPC fails to "0." However, the FF MDM latches its OPER discrete to the IMU at the last value ("1"); therefore, the IMU maintains the OPER mode.

FF MDM data path problems are annunciated by the fault message, I/O ERROR FFx (where x is 1, 2, 3, or 4). A data path failure due to loss of MDM power will result in loss of the OPER discrete, since MDM power is required to maintain output. A data path failure between the MDM and the GPC will not cause loss of the OPER discrete.

In all instances where the IMU does lose the OPER discrete, a BCE STRG x IMU fault message will be annunciated indicating that the IMU is not in OPER. Once back into inertial operation, the caged IMU must be realigned before being included in the selection filter. The IMU has a total time of 84 seconds from loss of OPER mode until back into inertial operation, awaiting realignment.

An operating IMU is constantly pulse torqued by digital command from the GPC to remove known drift (gyro bias compensation). This drift is characteristic of individual IMUs and is measured during ground calibration. Data path failures prevent these torquing pulses from reaching the IMU, causing it to drift at its noncompensated rate. An IMU could operate for a long period without GPC pulse torquing because most of the IMU compensation is housed in the Electrically Erasable Programmable Read Only Memory (EEPROM) hardware memory.

Questions

1. What comprises the IMU RM scheme?
2. What is the purpose of the attitude SF and the velocity SF?
3. What is the purpose of the FDIR?
4. List the two types of failures that can affect the thermal control system.

Section 5

Differences in the BFS

Performance Objectives

As a result of studying this section, you should be able to do the following:

- Describe the BFS RM scheme
- Describe how the BFS will downmode an IMU (from SF candidate)

BFS design requirements do not dictate support of all IMU operations. The BFS will not control the IMUs during warmup, the startup sequence, calibration, or alignments. BFS assumes that, upon being engaged by the crew, the IMUs are in inertial operation and properly aligned.

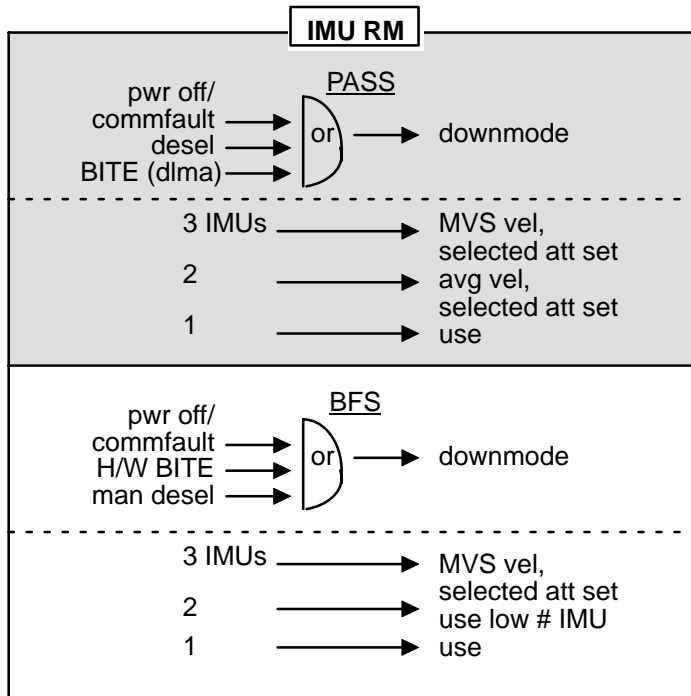
Preengage, the BFS IMU Hardware Interface Program (HIP) processes the available accelerometer and resolver data and provides them to other BFS programs. All gyro compensation and torquing are performed by the PASS.

Postengage, the BFS IMU HIP continues processing the available data, but it also uses preflight calibration data, transferred during its Initial Program Load (IPL) process along with PASS-calculated IMU calibration data sent at the one-shot transfer, to periodically torque the gyros to correct drift.

Upon BFS engage, commands are sent to the IMUs to stop any slewing, set the accelerometer scale factors to low, and halt all non-BFS initiated torquing commands. BFS also sends the IMU operate discrete to ensure that the IMUs do not downmode to standby during the engage process.

The BFS does not have a sophisticated IMU RM scheme like PASS. Its RM scheme consists of an SF with no FDIR. If there are three good IMUs (no previous deselections), the SF selects the midvalue on a component-by-component basis for the selected velocity vector and selects an attitude source. This resembles the three-level scheme in PASS. The BFS will downmode an IMU (from SF candidate) by (1) crew manual deselection, (2) IMU poweroff or commfault, or (3) a hardware BITE. If deselection occurs, the lowest numbered nonfailed IMU is selected as the velocity and attitude source. At the one-level (i.e., two IMUs have been deselected), the remaining IMU is the data source. The BFS will never return to the three-level SF after the first downmoding except when the BFS is moded through OPS 000. Crew manual deselections are carried across OPS transitions.

The following diagram from the Ascent Pocket Checklist shows an overview of BFS IMU RM.



The BFS does not recognize PASS IMU RM failures. If PASS downmodes an IMU, it will have to be manually deselected in the BFS. When an IMU is deselected in the BFS, a class 3 SM alert is annunciated along with an RM FAIL IMU fault message on a Cathode-ray Tube (CRT) driven by the BFS.

IMU information in the BFS is available on two displays. BFS OVERRIDE display (SPEC 51) provides the crew with the capability to deselect/reselect IMUs from the SF (see Figure 5-1). SPEC 51 also provides insight as to which IMU the BFS is using for attitude. Execution of the appropriate item number (item 25, 26, or 27) causes deselection of the particular IMU, and this is indicated by an asterisk. A subsequent reexecution of the item number reselects the IMU and the asterisk will be removed. Commfaults are not indicated on this display.

The other display with IMU information is the BFS GNC SYS SUMM display (DISP 18) (see Figure 5-2). This display provides information on any IMU deselection and commfault. A down arrow (↓) indicates the particular IMU that has been deselected for any one of the BFS deselection criteria. If the status area is blank, that particular IMU is usable.

```

XXXX/051/          OVERRIDE          XX X DDD/HH:MM:SS
                                     BFS DDD/HH:MM:SS
ABORT MODE          ENTRY FCS
TAL                1X          ELEVON  FILTER  ATMOSPHERE
ATO                2X          AUTO 17X  NOM 20X  NOM 22X
ABORT              3X          FIXED 18X ALT 21X  N POLE 23X
MAX THROT         4X          SSME REPOS 19 XXX  S POLE 24X

PROPLT DUMP        IMU DES ATT      AA  RGA  SURF
XXX ICNCT 5 XXXX   1 25X X  LRU DES  DES  DES
OMS DUMP           2 26X      1 31X  35X 39X
ARM                3 27X      2 32X  36X 40X
START              6X          3 33X  37X 41X
STOP               7X          4 34X  38X 42X
9 QUAN/SIDE XXX   OMS DUMP TTG XXX

AFT RCS 13 XXX    ET SEP           VENT DOOR CNTL
14 TIME XXX      AUTO 28X          OPEN 43X
                SEP 29X          CLOSE 44X

FWD RCS 15 XXX    ET UMB DR
16 TIME XXX      CLOSE 30X

( XX)

```

TD3030501. CRT# 5
td_303b_022

Figure 5-1. BFS OVERRIDE display (SPEC 51)

```

XXXX/XXX/018      GNC SYS SUMM 1    XX X DDD/HH:MM:SS
                                     BFS DDD/HH:MM:SS

SURF  POS  MOM  DPS  1 2 3 4
L OB  XXX.X  XXS  MDM FF S S S S
  IB  XXX.X  XXS      FA S S S S
R IB  XXX.X  XXS      PL S S
  OB  XXX.X  XXS

AIL  XXX.X
RUD  XXX.X
SPD BRK XXX.X
BDY FLP XXX.X

MPS  L  C  R  NAV  1 2 3 4
HE TK P XXXXS XXXXS XXXXS TMU S S S
REG P A XXXXS XXXXS XXXXS TAC S S S
      B XXXXS XXXXS XXXXS ADTA S S S S
dP/dT XXXS XXXS XXXS
ULL P LH2 XX.XS XX.XS XX.XS
      LO2 XX.XS XX.XS XX.XS

MPS PNEU HE P MANF P
TK XXXXS LH2 XXXS
REG XXXXS LO2 XXXS
ACUM XXXXS

( XX)

```

TD3030502. CRT# 2
td_303b_023

Figure 5-2. BFS GNC SYS SUMM 1 display (DISP 18)

Questions

1. What comprises the BFS RM scheme?
2. How will the BFS downmode an IMU (from SF candidate)?

Appendix A

Acronyms and Abbreviations

A/D	Analog/Digital
ACC, ACCEL	Acceleration, Accelerometer
ANG	Angle
AOA	Abort–Once–Around
ATT	Attitude
AUTO	Automatic
AVG	Average
BCE	Bus Control Element
BFS	Backup Flight System
BITE	Built–in Test Equipment
C&W	Caution And Warning
C/O	Checkout
cal	calibration
cb	circuit breaker
CL	Close
CNTL	Control
COAS	Crew Optical Alignment Sight
COMP	Compensation
COMPOOL	Common Datapool
CPLT	Complete
CRT	Cathode–ray Tube
D&C	Display And Control
DAL	Digital Accelerometer Loop
DAP	Digital Auto Pilot
dc	direct current
DED	Dedicated
deg	degrees
DES	Deselect
DEU	Display Electronics Unit
DISP, DIS	Display
DLMA	Dilemma
DPS	Data Processing System
E	Error Vector
EEPROM	Electrically Erasable Programmable Read Only Memory
ENA	Enable

ERR	Error
EXEC	Execute
FCS	Flight Control System
FD	Fault Detection
FDIR	Fault Detection, Identification, and Reconfiguration
FDF	Flight Data File
FF	Flight Forward
g	acceleration due to gravity
GNC	Guidance, Navigation, and Control
GND	Ground
GPC	General Purpose Computer
GYROCOMP	Gyrocompensation
H/W (HDW)	Hardware
HI	High
HNGR	Hangar
HUD	Head Up Display
I/O	Input/Output
ID	Identification
IMU	Inertial Measurement Unit
IPL	Initial Program Load
LCC	Launch Control Center
LO	Low
LOS	Line-of-Sight
M50	Mean of 1950
micro-g	microgravity
MCC	Mission Control Center
MDM	Multiplexer/Demultiplexer
MET	Mission Elapsed Time
MM	Mass Memory
	Major Mode
MMU	Mass Memory Unit
MNVR	Maneuver
MON	Monitor
MVS	Midvalue Select
NAV	Navigation
NWU	North-West-Up

OP	Open
OPER	Operate
OPS	Operational Sequence Operations
P	Pitch Pressure
PASS	Primary Avionics Software System
PLAT	Platform
PREFLT	Preflight
PWR	Power
R/W	Read/Write
R(X)	Resolver
RCS	Reaction Control System
RDY	Ready
REFSMMAT	Reference Stable Member Matrix
RGA	Rate Gyro Assembly
RGM	Redundant Gyro Monitor
RM	Redundancy Management
RPC	Remote Power Controller
S/W	Software
SEL	Select
SF	Selection Filter Scale Factor
SM	Systems Management
SOP	Subsystem Operation Program
SPEC	Specialist Function
SSR	Single-system Recovery
ST	Self-test
STAT	Status
STBY	Standby
STRG	String
SUMM	Summary
SYS	System
TCS	Thermal Control System
TERM	Terminate
THRESH	Threshold
TRANS	Transmission
TRK	Tracker

VEL
VERN

Velocity
Vernier

Appendix B

Answers

Answers to Section 1

1. The IMU provides inertial attitude and velocity data to the GNC software functions.
2. There are three IMUs installed onboard the orbiter.

Answers to Section 2

1. The gimbal order from outermost to innermost is outer roll, pitch, inner roll, and azimuth.
2. The IMU resolvers are electromechanical devices that use the principle of magnetic induction to electrically measure the angle between two adjacent gimbals.
3. An accelerometer is basically a force rebalance type instrument. When the accelerometer experiences an acceleration along its input axes, it causes a pendulum mass displacement.
4. One fan is used to cool the IMUs. There are three IMU fans, but only one is used at a time.
5. False. The IMUs are powered by only two sources.

Answers to Section 3

1. The two IMU modes of operation are the warmup/standby mode and the operate mode.
2. A REFSMMAT is simply a 3 by 3 transformation matrix that enables measurements from one coordinate system to be expressed in another.
3. The three types of IMU alignments are the star alignment, the IMU/IMU alignment, and the matrix alignment. Star alignments are normally used on orbit.
4. False. STAR ALIGN and MATRIX ALIGN are available only in MM 301. IMU/IMU align is available in all OPS 3 major modes.

Answers to Section 4

1. The IMU RM scheme consists of an SF and FDIR software.
2. The purpose of the attitude SF is to select one IMU as the attitude source for the GNC software. The purpose of the velocity SF is to select component by component the best available data to propagate the orbiter SV.
3. FDIR searches for faulty data, attempts to identify the IMU producing these data, and if successful, reconfigures the SF to exclude data from the faulty IMU.
4. Two types of failures that can affect the thermal control system are fan failures and internal heater failures.

Answers to Section 5

1. The BFS RM scheme consists of an SF with no FDIR.
2. The BFS will downmode an IMU by crew manual deselection, IMU poweroff or comm fault, or a hardware BITE.

Appendix C

Mean of 1950 Coordinate System

Name: Aries Mean of 1950 Cartesian coordinate system

Origin: The center of the Earth

Orientation: The epoch is the beginning of Besselian year 1950 or Julian ephemeris date 2433282.423357.

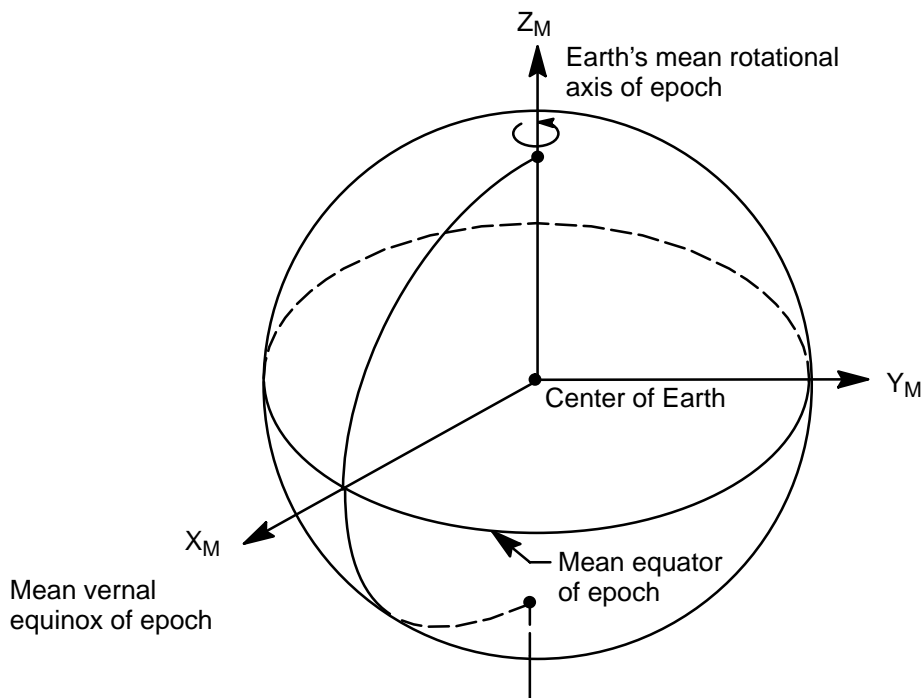
The X_M - Y_M plane is the mean Earth's equator of epoch.

The X_M axis is directed towards the mean vernal equinox of epoch.

The Z_M axis is directed along the Earth's mean rotational axis of epoch and is positive north.

The Y_M axis completes a right-handed system.

Characteristics: Inertial, right-handed Cartesian system



td_303b_024

Figure C-1. Aries Mean of 1950 Cartesian coordinate system

Appendix D

References

S TRK/COAS 2102 Workbook.

Inertial Measurement Unit Alignment Flight Procedures Handbook.

Attitude and Pointing Flight Procedures Handbook.

Level C FSSR, GNC, Part E, Inertial Measurement Unit Subsystem Operating Program.

GNC Systems Briefs, Section 6, IMU.