

APOLLO

GUIDANCE, NAVIGATION AND CONTROL

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AS-278
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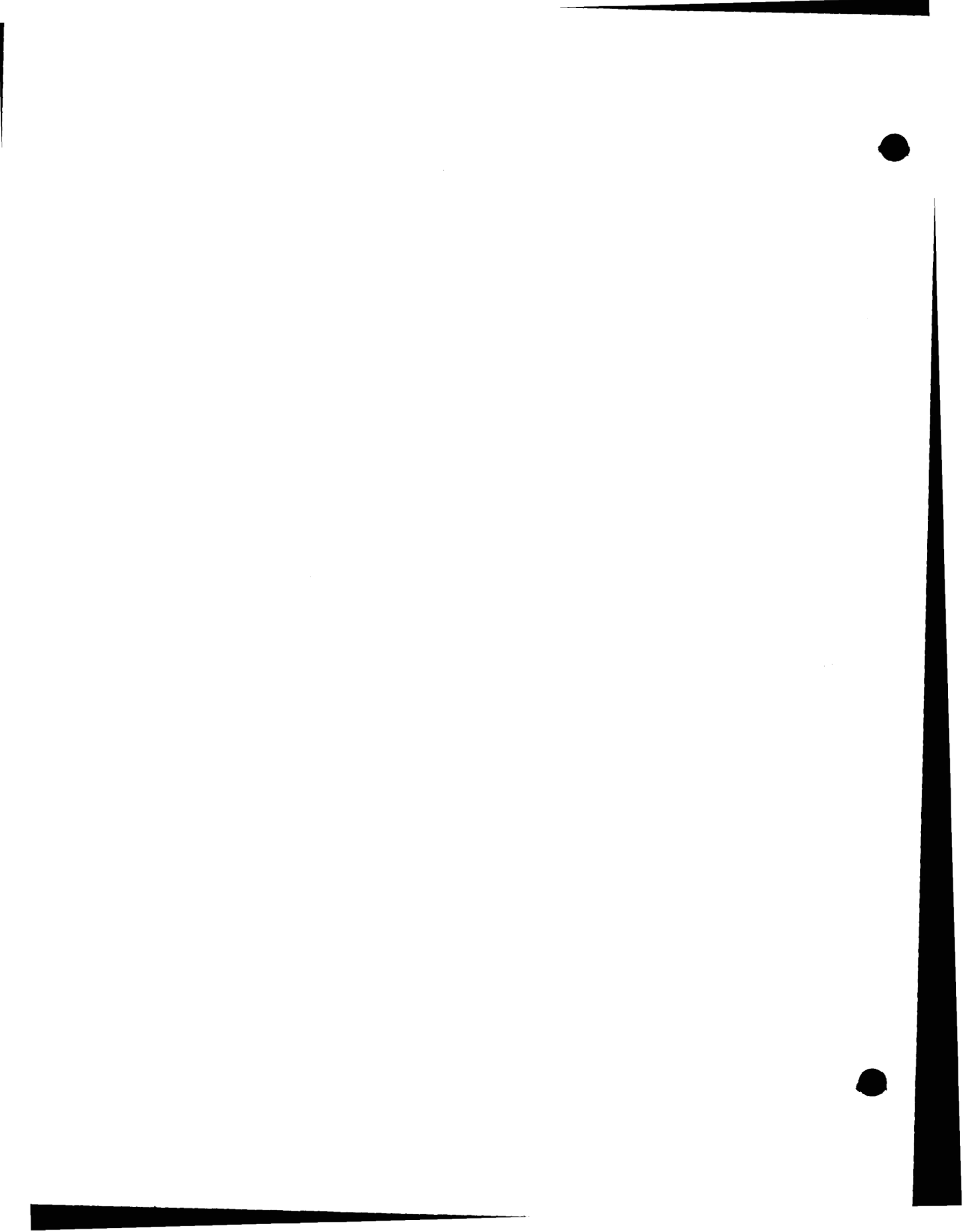
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SECTION 1

INTRODUCTION

1.1 Purpose

This plan governs the operation of the Command Module Guidance, Navigation and Control System and defines its functional interface with the spacecraft, flight crew, and ground support systems on Apollo Mission AS-278.

1.2 Authority

This plan constitutes a control document to govern the implementation of:

1. Digital Uplink and Downlink
(Ref Sect. 2 - Data Links)
2. Digital Autopilots
(Ref Sect. 3 - Digital Autopilots)
3. Structure of CMC mission programs, including GNCS interfaces with the flight crew and MCC.
(Ref Sect. 4 - GNCS Operations)
4. Guidance and Navigation Equations
(Ref Sect. 5 - CMC Guidance Equations)

To support these functions a Control Data volume (Vol. III) is provided to define the spacecraft, mission, and other data being used to design and verify the GNCS software.

Revisions to this plan which reflect changes in control items (1) through (4) and in the Control Data require NASA approval.

This plan also constitutes an information document to define:

1. Trajectory uncertainties due to GNCS component errors
(Ref: Vol IV - Error Analysis)
2. GNCS instrumentation (PCM telemetry and on-board recording) exclusive of CMC DOWNLINK
(Ref Sect. 2 - Data Links)

Revisions to this plan which reflect changes in information items (1) and (2) will not require approval of NASA.

1.3 Basic Software Design Considerations

The GNC System is designed to perform the spacecraft guidance and navigation functions required on the lunar landing mission in a self-contained mode and within specified accuracy and maneuver propellant constraints. The System is also designed to accept navigation data from Earth-based facilities whenever required to improve accuracy, to reduce maneuver propellant requirements, or to gain some other operational advantage. It is essential on AS-278 to demonstrate to the maximum extent possible both the self-contained and Earth-cooperative modes of operation since either mode may be required on the lunar mission.

Preparation of the GNCS for any mission involves the generation of computer programs, flight and ground crew procedures, and the provision of hardware to meet interface, accuracy, and instrumentation requirements. All of these mission-related items are specified in this Guidance System Operations Plan. Also, since their implementation requires specification many months before launch, great emphasis is placed upon flexibility. The guidance operational concept is therefore designed to comprise a set of manually-initiated programs and functions which may be arranged by the flight crew to implement a large class of flight plans. This concept of operation will permit both a late flight-plan definition and a powerful capability for real-time flight-plan changes.

2. GNCS Data Links

2.1 Digital UPLINK to CMC

By means of the CMC UPLINK, the ground can insert data or instruct the CMC in the same manner normally performed by the crew using the DSKY keyboard. The CMC will be programmed to accept the following UPLINK inputs:

- 1) LIFTOFF (backup to discrete input)
- 2) CMC CLOCK ALIGNMENT
- 3) CSM POSITION and VELOCITY data (provides ground capability to update CSM STATE VECTOR data in the CMC.)
- 4) LEM POSITION and VELOCITY data (provides ground capability to update LEM STATE VECTOR data in the CMC.)
- 5) EXTERNAL DELTA-V
- 6) TIME UPDATE (provides ground capability to update CMC clock and TEPHEM)

Operational procedures governing the use of these Uplink inputs must be developed to ensure proper operations within program constraints.

All information received by the CMC from the Uplink is in the form of keyboard characters. Each character transmitted to the CMC is triply redundant. Thus, if C is the 5-bit character code, then the 16-bit message has the form:

$$1 C\bar{C}$$

where \bar{C} denotes the bit-by-bit complement of C. To these 16 bits of information the ground adds a 3-bit code specifying which system aboard the spacecraft is to be the final recipient of the data and a 3-bit code indicating which spacecraft should receive the information. The 22 total bits are sub-bit encoded (replacing each bit with a 5-bit code for transmission.) If the message is received and successfully decoded, the receiver on-board will send back an 8-bit "message accepted pulse" to the ground and shift the original 16 bits to the CMC ($1 C\bar{C}$).

Any ground command sequence via the uplink may be duplicated by the astronaut via the keyboard. All uplink words given in this section are in the form transmitted from the uplink receiver to the CMC. Therefore they do not contain the vehicle or sub-system addresses added on by the ground facilities. For the purpose of this section, the following definitions hold:

- 1) 1 uplink word = 1 character
- 2) 5 characters or uplink words = contents of one CMC register

2.1.1 LIFTOFF - to send the backup liftoff discrete to the CMC the following words should be sent via the uplink:

Binary Uplink Word (1 C \bar{C} C)	Equivalent Keyboard Character (C)
1 10001 01110 10001	VERB
1 00111 11000 00111	7
1 00101 11010 00101	5
1 11100 00011 11100	ENTER

2.1.2 CMC CLOCK ALIGN - to align the CMC clock two procedures are required. To set the CMC clock to a specific value, the following uplink words must be sent.

Binary Uplink Word (1 C \bar{C} C)	Equivalent Keyboard Character (C)
1 10001 01110 10001	VERB
1 00010 11101 00010	2
1 00101 11010 00101	5
1 11111 00000 11111	NOUN
1 00001 11110 00001	1
1 00110 11001 00110	6
1 11100 00011 11100	ENTER

This must be followed by +00XXX ENTER +000XX ENTER +0XXXXX ENTER. Where the first three X's are decimal digits representing the hour, the next two X's represent the minutes, and the last four X's represent the centiseconds (.01 sec) to be loaded into the CMC clock.

Since there are uncertainties in time of transmission, et cetera it is anticipated that a time increment may be needed. To increment the CMC clock, the following uplink words must be sent.

Binary Uplink Word (1 C \bar{C} C)	Equivalent Keyboard Character (C)
1 10001 01110 10001	VERB
1 00101 11010 00101	5
1 00101 11010 00101	5
1 11100 00011 11100	ENTER

This must be followed by +00XXX ENTER +000XX ENTER +0XXXXX ENTER where the X's represent the hours, minutes, and centiseconds to be added to or subtracted from the CMC clock. If the increment is positive (i.e. to increase the clock), all the signs must be positive; if the increment is negative, all the signs must be negative.

2.1.3 CSM STATE VECTOR - to begin a CSM STATE VECTOR update on flight Mission AS-278 the following 4 words should be sent via uplink.

1 10001 01110 10001	VERB
1 00111 11000 00111	7
1 00110 11001 00110	6
1 11100 00011 11100	ENTER

The ground station should then await confirmation via Downlink that the CMC is in Major Mode 27.

In Major Mode 27 the CMC will accept a complete ground STATE VECTOR update in the format to be described below.

The data itself will take the form of three (3) double precision components of position, three (3) double precision components of velocity, and double precision time. The position and velocity components should be given in navigation co-ordinates (see Sec. 5) and the time should be in the time of the "fix" referenced to CMC CLOCK ZERO. The data must be sent in the following sequence:

<u>octal identifier</u>			
1	XXXXX	(most sig. part of X position)...	ENTER
2	XXXXX	(least sig. part of X position)...	ENTER
3	XXXXX	(most sig. part of Y position)...	ENTER
4	XXXXX	(least sig. part of Y position)...	ENTER
5	XXXXX	(most sig. part of Z position)...	ENTER
6	XXXXX	(least sig. part of Z position)...	ENTER
7	XXXXX	(most sig. part of X velocity)...	ENTER
10 ₈	XXXXX	(least sig. part of X velocity)...	ENTER
11 ₈	XXXXX	(most sig. part of Y velocity)...	ENTER
12 ₈	XXXXX	(least sig. part of Y velocity)...	ENTER
13 ₈	XXXXX	(most sig. part of Z velocity)...	ENTER
14 ₈	XXXXX	(least sig. part of Z velocity)...	ENTER
15 ₈	XXXXX	(most sig. part of time from CMC clock zero).....	ENTER
16 ₈	XXXXX	(least sig. part of time from CMC clock zero).....	ENTER

where each "X" and "ENTER" above represents an uplink word. If, for some reason, the ground wishes to resend any 5 uplink word group before the ENTER associated with that group has been transmitted, the following "CLEAR" word would be sent

1 11110 00001 11110

and the 5 word group retransmitted.

If the ground station wishes to terminate the load at any time, the following 4 uplink words must be sent.

<u>Binary Uplink Word</u> (1 CCC)	<u>Equivalent Keyboard Character</u> (C)
1 10001 01110 10001	VERB
1 00011 11100 00011	3
1 00100 11011 00100	4
1 11100 00011 11100	ENTER

which will return the CMC to the mode it was in before the update was initiated.

After the ENTER associated with the least sig. part of time, the ground station must verify via Downlink that the CMC has correctly received the navigational update before sending the following 4 uplink words to signal the CMC that it can use the data in guidance computations.

1 10001 01110 10001	VERB
1 00011 11100 00011	3
1 00011 11100 00011	3
1 11100 00011 11100	ENTER

If the STATE VECTOR update is associated with a pre-thrusting mode, the entire load must be completed before the pre-thrusting mode is entered.

If, during the final verification period after the ENTER associated with the least significant part of time, the data in the CMC are not correct the ground station may change the load in either of the following ways:

- 1) If only a few parts must be changed the ground station should send the octal identifier of the part to be changed, i. e., if the least significant part of the Y velocity were to be changed.

1 00001 11110 00001	1
1 00010 11101 00010	2
1 11100 00011 11100	ENTER

then the 5 uplink words corresponding to the part to be changed are sent followed by an ENTER. This procedure, octal identifier ENTER et cetera, must be repeated for each part to be changed. When all changes are made and verified via Downlink the VERB 33 ENTER must be sent to signal the CMC that it can use the data.

- 2) If many parts must be reloaded, the ground station may choose to start the load from the beginning. To do this, as stated above, the ground station must send VERB 34 ENTER which will terminate the load and allow the CMC to return to its pre-update condition.

If the CMC receives an improperly coded word from the uplink receiver during the load (not C \bar{C} C) it will turn on bit 4 of OUT 1 which is transmitted via Downlink (see Sec. 3.4). When this occurs the ground station should send the following 3 uplink words:

Binary Uplink Word (1 CCC)	Equivalent Character (C)
1 00000 00000 00000	(to clear uplink buffer)
1 10010 01101 10010	ERROR RESET
1 11110 00001 11110	CLEAR

The ground station should then begin loading with the first word of the 5 word group it was sending when the alarm condition occurred.

If insufficient time remains to SPS + X translation, the CMC will change its major mode and proceed with the internally computed data.

The scale factors for CMC navigation updating are:

position	meter/ 2^{24}
velocity	(meter/C.S.)/ 2^7
"fix" time	C.S./ 2^{28}

(1C.S. = .01 sec)

The CMC is a fixed point machine with the point just to the left of the most significant bit.

The scaling indicated above will be sufficient to force the 3 components of position and the 3 components of velocity and time to numbers less than one.

To form the double precision quantities ready for coding and transmission the scaled magnitudes of time and each component of position and velocity should be expressed as two binary words as follows:

1st word	0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	2^{-8}	2^{-9}	2^{-10}	2^{-11}	2^{-12}	2^{-13}	2^{-14}				
2nd word	0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		2^{-15}	2^{-16}	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}	2^{-24}	2^{-25}	2^{-26}	2^{-27}	2^{-28}				

Each X above represents a binary bit of the appropriate magnitude, the place value of which is indicated below the corresponding X. Once the magnitude of the component is accounted for in the above 28X's, the sign must be considered.

If the component is positive, the words remain as formed; if the component is negative, the "1's complement" of the 2 words is used (all 1's are replaced by 0's and all 0's by 1's.)

The first word is then transformed into a 5 character octal word. The first character is the octal equivalent of the first three bits, the second character is the octal equivalent of the next three bits, et cetera. This word is referred to as the "most significant part" of data in the text above.

Similarly the second word is transformed into a 5 character octal word which is the "least significant part" of data.

Each character must now be coded into a 16 bit uplink word for transmission. A table of the characters and their uplink word follows. (Table 2-1)

2.1.4 State Vector Update - LEM

To update the LEM state vector via the uplink the ground should send Verb 70 Enter and then enter the parameters in a manner identical to that described for CSM updates in Section 2.1.2.

2.1.5 External Delta -V

To load the CSM for an External Delta -V maneuver the ground should send Verb 72 Enter followed by the parameters listed below, in the order given below.

Octal Identifier

1	XXXXX Enter	(most sig. part of T_{ign})
2	XXXXX Enter	(least sig. part of T_{ign})
3	XXXXX Enter	(most sig. part of X component of V_g)
4	XXXXX Enter	(least sig. part of X component of V_g)
5	XXXXX Enter	(most sig. part of Y component of V_g)
6	XXXXX Enter	(least sig. part of Y component of V_g)
7	XXXXX Enter	(most sig. part of Z component of V_g)
10 ₈	XXXXX Enter	(least sig. part of Z component of V_g)

The ground should use the same procedure for correcting, terminating or accepting this data as outlined for Verb 76 above.

2.1.6 TIME UPDATE - to begin a time update for Mission AS-278 the following four words should be sent via uplink.

<u>Binary Uplink Word</u> (1 C \bar{C} C)	<u>Equivalent Keyboard Character</u> (C)
1 10001 01110 10001	VERB
1 00111 11000 00111	7
1 00111 11000 00111	7
1 11100 00011 11100	ENTER

This must be followed by XXXXX ENTER where the 5 X's represent 5 octal characters which give the time change scaled as C.S. / 2^{14} .

A positive value indicates that the clock reading should be decreased and TEPHEM should be increased, while a negative value indicates that the clock should be increased and TEPHEM decreased.

TABLE 2-4

<u>Character</u>	<u>Uplink Word</u>
0	1 10000 01111 10000
1	1 00001 11110 00001
2	1 00010 11101 00010
3	1 00011 11100 00011
4	1 00100 11011 00100
5	1 00101 11010 00101
6	1 00110 11001 00110
7	1 00111 11000 00111
8	1 01000 10111 01000
9	1 01001 10110 01001
VERB	1 10001 01110 10001
NOUN	1 11111 00000 11111
ENTER	1 11100 00011 11100
ERROR RESET	1 10010 01101 10010
CLEAR	1 11110 00001 11110
KEY RELEASE	1 11001 00110 11001
+	1 11010 00101 11010
-	1 11011 00100 11011

NOTE: It is good operational procedure to end every uplink message with a KEY RELEASE.

2.2 CMC Digital Downlink

The CMC digital downlink is transmitted at a rate of 50 words per second on the high bit rate and 10 words per second on the low bit rate. Each word consists of 33 bits; the first bit is a "word order code" bit, the next 16 bits are the contents of one 16 bit CMC register and the last 16 bits are the contents of another 16 bit CMC register. (Because the PCM telemetry format requires data in multiples of 8-bit words, the CMC downlink program repeats the last 7 bits from the first 16-bit register, after the 33-bit transmission, in order to "fill" the 40-bit downlink allocation.) In this manner the contents of 100 CMC registers are transmitted in one second at high rate and 5 seconds at low rate.

The downlink format is controlled by a CMC program which loads the next 2 registers to be transmitted into channels 34 and 35. This program is entered on an interrupt caused by an "endpulse" from the telemetry system.

The general CMC downlink format is shown in Table 2-2. Each list contains 50 words (i. e., 100 CMC registers). The first word in any list contains the ID and sync registers and has a word order code bit of zero. The ID register marks the beginning of a list and also identifies which list is being transmitted. The sync register always contains the same 16 bits. These bits (000 0001000111111) are used to sync certain remote site downlink processing equipment. The next 12 words (24 registers) may also change for different lists. These twelve words will have word order code bits of one. Since certain data on the downlink are only meaningful when considered in multiregister arrays (i. e. state vectors) and since the programs which compute these arrays are not synchronized with the downlink program, a "snapshot" is taken of these registers so that changes in their values will not occur while these arrays are being transmitted to the ground. The next 26 words (52 registers) will have word order code bits of one and will probably change from list to list. Since both registers of a word are loaded at the same time, no synchronization problems can arise on double precision parameters. The next 6 words (12 registers) have word order code bits of one and transmit the contents of the latching relays in the DSKY. As such they indicate all displays and certain other functions (i. e. G&N mode switching) handled through the latching DSKY relays. All downlink lists will contain DSPTAB registers in this position in the list.

The next downlink word contains the double precision contents of the CMC clock (i. e. TIME1 and TIME2). This word will have a word order code bit of one and will always retain the position indicated in all lists. The last 4 downlink words (8 registers) contain the contents of channels 11, 12, 13, 14, 30, 31, 32 and 33 in that order. These channels have similar functions to the in and out registers for the Block I computer. Therefore, they will contain the status of a number of discrete interfaces of the CMC. These 4 words will have word order bits of one and

TABLE 2-2

GENERAL LGC DOWNLINK FORMAT

Word #	Word Order Code	Contents of	
		1st register	2nd register
1	0	ID	sync
2	1	"snapshot" data which will probably change with different lists	
↓	↓		
13	1		
14	1	data which will probably change with different lists	
↓	↓		
39	1		
40	1	DSPTAB registers	
↓	↓		
45	1		
46	1	TIME2	TIME1
47	1	channel 11	channel 12
48	1	channel 13	channel 14
49	1	channel 30	channel 31
50	1	channel 32	channel 33

will be in the same position on all downlink lists.

More detailed information will be included as addenda to this document as it becomes available.

2.3 Analog Data Telemetry

2.3.1 Types

The inflight information from the Block II CSM G&N system is of four types:

- a) PCM telemetry of the CMC Digital Downlink (described in sec. 2.2),
- b) PCM telemetry of OPERATIONAL (required for all Block II missions) analog measurements, which include the following categories:
 - 1) PCM Pulse-code-modulated analog measurements digitally coded into 8-bit words and transmitted at the normal (51.2k-c) operational bit rate.
 - 2) PCM+ Flight-critical PCM measurements, which continue to be monitored when the PCM is operated in the "slow-format" mode.
 - 3) PCME PCM monitor of discrete events (1 bit per word).
 - 4) PCME+ Flight critical PCME measurements monitored in "slow-format" mode;
- c) PCM telemetry of FLIGHT QUALIFICATION measurements which is discontinued after the flight qualification requirements are fulfilled.
- d) On board recordings of FLIGHT QUALIFICATION measurements for retrieval by subsequent transmission or by examination after S/C recovery.

2.3.2 Authority

The PCM telemetry and on-board recorder allocations have been defined by NASA in SID 65-1642 (2 March 1966), CSM Measurement Requirements Specification for Block II Spacecraft Apollo CSM System. The G&N measurements are listed below.

2.3.3 OPERATIONAL PCM Measurements

<u>Measurement #</u>	<u>Description</u>	<u>T/M</u>	<u>Response S/S</u>
CG 0001V	Computer Digital Data 40 Bit	PCMD	50
CG 1040V	+120 VDC PIPA Supply DC Level	PCM	1
CG 1110V	2.5 VDC T/M Bias	PCM	1
CG 1201V	IMU28V .8KC 1 PCT 0 Deg. RMS	PCM	1
CG 1331V	3.2KC 28V Supply	PCM	1
CG 1513X	+28V IMU Standby	PCME	10
CG 1523X	+28V CMC Operate	PCME	10
CG 1533X	+28V OPTX Operate	PCME	10
CG 2001V	X PIPA SG Output In Phase	PCM	50
CG 2021V	Y PIPA SG Output In Phase	PCM	50
CG 2041V	Z PIPA SG Output In Phase	PCM	50
CG 2112V	IG 1X Resolver Output SIN	PCM	10
CG 2113V	IG 1X Resolver Output COS	PCM	10
CG 2117V	IG Servo Error In Phase	PCM	100
CG 2142V	MG 1X Resolver Output SIN	PCM	10
CG 2143V	MG 1X Resolver Output COS	PCM	10
CG 2147V	MG Servo Error In Phase	PCM	100
CG 2172V	OG 1X Resolver Output SIN	PCM	10
CG 2173V	OG 1X Resolver Output COS	PCM	10
CG 2177V	OG Servo Error In Phase	PCM	100
CG 2300T	PIPA Temperature	PCM+	1
CG 3721V	Shaft CDU DAC Output	PCM	10
CG 3722V	Trunnion CDU DAC Output	PCM	10
CG 5040X	CMC Warning	PCME	10

2.3.4 FLIGHT QUALIFICATION PCM Measurement for CSM 101

<u>Measurement #</u>	<u>Description</u>	<u>T/M</u>	<u>Response S/S</u>
CG 1211V	OPTX 28V .8KC 1 PCT 0 Deg. Rms	PCM	1
CG 2219V	Pitch Att. Error-CDU DAC Out	PCM	10
CG 2249V	Yaw Att. Error-CDU DAC Out	PCM	10
CG 2279V	Roll Att. Error-CDU DAC Out	PCM	10
CG 2301T	IRIG Temperature	PCM	1
CG 2302X	IMU Heater Current	PCME	1
CG 2303X	IMU Blower Current	PCME	1
CG 3011V	Trunnion CDU Fine Error	PCM	10
CG 3021V	Shaft CDU Fine Error	PCM	10
CG 3140V	SXT Shaft Tachometer Output	PCM	10
CG 3150V	SXT Trun Tach Output	PCM	10
CG 3160V	SCT Shaft Tach Output	PCM	1
CG 3170V	SCT Trun Tach Output In Phase	PCM	1

2.3.5 FLIGHT QUALIFICATION Flight Recorder Measurement for CSM 101

<u>Measurement #</u>	<u>Description</u>	<u>Recoverable B/W CPS</u>
CG 2120C	IG Torque Motor Current	35
CG 2122V	IG 1X Resolver Output SIN 11 Deg.	35
CG 2150C	MG Torque Motor Current	25
CG 2152V	MG 1X Resolver Output SIN 11 Deg.	25
CG 2180C	OG Torque Motor Current	20
CG 2182V	OG 1X Resolver Output SIN 11 Deg.	20
CG 6001D	Vibration Navigation Base Roll	2K
CG 6002D	Vibration Navigation Base Pitch	2K
CG 6003D	Vibration Navigation Base Yaw	2K



SECTION 3 DIGITAL AUTOPILOTS AND CONTROL INTERFACES

3.1 Introduction

The GNC System is designed to control attitude and/or steering and propulsion during all phases of the 278 mission after first-stage booster cutoff. The Saturn autopilot may be directed by GNC, both during SIVB burn and during coast. CSM free-fall attitude control is performed by GNC with and without LM attached. TVC (thrust-vector control) is performed by GNC using either the RCS or SPS systems with and without LM attached. Attitude of the CM is controlled from SM separation through entry.

3.1.1 General Description

These various control operations are performed by mutually exclusive, separate sections of the CMC. For the several CSM and CM operations, GNC provides self-contained digital autopilots (DAP's). For Saturn control, rate command signals are transmitted to the SIVB autopilot,

The activation of any DAP or Saturn-control function and its interfaces with other programs are governed by the major mission program in process. This section describes external stimuli to which the control functions are sensitive, the crew's role in selection of control parameters and the means for transitions from one control operation to another. Section 3.2 defines the operation of the RCS DAP (including TVC using the RCS jets). Section 3.3 defines the TVC DAP (using SPS) and also describes the "Stroking-test" mechanization which is integrated with the TVC DAP for Mission 278. Section 3.4 defines the entry DAP. Section 3.5 defines the various control functions provided for Saturn control.

3.1.2 Enablement and Mode Control of GNC DAP's and Saturn-Control Functions.

In order to initiate any DAP or Saturn-control function, the GNC ISS subsystem must be in the inertial mode (evidenced to the crew by the absence of the "No Attitude" indication). * Furthermore, the GNC A/P Control discrete must be present. Other discrettes from the spacecraft or the crew influence performance:

* The exception is the Free Mode of the CSM RCS DAP.

SIVB Separate **	Initiates CSM RCS DAP
Attitude Hold	Commands Hold mode of CSM RCS DAP ***
Free Drift	Commands Free mode of CSM RCS DAP ***
LM Attached **	Influences parameters of CSM RCS DAP and selects one of two TVC DAP's
CM/SM Separate **	Initiates entry DAP sequence
Rotational Hand Controller (RHC)	Six (6) discrettes command angular rotations during CSM RCS DAP and Saturn -control operations.
Translation Hand Controller (THC)	Six (6) discrettes command translation accelerations during CSM RCS DAP operations.
Minimum Impulse Controller (MIC)	Six (6) discrettes command rate increments during Free mode of CSM RCS DAP operations.
S/C Control of Saturn	Initiates Saturn Control Operations.

It will be noted that the CSM RCS DAP reponds to all discrettes, i. e., HOLD, FREE, RHC, THC, MIC. The Saturn-control function responds only to the RHC. The other DAP's are virtually free-running and do not respond to any mode-control or manual-control inputs. In order to suspend normal GNC control operations, the crew must switch out of the GNC A/P Control mode; the GNC System will attempt to resume control if the control switch is returned to GNC, but results may not be satisfactory if extravagant initial conditions obtain at that time; in no event should unstable performance develop; however, steering accuracy may be impaired.

3.1.3. Crew Control of DAP Characteristics

Many of the constants and other data which characterize DAP operation are stored in or transferred to erasable memory. The crew has access to examine this data. In certain instances (such as gains, iteration rate and filter poles and zeros for the TVC autopilot) the crew may be called upon to change coefficients (only after coordination with the ground, as a contingency portion of the mission plan). In other instances (such as selection of

** These functions may be alternatively supplied by DSKY entry.

*** The Auto mode of CSM RCS DAP is commanded by the absence of Attitude-Hold and Free-Drift discrettes.

manuever rates or accounting for the effects of fuel depletion), the crew are expected to change the data as a matter of normal procedure.

The autopilots should be considered as hardware with some adjustment capability. The basic autopilots are stored in fixed memory; major changes in performance may be achieved by changes in erasable memory, however, these manipulations are time-consuming.

For normal activity, the data are grouped into "nouns" for more convenient display and change. In this group are:

N	{ SPS pitch trim SPS yaw trim TL (SPS thrust-moment)
N	{ I roll I pitch-yaw Weight
N	{ RCS dead-band Maneuver Rates Thruster Quad Fails

The display and change are performed by normal DSKY procedures: e. g., V06N ___ E; V21N ___ E, etc.

For the less changeable data, individual addressing must be used; e. g., V06N01E, address E; etc.

3.1.4 Transitions in Operating Mode

Transitions are effected by discrettes or by major mission program commands. The first type is represented by activation of the Entry DAP 5 sec. after reception of the CM/SM Separate discrete (backed up by a DSKY entry). The prime examples of the second type are transition from RCS DAP to TVC DAP at ignition and transition from TVC DAP to RCS DAP at SPS-engine cut-off. These transitions are described here for information only; the details are defined in Section 4.

3.1.4.1 Transition from RCS to TVC

Immediately prior to sequence initiation of a TVC burn using the SPS, the RCS system is holding initial thrusting attitude in narrow deadband, the preselected trim has been commanded to the engine and confirmed by the crew and the crew has accepted the thrusting parameters including time-of-ignition (TIG).

At a prescribed time before TIG the crew signals SPS Ready and the RCS autopilot initiates ullage while holding attitude in the narrow deadband. At TIG the RCS DAP is ceased and TVC DAP controls engine excursion. Ullage is terminated by the major program when successful thrust build-up sensed.

3.1.4.2 Transition from TVC to RCS

At commanded engine cut-off, engine gimbal commands are stored for trim reference for subsequent burns, and TVC DAP operation ceases. RCS DAP operation is simultaneously initiated in the wide deadband mode.

3.2 RCS DAP

The RCS DAP provides CSM attitude control during non-thrusting (SPS) periods of flight and provides translation capability using the RCS thrusters. The primary requirement for this DAP is RCS-fuel conservation. To this end coordinated 3-axis maneuvers are performed with a selectable rate and, wherever possible, the jets are fired so as to achieve highest specific impulse. Wherever possible, translation and rotation are performed simultaneously. The capability exists of operating with single jets in the attitude-hold mode. When performing attitude hold and automatic maneuvers, the system operates with a minimum-impulse limit cycle within a wide or narrow deadband. A jet-selection logic is employed which permits one-jet or multi-jet operation, selects non-failed quads to effect any possible rotation or translation operation and allows for fuel management among the various tanks.

3.2.1. Reaction Control System

The RCS DAP controls spacecraft attitude and attitude rate by means of commands to the reaction jets on the Service Module. Spacecraft attitude is measured with the IMU through the CDU. Attitude rates must be computed from the CDU information. An accurate estimation of the attitude rates requires that the commanded angular accelerations be included in this computation.

As a function of attitude error and attitude-rate error, nonlinear switching functions in the computer are employed to generate ON-OFF commands to the RCS jets. A jet-selection logic is then used to select the individual jets to be fired. Simultaneously, attitude error signals are transmitted via the CDU digital-to-analog converters to drive displays on the FDAI.

Central to the operation of the RCS DAP is the angular-rate estimator. Derivation of the body rates of the spacecraft from the gimbal angles is complicated by the effects of CDU angular quantization and the effects of body bending modes of the vehicle. The accuracy of estimating body rates relates directly to the fuel economy achievable through operating at a minimum-impulse limit cycle within the deadband.

For the RCS DAP the IMU gimbal-angle differences (rates) are transformed into body-angle differences and smoothed by a second-order filter, as shown in Figure 3-1. Except for the high-rate (abort) case, the selection of a break frequency at least an order of magnitude below the natural frequency of the lowest bending mode assures virtual isolation from bending-mode effects and effective smoothing of quantization effects. The resulting filter has a serious time delay in responding to changes in input rate. To improve this response, two additional measures are taken. First, a Kalman-filter approach is undertaken during the first second after turn-on; i. e., the bandpass of the filter is increased many-fold initially and rapidly reduced to the nominal value in order to initialize the estimator as quickly as possible. Second, estimates of vehicle angular accelerations are derived from the number of jets fired, the time of firing, nominal thrust and a nominal Moment-of-Inertia about each axis.

The gains programmed for the filter are included in Figure 3-1. The first set of gains define the Kalman filter. The second set of gains define the filter for normal low-rate operation. The third set of gains define the filter for high-rate operation; in this mode, fuel economy and smoothing are sacrificed for speed of response. The normal filter characteristics are:

$$W_n = 0.4 \text{ rad/sec}, \zeta = 0.8$$

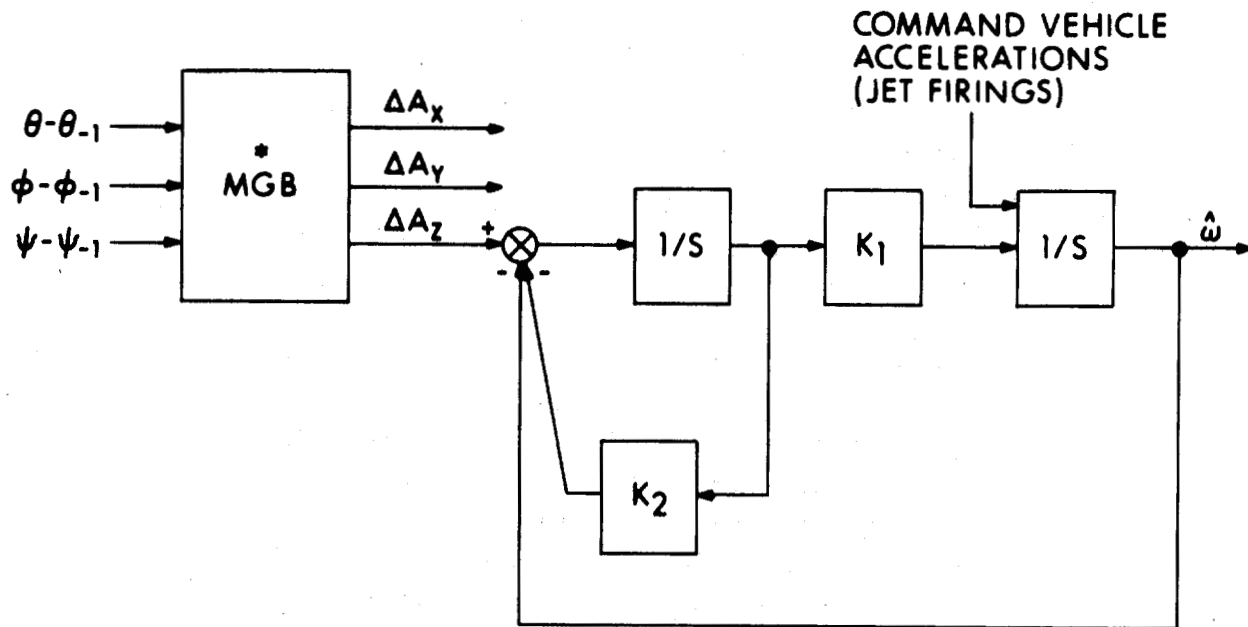
The high rate filter characteristics are:

$$W_n = 1.32 \text{ rad/sec}, \zeta = 0.8$$

3.2.2. Attitude Hold and Rate Limiting

The attitude hold and rate limiting functions of the autopilot are performed in the same part of the computer logic. The inputs to the logic are the vehicle attitude error and the body rates. The attitude errors are assumed to be small and are equal to the difference between vehicle attitude and the desired vehicle attitude resolved into the three control axes. Rate has been derived in control axes. We will consider the logic used in only one channel since the others are identical.

The dynamics of the switching logic can be best understood by interpretation in the phase plane as shown in Figure 3-2. The abscissa is the vehicle angular error; the ordinate is the vehicle body rate. Paths of zero acceleration are horizontal lines and paths of constant acceleration are parabolas.



KALMAN FILTER

T	K_1	K_2
0.1	88.83	9.342
0.2	48.17	8.151
0.3	29.55	6.933
0.4	19.85	5.970
0.5	14.22	5.223
0.6	10.69	4.634
0.7	8.32	4.161
0.8	6.66	3.774
0.9	5.45	3.452
1.0	4.54	3.180
1.1	0.16	0.640
NORMAL	0.16	0.640
HIGH RATE	1.742	0.112

Fig. 3.1 Rate Estimation Filter

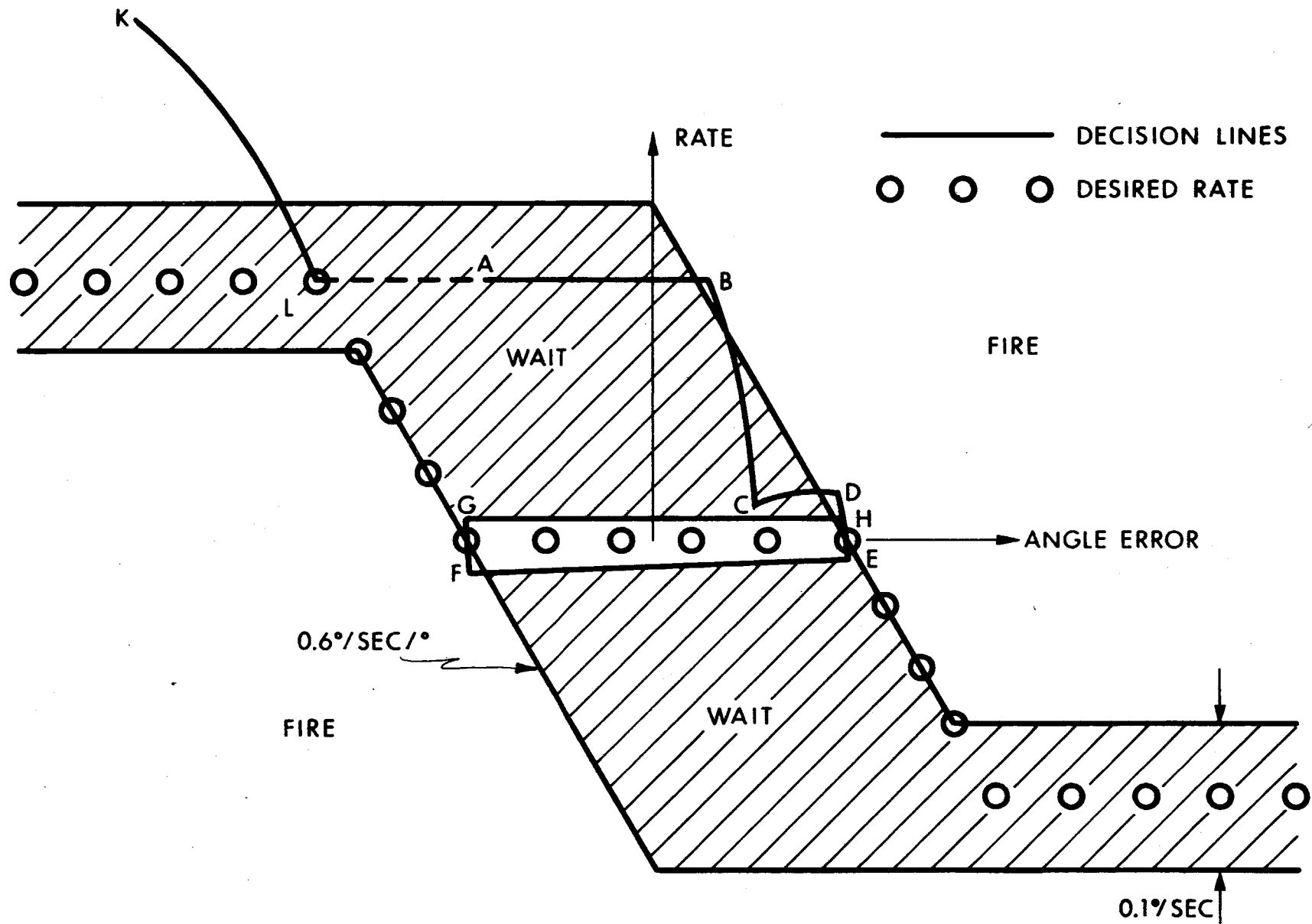


Fig. 3.2 Phase Plane Showing Switching Logic

In the attitude hold mode we can consider what happens to the vehicle when it starts in the state A. The velocity drives the state along the error axis until it reaches the decision line at B. The logic then fires an impulse on the reaction control jets to attain the desired rate corresponding to that attitude error (zero in this case). Due to tolerances in the torque produced by the jets and to uncertainties in the vehicle moment of inertial, the impulse fired is actually short (20%) of the desired impulse. Thus the state drops to C, and now moves more slowly towards the decision line. During this time the Rate Derivation filter drives the rate estimate from the predicted value towards the actual value. Now the state hits the decision line again at D and fires the jets again to bring it to E. The effect of limiting the shortest firing to a minimum impulse is to reverse the velocity and to drive the vehicle into the minimum impulse limit cycle EFGHE, etc.

In the rate limiting mode the vehicle is at some high-rate condition such as at point K. The jets fire to bring the operating state within the rate limiting deadband at L. Then the state moves until it reaches the attitude deadband, at A for example, and the vehicle moves into an attitude hold mode.

The value of rate limit is fixed at $0.2^\circ/\text{second}$. The Astronaut may select his angular deadband (0.5° or 5.0°) by Keyboard command.

3.2.3. Automatic Attitude Maneuvers

Attitude maneuvers are implemented by exactly the same logic as that used in attitude hold, except that the inputs to the logic are error rate and attitude error; i. e., the rate ordinate is the difference between actual rate and desired rate. Thus, throughout a maneuver, the vehicle attitude is being held about a desired attitude moving from the initial vehicle position toward the final position.

Due to the requirement for high vehicle maneuver rates, the above scheme has one shortcoming; the initial error rate in the phase plane can be great enough to prevent the initial firing of the jets from driving the operating point into the attitude deadzone. As a result, the vehicle-rate limits on the opposite side before returning to the deadzone. This results in opposite firing of the jets, which is wasteful of propellants. In order to overcome this problem, a bias is introduced into the attitude error. The bias is computed by dividing the component maneuver rates by the slope of the decision line. With this bias present the vehicle state moves into the correct rate limiting deadband before moving into the attitude hold deadzone.

The generation of the moving desired attitude (3 CDU-values) required for the automatic attitude maneuver is performed in two stages.

First, on the basis of current attitude (CDU angles) and desired attitude as supplied by the crew or by a peripheral program, the attitude maneuvering routine* determines the arbitrary axis (fixed in inertial space) about which a single rotation will achieve the desired reorientation. The routine will then determine if the maneuver as calculated will drive the spacecraft through gimbal lock. If so, the rotation axis will be readjusted so that the spacecraft will skim the gimbal-lock zone and properly point its x-axis. In general a final roll will be necessary to complete the maneuver. The output of this calculation is transformation $\overset{*}{D}\overset{*}{E}\overset{*}{L}$ representing a rotation about the computed vector by an incremental angle A equal to the selected maneuver rate times the iteration period. (For details see Figure 3-6)

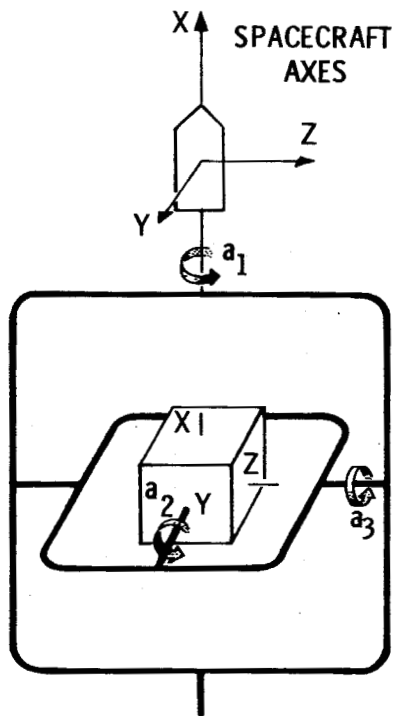
Second, the transformation $\overset{*}{M}\overset{*}{I}\overset{*}{S}$ is developed equal to the initial s/c to stable member axes $\overset{*}{M}\overset{*}{I}\overset{*}{S}_{-1}$ times the rotation matrix $\overset{*}{D}\overset{*}{E}\overset{*}{L}$. Once per computation cycle $\overset{*}{M}\overset{*}{I}\overset{*}{S}$ is updated. Desired CDU angles are developed at each iteration cycle, compared with actual CDU angles, and the difference transformed into control axes to constitute attitude errors. In order to minimize discontinuity, the desired CDU angles are interpolated between computation cycles.

3. 2. 4. CSM RCS DAP Modes and the Hand Controllers

The three-position mode control switch interfaces with the CMC. In the "Free" mode, no jet firings will be made except for rotational and translational accelerations in response to the manual controls, including the minimum impulse control. In the "Hold" mode, the S/C is held about the attitude reached upon switching to "Hold" or upon terminating a manual rotation. In the "Auto" mode the mission program controls the S/C attitude.

The manual translation and rotation controls interface directly with the CMC and have priority at all times, over automatic commands. In the "Hold" mode manual rotation commands cause the vehicle to move at a pre-selected fixed rate about the appropriate axis, and translation commands cause all appropriate jets to fire whenever possible. The CSM RCS DAP responds to manual commands in the "Auto" mode in an identical manner to that in the "Hold" mode; when the crew releases the manual controllers, the DAP will hold the attitude at release; to resume an automatic maneuver the crew must recall it by DSKY command.

* It is not the purpose of this section to define the attitude maneuvering routine. However, Figures 3-3, 3-4 and 3-5 may be useful as a rudimentary explanation.



INERTIAL PLATFORM
WITH THREE ISOLATION
GIMBAL AXES

1. Compute initial \underline{C}_I and final \underline{C}_F
orientation matrix from gimbal angles

2. Compute rotation matrix

$$\underline{R} = \underline{C}_F \overline{\underline{C}_I} \quad \text{components } r_{ij}$$

3. Take antisymmetric part

$$\underline{A} = \frac{1}{2} (\underline{R} - \underline{R}^T)$$

4. Find maneuver angle θ

$$\sin \theta = \sqrt{a_{32}^2 + a_{13}^2 + a_{21}^2}$$

$$\cos \theta = \frac{1}{2} (r_{11} + r_{22} + r_{33} - 1)$$

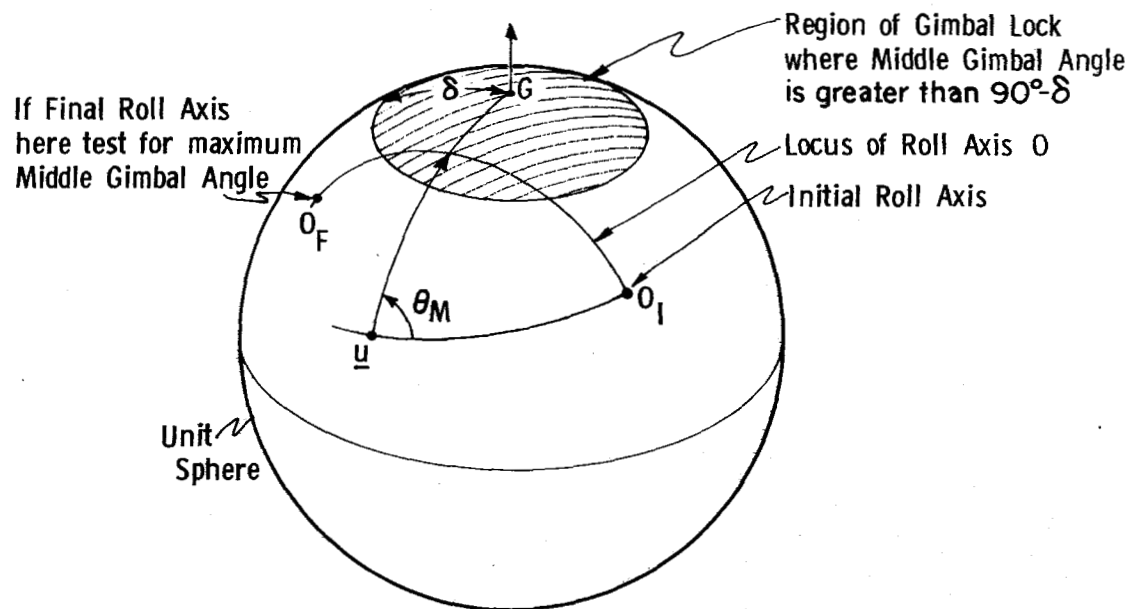
5. Find axis \underline{u} and rate $\underline{\omega}$

$$\underline{u} = (a_{32}, a_{13}, a_{21}) / \sin \theta$$

$$\underline{\omega} = \underline{u} \theta / T$$

Fig. 3-3 Computation of Axis and Angle

DETECTION OF GIMBAL LOCK



- LOGIC**
1. Ensure that the Initial and Final Roll Axis are outside the G region.
 2. Find Angle of Maneuver for maximum a_3 .

$$\theta_M = \text{ARCCOS } \underline{u} \times \underline{O} \cdot \underline{u} \times \underline{G}$$
 3. If $\theta > \theta_M$ Gimbal Lock may occur.
 If $\delta > \text{arc } \underline{O}\underline{G}$ we pass through Gimbal Lock.
 i. e. $\delta > \text{ARCCOS } \underline{u} \cdot \underline{G} - \text{ARCCOS } \underline{u} \cdot \underline{O}_I$

Fig. 3-4 Detection of Gimbal Lock

New maneuver axis \underline{u}' computed so that maximum middle gimbal angle = $\pi / 2 - \delta$

Constraints are

$$\underline{u}' \cdot \underline{O}_I = \cos \alpha$$

$$\underline{u}' \cdot \underline{O}_F = \cos \alpha$$

$$\underline{u}' \cdot \underline{G} = \cos (\alpha + \delta)$$

$$\underline{u}' \cdot \underline{u}' = 1$$

Choose solution \underline{u}' nearest \underline{u}

Final roll is then minimized.

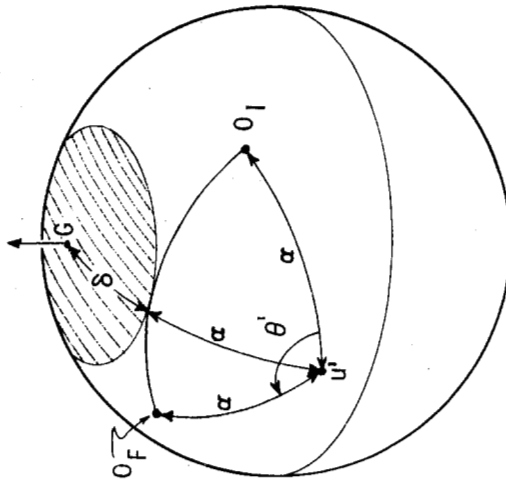
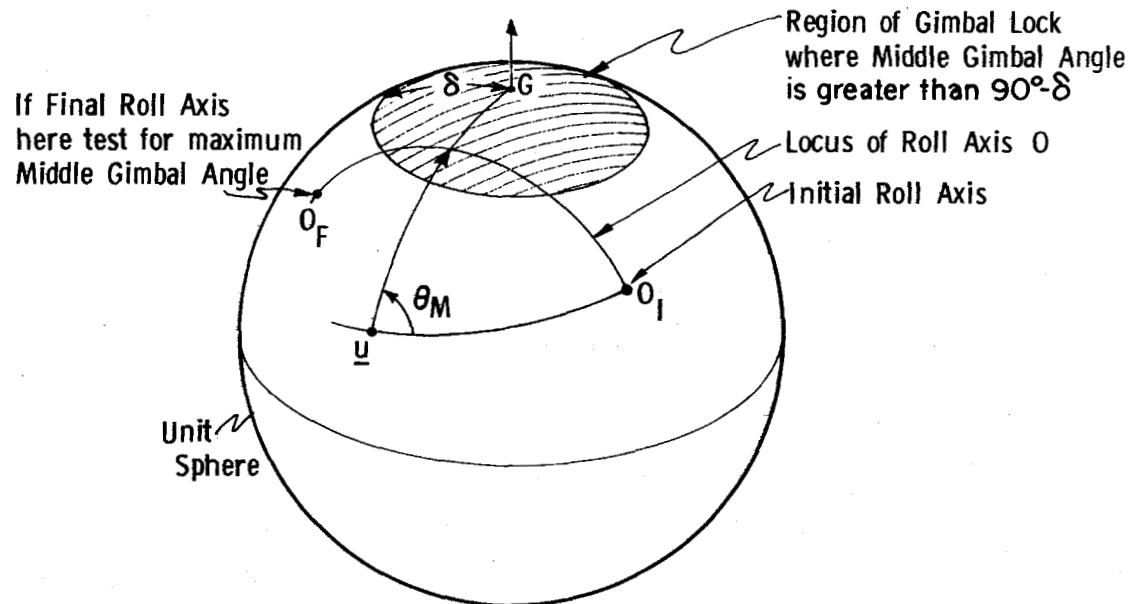


Fig. 3-5 Avoiding Gimbal Lock

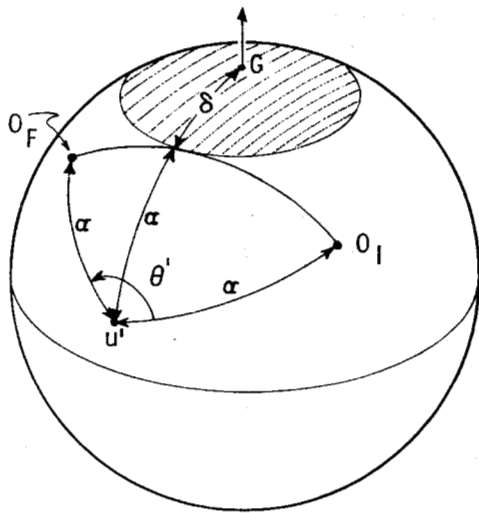
DETECTION OF GIMBAL LOCK



- LOGIC**
1. Ensure that the Initial and Final Roll Axis are outside the G region.
 2. Find Angle of Maneuver for maximum a_3 .

$$\theta_M = \text{ARCCOS } \underline{u} \times \underline{O} \cdot \underline{u} \times \underline{G}$$
 3. If $\theta > \theta_M$ Gimbal Lock may occur.
 If $\delta > \text{arc } \underline{O}\underline{G}$ we pass through Gimbal Lock.
 i. e. $\delta > \text{ARCCOS } \underline{u} \cdot \underline{G} - \text{ARCCOS } \underline{u} \cdot \underline{O}_I$

Fig. 3-4 Detection of Gimbal Lock



New maneuver axis u' computed
so that maximum middle gimbal
angle = $\pi / 2 - \delta$

Constraints are

$$\underline{u}' \cdot \underline{O}_I = \cos \alpha$$

$$\underline{u}' \cdot \underline{O}_F = \cos \alpha$$

$$\underline{u}' \cdot \underline{G} = \cos (\alpha + \delta)$$

$$\underline{u}' \cdot \underline{u}' = 1$$

Choose solution u' nearest u

Final roll is then minimized.

Fig. 3-5 Avoiding Gimbal Lock

Fig. 3-6 Attitude and Rate Transformations

$${}^* \text{MGB} = \begin{bmatrix} 1 & \sin \psi & 0 \\ 0 & \cos \psi \cos \phi & \sin \phi \\ 0 & -\cos \psi \sin \phi & \cos \phi \end{bmatrix}$$

$\phi^*, \theta, \psi = 0, 1, M$ gimbal angles
ONE SECOND UPDATE MATRIX

${}^* \text{DEL} =$ TRANSFORMATION REPRESENTING A ROTATION ABOUT A UNIT VECTOR \bar{u} BY AN ANGLE A

$${}^* \text{DEL} = {}^* I \cos A + \bar{u} \bar{u}^T [1 - \cos A] + {}^* u_x \sin A$$

where ${}^* I = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

$$\bar{u} \bar{u}^T = \begin{bmatrix} u_x^2 & u_x u_y & u_x u_z \\ u_x u_y & u_y^2 & u_y u_z \\ u_x u_z & u_y u_z & u_z^2 \end{bmatrix}$$

$${}^* u_x = \begin{bmatrix} 0 & -u_z & u_y \\ u_z & 0 & -u_x \\ -u_z & u_x & 0 \end{bmatrix}$$

$${}^* \text{MIS} = {}^* \text{MIS}_{-1} {}^* \text{DEL}$$

${}^* \text{MIS} =$ TRANSFORMATION FROM S/C AXES TO STABLE MEMBER AXES

$${}^* \text{MIS} = \begin{matrix} 0 & \cos \theta \cos \psi \\ 1 & -\cos \theta \sin \psi \cos \phi + \sin \theta \sin \phi \\ 2 & \cos \theta \sin \psi \sin \phi + \sin \theta \cos \phi \\ 3 & \sin \psi \\ 4 & \cos \psi \cos \phi \\ 5 & -\cos \psi \sin \phi \\ 6 & -\sin \theta \cos \psi \\ 7 & \sin \theta \sin \psi \cos \phi + \cos \theta \sin \phi \\ 8 & -\sin \theta \sin \psi \sin \phi + \cos \theta \cos \phi \end{matrix}$$

* In order to account for the roll displacements of the reaction jets with respect to navigation base coordinates, $\phi = \text{CDUX } \underline{-7.25^\circ}$.

3.2.5 Rate, Deadband and Jet-Thruster Management

The crew have the responsibility to select or approve the maneuver rate and deadband for the RCS DAP. They also must advise the CMC of failed thruster quads and may insert pseudo fails, if fuel economy dictates, to implement single-jet rotational maneuvers. These various selections have been grouped for economy into a single CMC Noun (Noun _____). As shown in Figure 3-7, the five (octal) characters in the Noun refer to Rate/Deadband, Quad A, Quad B, Quad C and Quad D respectively.

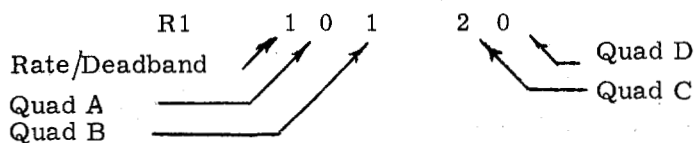


Figure 3-7 Noun _____

Table 3-I defines Rate/Deadband selection in which even numbers (0, 2, 4, 6) specify low deadband and odd numbers (1, 3, 5, 7) specify high deadband and in which increasing numbers in each group specify maneuver rates from lowest to highest. The deadbands are ± 0.5 degrees and ± 5 degrees. The rates are 0.05, 0.2, 0.5, and $4^\circ/\text{second}$.*

The coding for Quads is presented in Table 3-II. A "0" denotes no fails, a "1" denotes a pseudo fail, a "2" denotes a hard fail and a "4" (in any Quad position) specifies B-D rather than A-C for roll control (which will be explained in detail in a later paragraph). It is noted that the difference between a pseudo fail and a hard fail relates to commanded translations; the DAP will not endeavor to perform a translation which requires the use of a hard-failed jet, but will use (reinstate) a pseudo-failed jet. The normal effect of a pseudo fail is to control the selection of quads used for single-jet rotation.

The crew may select which quads are used for roll control and which are used for ullage. If a "4" is inserted in any of the Quad digits of Noun _____, BD is selected for roll; otherwise A-C is used. Normally ullage will use the same quads as roll control. The crew may command different ullage quads by inserting a pseudo fail into either of the quads selected for roll control.

The crew must also periodically update the moment-of-inertia values used in the acceleration prediction.

The applicable program will normally select rates and deadbands for the _____ maneuver (no "4" and no pseudo-fail "1"s, the CMC's standard condition, defines the normal situation of A-C ullage and roll-control, and no one-jet rotations). The crew has the opportunity to approve and change

* The $4^\circ/\text{sec}$ rate is for CSM alone only.

Table 3-I Rate Dead-Band

OCTAL DIGIT	RATE ($^{\circ}$ /sec)	DEADBAND (\pm DEC)
0	0.05	0.5
1	0.05	5
2	0.2	0.5
3	0.2	5
4	0.5	0.5
5	0.5	5
6	4.0	0.5
7	4.0	5

Table 3-II Quad Management

OCTAL DIGIT	REGULAR	SPECIAL	PURPOSE
0	✓		NO FAIL
1	✓		PSEUDO FAIL
2	✓		HARD FAIL
3			ILLEGAL* (1)
4		✓	COMMANDS B-D ROLL
5			ILLEGAL* (2)
6			ILLEGAL* (3)
7			ILLEGAL* (4)

- * 1) interpreted as a hard fail
- 2) interpreted as a pseudo fail plus B-D Roll
- 3) interpreted as a hard fail plus B-D Roll
- 4) interpreted as a hard fail plus B-D Roll

these selections.

An illustrative example of Noun is presented below.

	R A B C D
Noun	3 4 1 1 0
R = 3	+ 5° deadband, .2°/second rate
A = 4, C = 1	Single jet pitch (A)
B = 1, D = 0	Single jet yaw (D)
A = 4, B = 1	Single jet roll (D)
A = 4, B = 1	For pre-TVC operations, ullage is A-C, roll is B-D.

3.2.6 Jet Selection Logic

The reaction jets are identified in Figure 3-8. For the purpose of jet selection we can divide the jets into three groups as shown in Tables 3-III, 3-IV, 3-V, 3-VI. Each group's rotational effect on the vehicle is essentially independent (ignoring c. g. displacement effects in the presence of quad fails or single-jet operation).

In the case of ROLL jets, only one pair of quads is used to perform rotations, in order to save propellants. These roll rotation quads use the same logic as pitch and yaw rotation quads. The remaining pair, the "roll" translation quads, are used only for the appropriate translation when there is no prejudice to rotations being performed by the other pair.

3.2.6.1 Pitch, Yaw, Roll Rotation Logic

If any quad of a rotation pair fails it is impractical to attempt translations since the resulting rotation torque will immediately cause the control system to ask for an opposite torque. Thus, the first step of the logic is to ignore translations in the presence of reported fails. (See Figure 3-9.) Where there is a failure, no attempt is made to fire jets on the failed quad, but an increase is made in the firing time of the jet in the opposite quad to allow for the reduced torque.

In order to provide single-jet operations in attitude hold, the program also allows for pseudo quad fails; however, for reasons stated above, these must be discounted in the presence of translations. (Translational commands will automatically clear pseudo fails from CMC memory.) The final part of the logic is done by table look-up. Each table is in two sections; rotations with translations, and rotations with failures. (See Tables 3-VII, 3-VIII, 3-IX, 3-X)

The torque part of the table is used to correct firing times and to provide correct acceleration estimates to the attitude rate filter. When

3-17

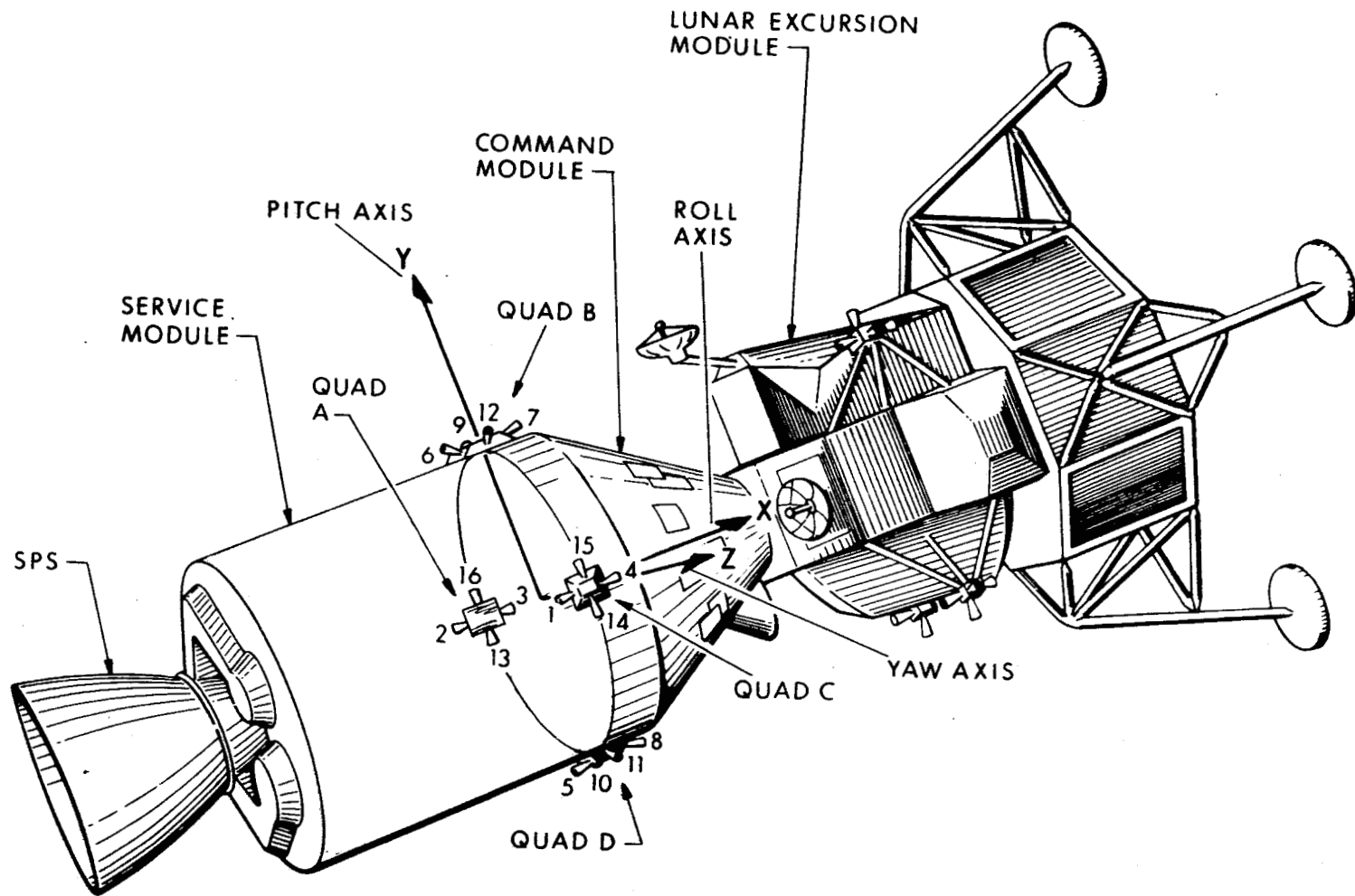


Fig. 3.8 Apollo Spacecraft

TABLE IIIPitch Jets also Control \pm X Translation

<u>Quad</u>	<u>Jet</u>	<u>Pitch</u>	<u>Translation</u>
A	3	+	-X
C	1	+	+X
A	2	-	+X
C	4	-	-X

TABLE IVYaw Jets also Control \pm X Translation

<u>Quad</u>	<u>Jet</u>	<u>Yaw</u>	<u>Translation</u>
B	7	+	-X
D	5	+	+X
B	6	-	+X
D	8	-	-X

TABLE VA-C Jets Controlling \pm Y Translation

<u>Quad</u>	<u>Jet</u>	<u>Roll</u>	<u>Translation</u>
A	13	+	+Y
C	15	+	-Y
A	16	-	-Y
C	14	-	+Y

TABLE VIB-D Jets Controlling \pm Z Translation

<u>Quad</u>	<u>Jet</u>	<u>Roll</u>	<u>Translation</u>
B	9	+	+Z
D	11	+	-Z
B	12	-	-Z
D	10	-	+Z

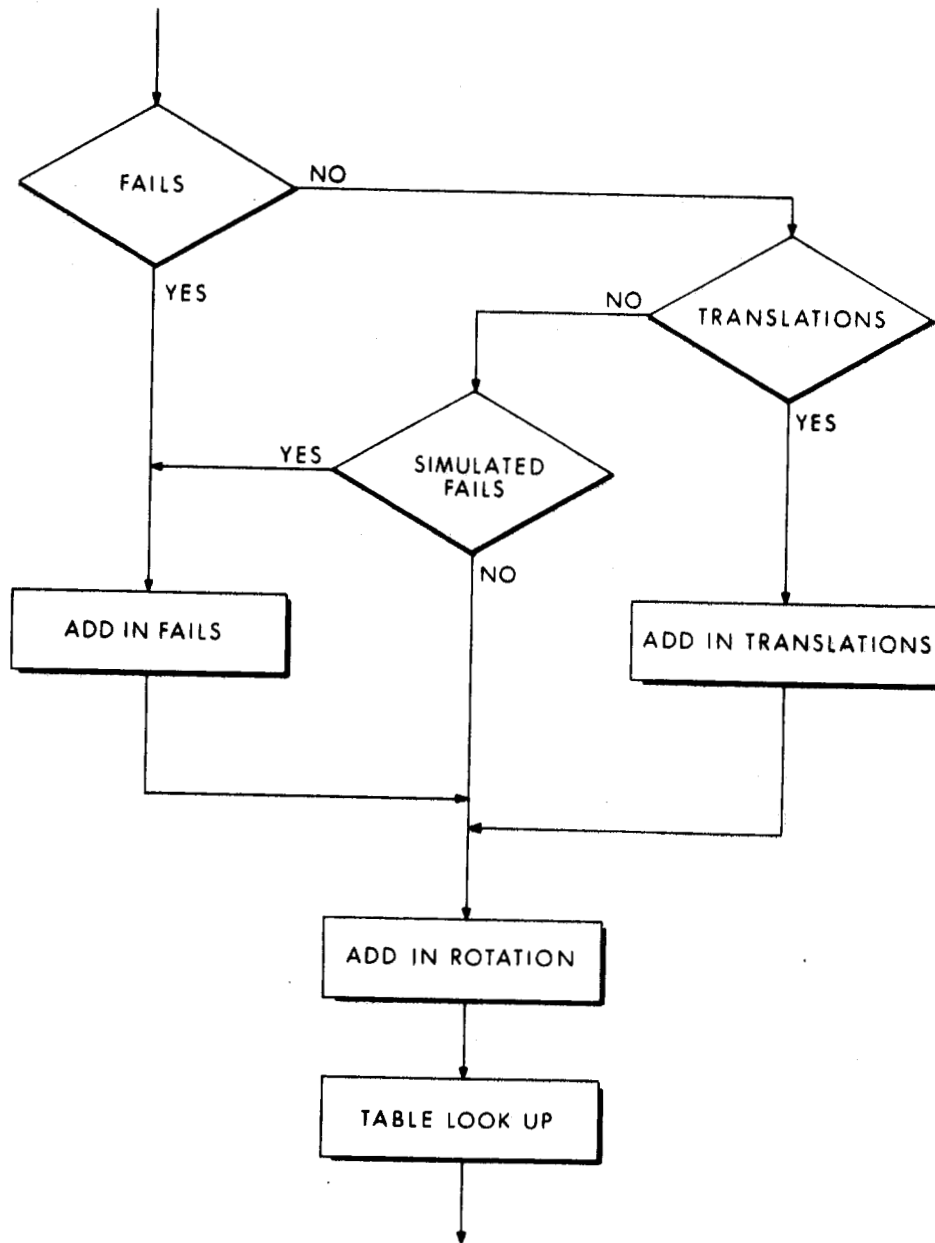


Fig. 3.9 Logic for Rotation Quads

Table 3-VII
Jet Selection for Pitch Rotations

Item	Pitch	X-Translation	Quad Fail	Jets	Torque
1	0	0			0
2	+	0		1,3	2
3	-	0		2,4	-2
4	0	+		1,2	0
5	+	+		1	1
6	-	+		2	-1
7	0	-		3,4	0
8	+	-		3	1
9	-	-		4	-1
10	0		A		0
11	+		A	1	1
12	-		A	4	-1
13	0		C		0
14	+		C	3	1
15	-		C	2	-1

Table 3-VIII
Jet Selection For YAW Rotations

Item	YAW	X-Translation	Quad Fail	Jets	Torque
1	0	0			0
2	+	0		5,7	2
3	-	0		6,8	-2
4	0	+		5,6	0
5	+	+		5	1
6	-	+		6	-1
7	0	-		7,8	0
8	+	-		7	1
9	-	-		8	-1
10	0		B		0
11	+		B	5	1
12	-		B	8	-1
13	0		D		0
14	+		D	7	1
15	-		D	6	-1

Table 3-IX
Jet Selection for A-C Quad Roll

Item	Roll	Y-Translation	Quad Fail	Jets	Torque
1	0	0			0
2	+	0		13,15	2
3	-	0		14,16	-2
4	0	+		13,14	0
5	+	+		13	1
6	-	+		14	-1
7	0	-		16,15	0
8	+	-		15	1
9	-	-		16	-1
10	0		A		0
11	+		A	15	+1
12	-		A	14	-1
13	0		C		0
14	+		C	13	1
15	-		C	16	-1

Table 3-X
Jet Selection for B-D Quad Roll

Item	Roll	Z-Translation	Quad Fail	Jets	Torque
1	0	0			0
2	+	0		9,11	2
3	-	0		10,12	-2
4	0	+		9,10	0
5	+	+		9	1
6	-	+		10	-1
7	0	-		11,12	0
8	+	-		12	1
9	-	-		11	-1
10	0		B		0
11	+		B	11	1
12	-		B	10	-1
13	0		D		0
14	+		D	9	1
15	-		D	12	-1

two jet X-translation is required, the X-translation will normally be performed by the same quads used to satisfy the roll commands. If a failure (pseudo or real) is present however, the translation will be performed by the alternate quad pair provided no real failures are present on these quads.

3.2.6.2. "Roll" Translation Quad Logic

If the unused roll quad pair has a translation demand ($\pm Y$ on A-C or $\pm Z$ on B-D), then, we determine the appropriate jets to fire, allowing for failures, by reference to a table (See Figure 3-10 and Tables 3-XI and 3-XII). As can be seen, in cases of failure, we introduce a roll torque and thus, we must not make the translation if a previous roll demand is nullified.

3.2.7. Counters and Timing for the RCS DAP

Counter T5 is provided for timing the iteration rate of the RCS digital autopilot and other autopilot programs. The counter may be set to any number, and is incremented at 100 pps causing an interrupt (T5 RUPT) on overflow. Counter T6 is provided for timing the length of firing of the Reaction Control jets. The counter may be set to any number, and is diminished at 1600 pps when the T6 activity bit is set. When the counter reaches state zero, an interrupt occurs on the next pulse (T6 RUPT) and the activity bit is knocked down.

At the beginning of each T5 interrupt the GNC A/P Control discrete is examined. If no spacecraft control is required, T5 is reset to sample again in one second. A switch is also set to allow for the initialization of the autopilot variables upon resumption of GNC control. During this initialization phase (phase 0), all appropriate variables, counters, flags and switches are initialized. In addition the Kalman filter is activated to reestablish the angular rate estimates within one second. During this period normal autopilot operation is inhibited. Refer to Figure 3-11.

Because of the length of the T5 interrupt program it has been divided into two parts, phase 1 and phase 2, to prevent excessive delays in the execution of other interrupts. During phase 1, T5 is reset to begin the execution of phase 2 in 20 ms. The vehicle angular rates are then computed (in control axes) and the program updates the attitude error displays on the FDAI. Every tenth iteration a program is called under the executive to compute the gimbal-to-control axis transformation matrix. The CMC is then allowed to resume its previous activity.

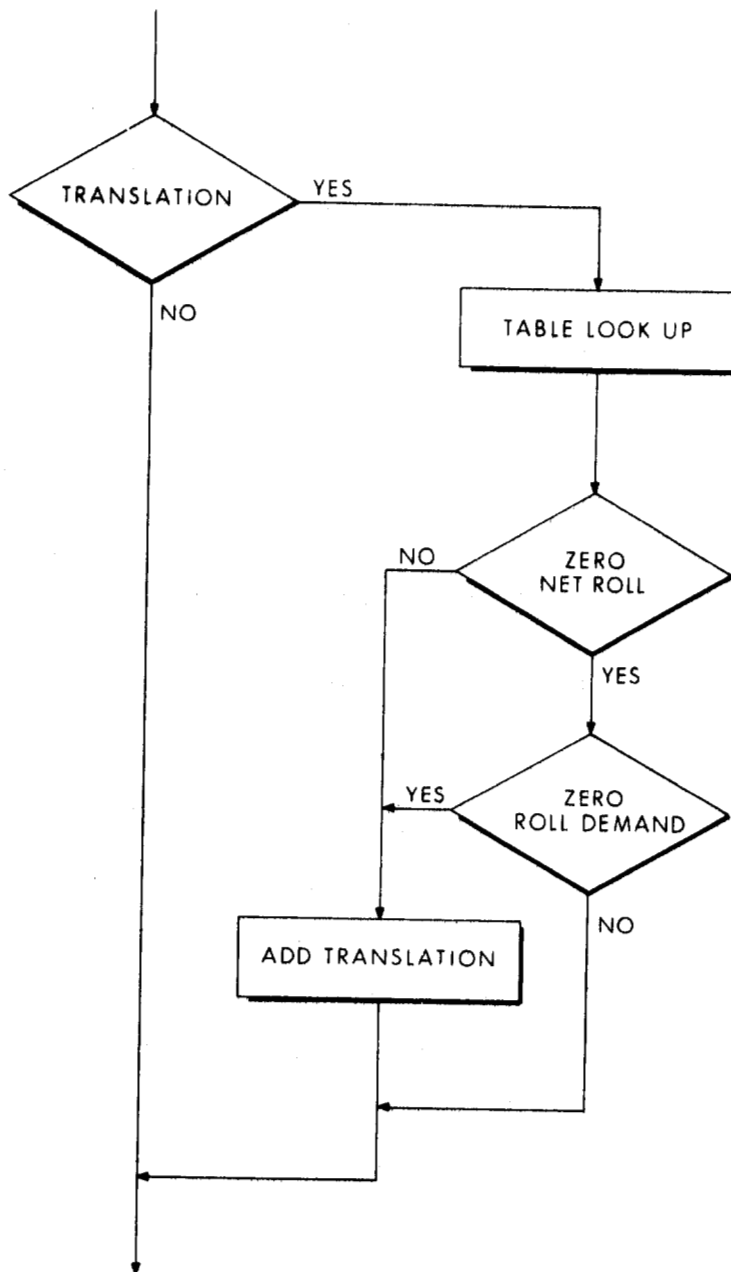


Fig. 3.10 Logic for "Roll" Translation Quads

3-XI A-C Y-Translation Only

Item	Translation	Quad Fail	Jets	Roll Torque
1	0			0
2	+Y		13, 14	0
3	-Y		15, 16	0
4	0	A		0
5	+Y	A	14	-1
6	-Y	A	15	+1
7	0	C		0
8	+Y	C	13	+1
9	-Y	C	16	-1

3-XII B-D Z-Translation Only

Item	Translation	Quad Fail	Jets	Roll Torque
1	0			0
2	+Z		9, 10	0
3	-Z		11, 12	0
4	0	B		0
5	+Z	B	10	-1
6	-Z	B	11	+1
7	0	D		0
8	+Z	D	9	+1
9	-Z	D	12	-1

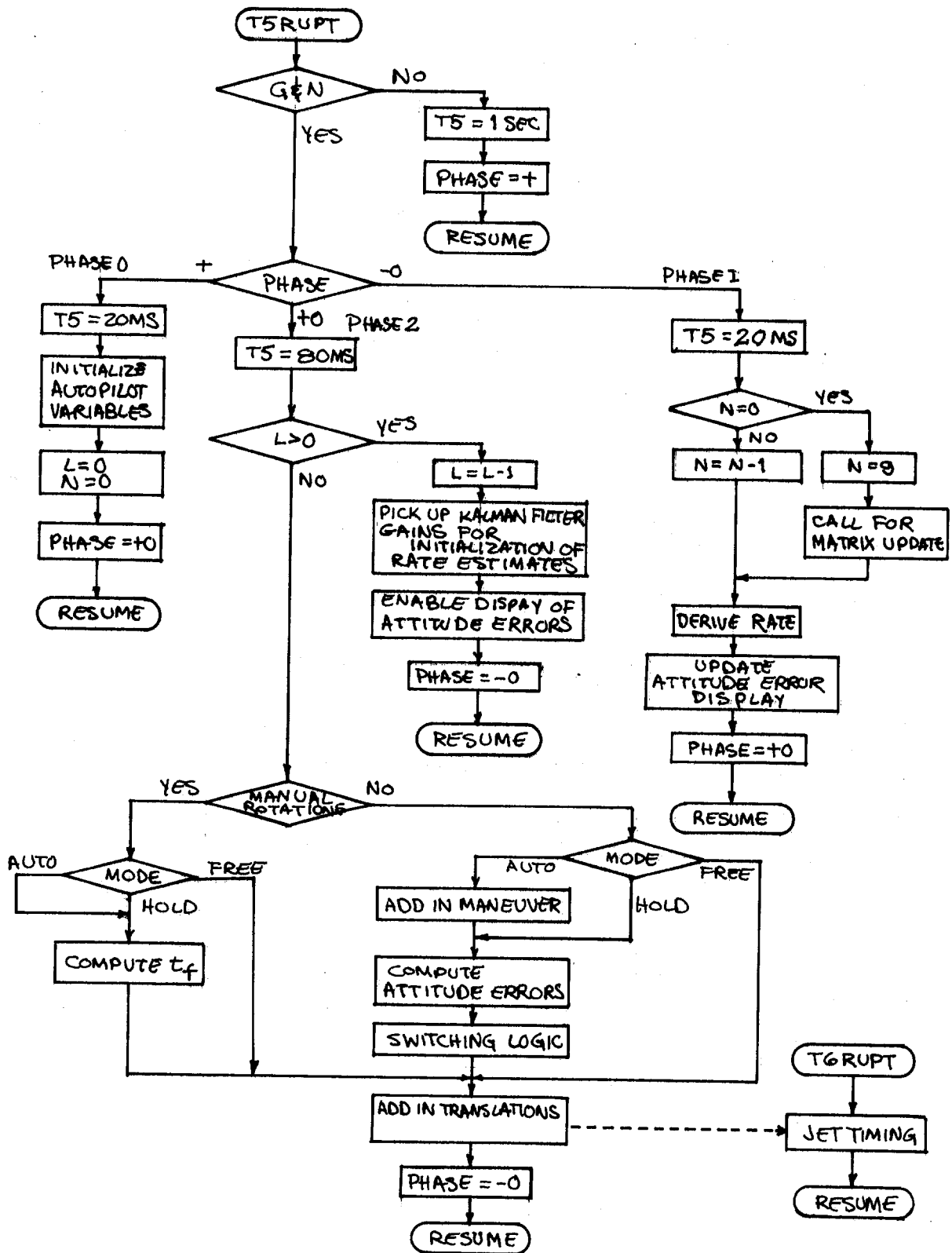


Fig. 3-10 Program Logic Flow

During phase 2, T5 is reset to begin execution of phase 1 in 80 ms. Thus, T5 alternates between phase 1 and phase 2 with a basic iteration rate of 100 ms. If manual rotation commands are present, they are processed in a manner appropriate to the mode, and a flag is set indicating to the attitude hold logic that a new attitude is being set, to be called for on resumption of attitude hold.

Alternatively, if there were no rotation hand controller demands, the modes are examined, and if in "Auto", automatic maneuvers are processed; if in "Hold", a reference attitude is held; if in "Free", the minimum impulse controller inputs are examined and the jet selection logic made as before. The firing times are then computed and other CMC activity resumed.

3.2.7.1 Manual Controls.

The manual control input bits are sampled every iteration of the T5 interrupt, i. e., every 0.1 seconds, except for the GNC control bit, which is sampled once every second after it has been turned off. The minimum impulse controller is sampled only when in the "Free" mode. As a result of the sampling, manual controls will be quantized in time, but so rapidly that the quantization will not be apparent to the crew.

In the "Free" mode both the rotation and translation controllers will result in vehicle acceleration. The combination of rotations and translations is discussed in subsection 3.2.6. the Jet Selection Logic. The minimum impulse controller fires a single pulse (14 msec) of rotation for each occurrence of the discrete, i. e., the controller must be returned to the central position giving a zero discrete before another pulse can be fired. Single-jet operation is obtained by the use of pseudo fails as described in subsection 3.2.5. In the "Auto" and "Hold" modes the rotational hand controller is mechanized to give a fixed rate on each axis. This rate may be chosen from a discrete set. The desired rate is compared with the rate as derived by the filter, and, if the difference exceeds some threshold,* the reaction jets are fired for a length of time to reduce the rate error. The magnitude of this threshold is based upon the current estimate of the roll inertia of the spacecraft. As explained before, a flag is set by a manual rotation to indicate a new desired attitude on return to the attitude hold.

3.2.7.2 Jet Timing

Each T5 iteration cycle, the jet selection logic generates two words of instruction for each axis of control: "Word One" indicates the jets to be fired for combined rotations and translations, "Word Two" indicates which jets are to be fired for translation only.

*The rate deadband is $\pm 3/2$ (minimum impulse torque)/(I-roll), in which I is manually loaded.

The duration of the combined translation and rotation command, t_f , includes the corrections for the number of jets used in generating the required torque (see section 3.2.6.1). Note that all jet firings are limited to a minimum of 14 ms to assure the firing of at least a minimum impulse and the reversal of rate in the limit cycle. (See Figure 3-12.)

If the firing is less than 0.1 seconds, the feedback acceleration time for the rate derivation is set equal to the command, plus any effect due to unbalanced translation, and the rotation command is zeroed. Otherwise t_f is limited to 0.1 seconds, the command is proportionately diminished and the angular feedback acceleration set equal to the number of rotation jets scaled by the sampling interval of 0.1 seconds.

If the firing time is not zero, the T6 counter is set to interrupt after that time, the jet control channel is loaded with "Word One", and t_f is zeroed. On the occurrence of the T6 interrupt "Word Two" replaces "Word One" in the channel.

In practice the T6 counter is shared between three control axes. When there is more than one firing to be timed, the shortest is loaded into T6 first. Subsequently, the counter is loaded with the differences between times. However, the words are changed at the appropriate time as before.

3.2.7.3. Automatic Thrusting with the RCS DAP

For small values of V_g or in the case of contingencies, an automatic TVC maneuver using the RCS autopilot may be employed. In this instance the steering equations will develop the CDU desired angles and the V_g program will generate the automatic translational commands. The autopilot in turn will process these commands in a manner similar to the manual translation discrettes. The automatic command must also specify the number jets to be used in performing X-translation. In the case of ullage two jets will be used.

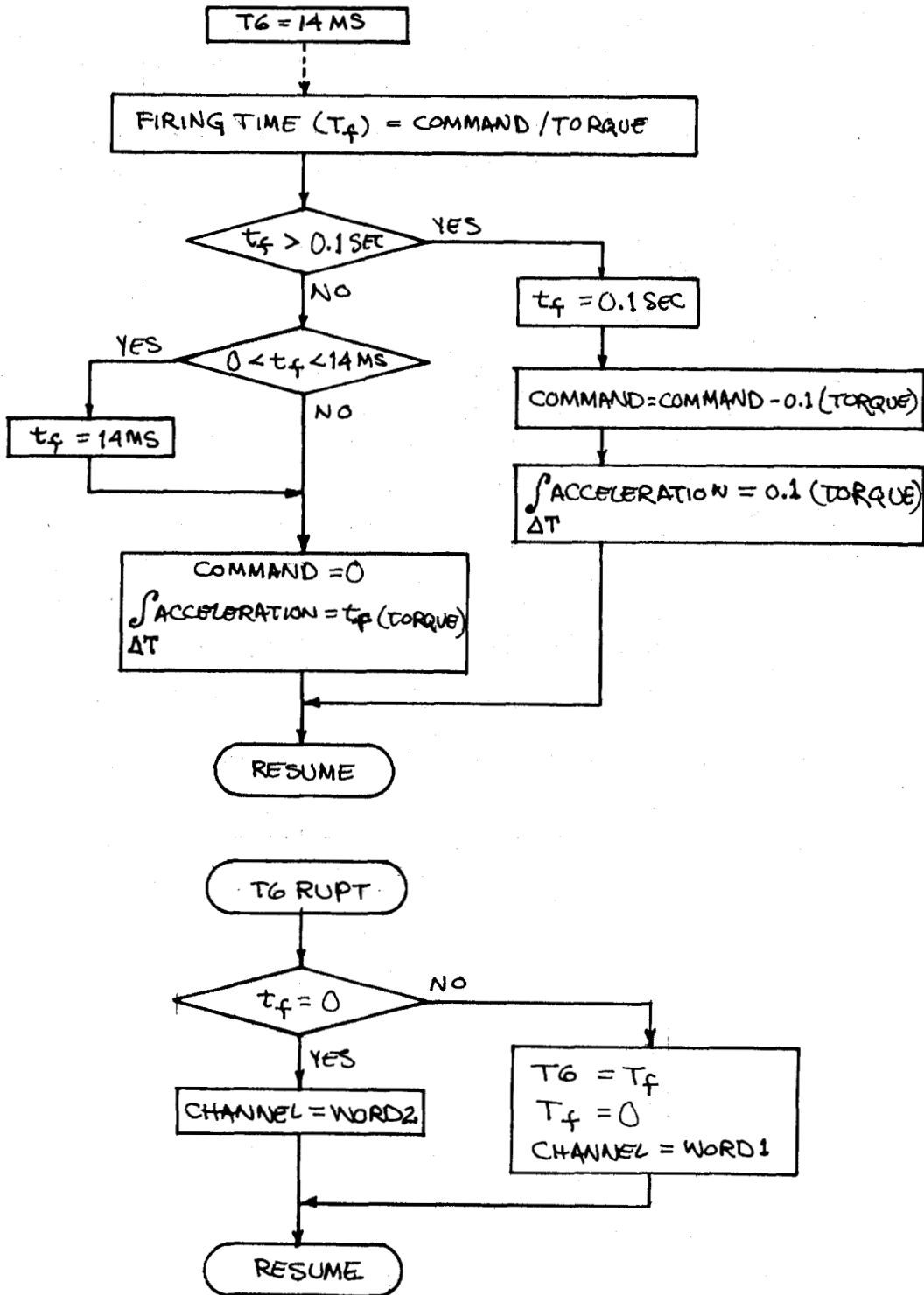


Fig. 3-12 Jet Timing Logic

3.3 TVC Digital Autopilots

During SPS thrusting periods of the CSM, the CMC generates vehicle attitude commands and compares these commands with the IMU-measured vehicle attitude to generate a set of attitude errors expressed as rotations about the pitch, yaw, and roll axes of vehicle. These attitude errors are generated in three steps:

1. Transform the CMC-generated increments in attitude command into equivalent angular increments of the IMU gimbals.
2. Accumulate the IMU angle command increments and compare with the measured IMU angles.
3. Transform the angular errors of (2) into pitch, yaw and roll error about the body axes.

The CMC treats the control of each of the three attitude errors as a separate problem. Three independent control signals are generated by the computer to control the vehicle about the pitch, yaw and roll axes in accordance with the attitude errors about these axes.

Implementation of roll control is achieved by reaction jets whose firing is controlled by a separate roll autopilot program in the CMC computer.

Control of the pitch and yaw attitude of the vehicle is achieved by pitch and yaw deflections of the gimbaled rocket engine of the CSM. These engine deflections are produced by pitch and yaw gimbal servos whose command signals are generated by independent pitch and yaw autopilot programs in the CMC computer.

3.3.1 TVC DAP Design

The TVC DAP programs must fulfill the primary requirement of operating in conjunction with the external guidance loop to provide satisfactorily small velocity pointing errors at thrust cutoff. The DAP programs must also limit excursions in vehicle attitude and in thrust vector in such a way as to minimize propellant usage, gimbal-servo clutch-wear and crew malaise. The regulation of the roll angle within ± 5 degrees of a preset value by a simple roll control program is sufficient to prevent adverse cross-coupling between pitch and yaw controls resulting from the effect of roll transients on the CMC matrix transformations employed to generate pitch and yaw attitude errors.

The DAP programs must operate with uncertainties in initial conditions and with vehicle characteristics which are only roughly defined prior to the 278 flight and which also vary with time during the flight.

3.3.1.1 Uncertain Initial Conditions

The performance of the TVC DAP programs is perturbed by the following uncertainties at SPS engine ignition:

1. Misalignment of the thrust vector relative to the vehicle center-of-gravity. Prior to thrust initiation, the CMC supplies trim signals to the engine-gimbal servos which orient the thrust vector through the estimated position of the vehicle c. g. An error in the c. g. estimation and a misalignment of the engine thrust vector relative to its nozzle center line can combine to produce as much as one-degree misalignment of the thrust vector.
2. Initial turning rates in roll, pitch and yaw. . . Out-of-nominal RCS-jet performance during ullage may lead to turning rates at SPS ignition of up to one degree-per-second.
3. Slosh-mass displacement. . . Initial displacements of the fuel and oxidizer slosh masses in the CSM tanks may be as much as 0.27 times the radius of the tanks.

3.3.1.2 Variation in Vehicle Characteristics

The dynamical characteristics of the CSM-LM docked vehicle are sufficiently different from those of the CSM alone as to require the development of separate autopilot programs tailored to the characteristics of each vehicle. The three principal differences in the two vehicles are:

1. The bending mode frequencies of CSM-LM vehicle are as low as approximately 1 cps, while the bending mode frequencies of the CSM alone are more than a decade higher.
2. There are substantial differences in the moment arm of the gimbaled engine to the center of gravity and in the vehicle moment of inertial between the CSM and CSM-LM Vehicles. As a result of these differences a given deflection of the gimbaled engine of the CSM alone produces almost 4 times the angular acceleration which would be produced by the same deflection in the CSM-LM vehicle.
3. The fuel and oxidizer slosh picture in the CSM-LM vehicle is different from the CSM alone, because of the additional slosh masses in the LM tanks and the effects of the increased mass of the overall vehicle.

The problem of minimizing the excitation of slosh modes and preventing any de-stabilization of these modes is of comparable importance in both CSM and CSM-LM vehicles. The problem of avoiding the excitation of the bending modes and preventing their potentially de-stabilizing influence is primarily a problem in CSM-LM autopilot design.

The Pitch/Yaw DAP design for the CSM alone is presented in Section 3.3.2. The Pitch/Yaw DAP design for the CSM-LM is presented in Section 3.3.3.

3.3.1.3 The Autopilot Programs and Associated Guidance Equations

Programming implications of the autopilots and guidance system, computer utilization, and flexibility of performance are discussed in Section 3.3.5. The stroking test to definitively determine CSM-LM bending modes is discussed in Section 3.3.6.

3.3.2 CSM Pitch-Yaw Autopilot

Figure 3-13 shows a schematic block diagram of one channel (pitch or yaw) of a pitch-yaw autopilot which can serve as a basis for describing the autopilots of both the CSM and CSM-LM vehicles. For the sake of simplification this diagram neglects the various transformations involved in generating the pitch and yaw attitude errors, and treats these errors as if they were generated by the comparison of command and feedback signals expressed in body coordinates. The role of the CMC computer in this autopilot is to perform a dynamic filtering operation on the sampled attitude error, $e^*(t)$, as required to generate a suitable sampled command to gimbal-servo, $\int_c^*(t)$. A digital-to-analog converter changes the gimbal servo command signal to an analog voltage which it holds for each sample period. The output of this digital-to-analog converter is quantized with increments of 0.0237 degrees. Both the command signal and the feedback signal are also quantized, with increments of .0111 degrees.

The operation of the CSM autopilot is best explained in terms of the mathematical tools by which the autopilot was designed. The design of the autopilot was carried out in terms of a linearized model of the vehicle, engine gimbal servo, and autopilot filter which neglected the signal quantization and other non-linearities in the engine-vehicle system. Using this linearized model, the characteristics of the digital filter and the engine-vehicle system can be described in terms of pulse transfer functions, which can be conveniently combined to describe the overall system. The use of these pulse transfer functions to describe the system is illustrated in Figure 3-14. Here, the transfer function of the vehicle plus engine gimbal servo plus digital-to-analog converter is represented by the pulse transform $G^*(s)$.

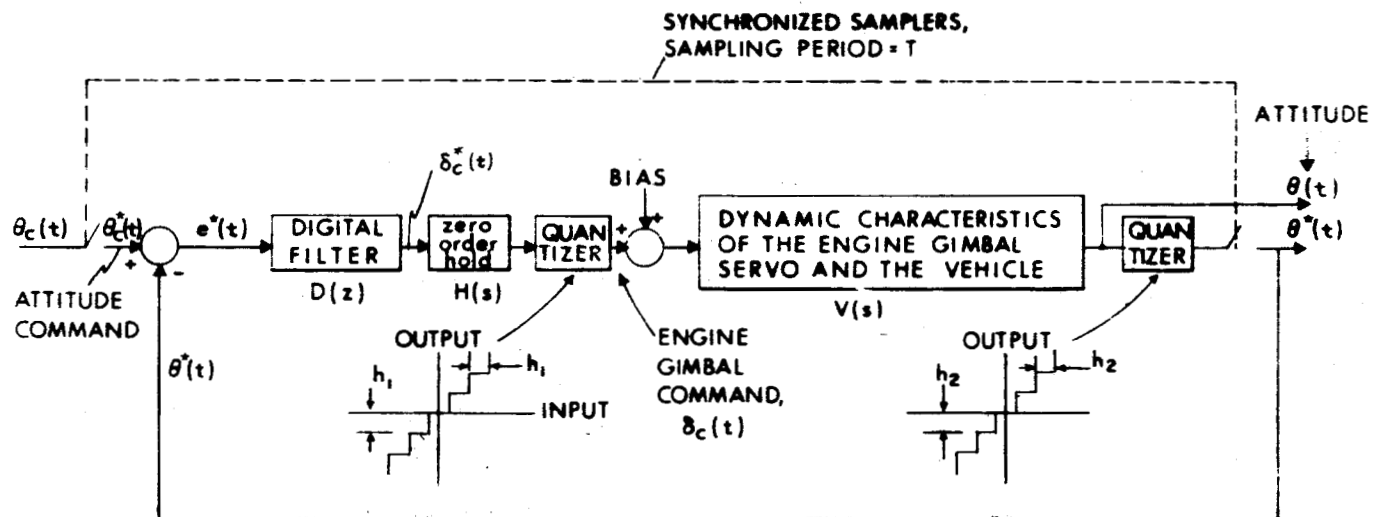


Fig. 3.13 Simplified Schematic Block Diagram of One Channel of the CSM Pitch-Yaw Autopilot.

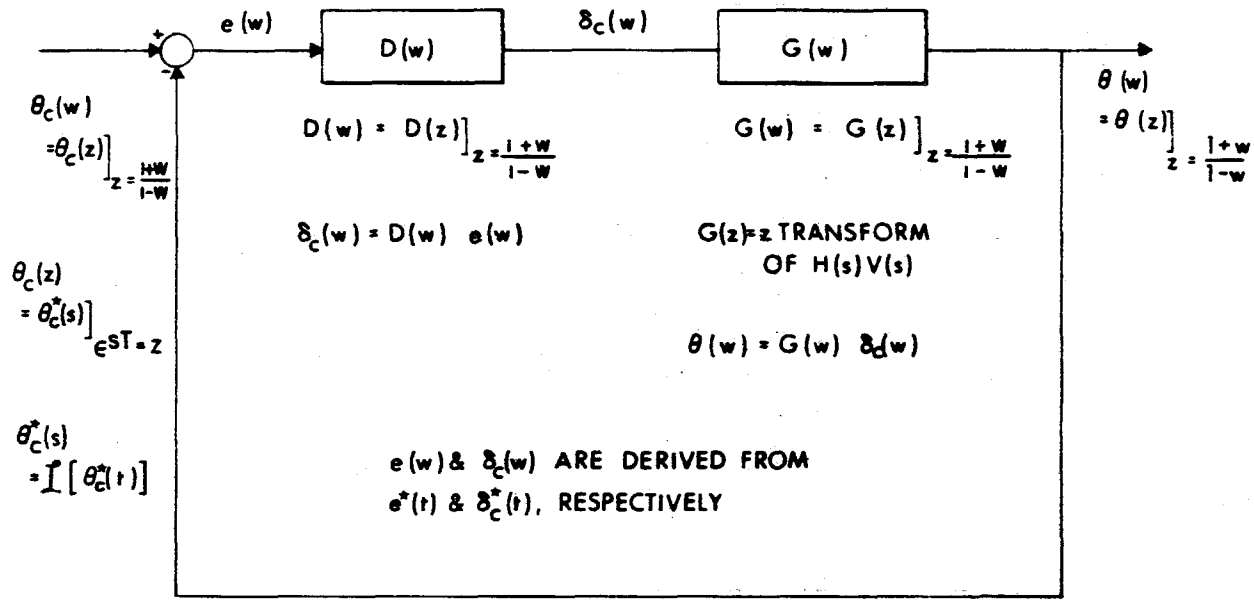


Fig. 3.14 Digital Autopilot Transfer Function Relationship

This transform may be alternatively expressed as the z transform,

$$G(z) = G^*(s) \Big]_{e^{st} = z}$$

or in terms of the w transform,

$$G(w) = G(z) \Big]_{z = \frac{1+w}{1-w}}$$

Similarly, the digital filter transfer function is represented by $D^*(s)$, $D(z)$, and $D(w)$. The open-loop transfer function of the autopilot system is then given by the product of the two component transfer functions, e. g., $D(w)G(w)$. The overall transfer function of the system is given by

$$\frac{\Theta(w)}{\Theta_c(w)} = \frac{D(w)G(w)}{1 + D(w)G(w)}$$

The autopilot design can be described and analyzed conveniently either in terms of the z transforms or in terms of the w transforms. The z transforms offer the advantage that $D(z)$ can be translated directly into computer program equations. The w transforms, on the other hand offer the advantage that the characteristics of the engine-vehicle system and any variations in these characteristics can be readily expressed in terms of the poles and zeros of $G(w)$.

It can be shown that $G(w) \Big]_{w = ju} = G(ju)$ when plotted versus u for $0 < u < \infty$ represents the real frequency response of the sampled engine-vehicle system over the real frequency range $0 < \omega < \omega_s/2$

That is,

Real-frequency response function =

$$\text{for } \begin{matrix} G^*(j\omega) = G(j\omega) \\ \Big] \\ u = \tan \frac{\omega T}{2} \\ 0 < \omega < \omega_s/2 \end{matrix}$$

where

T = sampling period, seconds

$\omega_s = \frac{2\pi}{T}$ = sampling frequency, radians/second

Similarly, the substitution of $u = \tan \frac{\omega T}{2}$ transforms

$D(ju) G(ju)$ and $\frac{D(ju) G(ju)}{1 + D(ju) G(ju)}$ into open loop and closed loop real-frequency response functions. It should be noted that for most of the frequencies of interest in the autopilot design the relationship between u and ω may be approximated by

$$u \approx \frac{\omega T}{2} \quad [\text{ where } u \ll 1]$$

The conventional, open-loop frequency-response methods of design which have been developed for continuous-data systems have been applied also to the sampled-data autopilot, using $D(j\omega)G(j\omega)$.

The selection of the compensation filters for the CSM alone and for the CSM-LM docked vehicle is strongly influenced by stability requirements. These requirements are conveniently described in terms of the open-loop phase characteristics in the vicinity of the frequency values where the open-loop magnitude approaches or crosses 0 db.

In the case of the CSM alone, the magnitude of the uncompensated function, $G(j\omega)$, drops off with frequency roughly as $1/\omega^2$ out to the slosh frequency range, and then somewhat beyond this range. The slosh resonances occur near $\omega \approx 0.09$ (or $\omega \approx 4.5$ rad/sec). Here, there are several closely-spaced, complex zero-pole pairs produced by fuel and oxidizer slosh in the CSM storage and sump tanks. In the case of Flight 278 only the sump tanks will be filled, producing two slosh modes, each resulting in a complex zero pair followed closely (in frequency) by a complex pole pair. Above the slosh frequency range, the slope of the magnitude drop-off becomes more steep as the result of the poles of the engine gimbal servo. Present bending-mode data indicates that the CSM bending-mode resonances can be neglected in their effects on the autopilots stability and control characteristics.

The phase shift of the CSM open-loop function, $G(j\omega)$, starts at a low-frequency value of -180 degrees, produced by the rigid-body rotation relationship. The time lags of the engine gimbal servo cause this negative phase shift to increase steadily in the range of frequency affected by the compensation filter. The zero-pole combinations resulting from slosh cause the phase angle to rise almost abruptly by nearly 180 degrees at the slosh zero frequency and to decay with the same steep slope at the pole frequency. Thus, the effect of the slosh zero-pole combination is to add a narrow, almost square, positive pulse in phase angle of nearly 180 degrees amplitude, to the open-loop phase angle curve that would occur in the absence of slosh.

The digital filter function of the autopilot program for both pitch and yaw control of CSM alone is a simple, first-order, z-transform transfer function*,

$$\frac{d_c(z)}{e(z)} = D(z) = 2.62 \left[\frac{z - 0.98}{z - 0.64} \right]$$

whose w-transform representation is

$$D(w) = 3.17 \left[\frac{w + 0.010}{w + 0.22} \right]$$

* The autopilot program is so mechanized that the filter may be extended to a third-order filter by manipulation of erasable memory. The generalized filter must have poles in the unit circle and zeroes in the double unit circle.

This filter employs a sampling time of $T = 0.04$ seconds, resulting in a low-frequency proportionality between the real frequency, ω , and the non-dimensional frequency, u [$w = ju$] given by

$$\omega = \frac{2}{T} u = \frac{2}{0.04} u = 50 u$$

The gain factor of the filter is selected to produce a 0-decibel crossover of the open-loop transfer function, $D(ju)G(ju)$, at $u = 0.03$ or $\omega = 1.5$ rad/sec. for a 26% full CSM. The CMC automatically changes this gain factor as a function of time during the thrusting periods so as to maintain the crossover frequency at approximately the same value.

The lead-lag filter function is designed to shape the open-loop phase shift at the main 0-db crossover frequency and in the vicinity of the slosh resonances. A positive phase margin of 40 degrees (where phase angle = $-180 + 40$ degrees) is produced at the main crossover frequency. The no-slosh phase angle is maintained at about -150 degrees in the slosh region, as required to provide over 30 degrees positive phase margin where the slosh resonance peak crosses 0 db.

The above filter function appears to give satisfactory response characteristics both with and without the guidance loop for the conditions of Mission 278.

As mentioned previously, one of the major obstacles to be overcome by the digital autopilot is the effect of an initial error in the alignment of the thrust vector through the vehicle center of gravity. This misalignment causes the attitude error to increase from its initial value of zero to approximately δ_{cg}/K_{SS} , where δ_{cg} is the angular misalignment of the thrust vector and K_{SS} is the steady state gain of the digital filter, as given by:

$$K_{SS} = D(w) \Big|_{w=0} = D(z) \Big|_{z=1}$$

Thus, in the steady state, the value of the attitude error must be such that the resulting output of the digital filter produces an engine deflection which is equal and opposite to the initial thrust misalignment. It is important to note that this steady state attitude error produced by thrust misalignment does not in general mean a steady state pointing error in the velocity of the guided vehicle, because the external guidance loop will act to readjust the attitude command signal to the autopilot to compensate for this attitude error. However, the pointing error can be appreciable during the short thrusting periods when there is insufficient time for the external guidance loop to react to the thrust vector misalignment before thrust cutoff. Investigations of the CSM autopilot with a closed guidance loop for short thrusting periods indicate that the resulting pointing errors are acceptable

for Apollo missions.

The value of K_{ss} based on the above compensation function is 0.146, which gives an approximate steady-state attitude error of 6.87 degrees per degree of misalignment of the thrust vector.

3.3.3. CSM-LM Pitch-Yaw Autopilot

One of the problems of generating a final design for the pitch-yaw autopilot of the CSM and CSM-LM vehicles has been the uncertain nature of the data on vehicle characteristics. The uncertainty in data has had a more severe effect on the design of the CSM-LM autopilot than it has had on the design of the autopilot of the CSM alone. Of very great concern is the uncertainty in the bending mode characteristics of the CSM-LM vehicle. The autopilot design is predicated upon the theoretical spacecraft characteristics presented in Section 6. If minor modifications in the vehicle data occur before the Mission 278 flight, they can be accommodated by means of manipulation of coefficients in erasable memory.

The problem of selecting a compensation filter function for the CSM-LM system is complicated by the fact that the bending modes of this vehicle system occur at lower frequencies than those of the CSM alone, and therefore can not be neglected in the compensation design. The most recent theoretical estimates indicate that the first bending mode frequency may be as low as 1 cps, which is only a factor of two above the slosh-resonance region (near 0.5 cps). The problem is further complicated by the fact that the values of the bending mode frequencies are presently somewhat in doubt, pending the completion of new theoretical estimations.

The present uncertainty in the degree of separation of the bending mode frequencies precludes consideration of any approach to compensating these modes on an individual basis, either by adaptive or non-adaptive control functions. Furthermore, uncertainties in the data also preclude any assumptions on the phase behavior of the higher order bending modes, as required for their phase stabilization. Only the first bending mode can be safely phase-stabilized at this time; the remaining modes must be gain stabilized (by attenuating their peaks below 0 db).

An autopilot design whose stability is essentially insensitive to vehicle bending characteristics is planned for Flight 278. This design is based on a drastic drop-off in open-loop gain starting below the slosh frequency, which produces a very conservative gain stabilization of the bending modes at 1 cps and above. The filter function also provides a phase stabilization in the 0.5 cps to 1 cps region which allows the first bending mode to be lower than its ~1cps estimated value. Slosh mode

stabilization is achieved by a combination of gain and phase shaping. The insensitivity of this autopilot to bending characteristics is accomplished at the expense of a decreased autopilot bandwidth and a decreased d-c gain of the filter function (compared to the CSM alone system). These performance degradations would significantly impair the system's ability to compensate for thrust vector misalignment were it not for the addition of a special CMC computation feature that corrects for this misalignment independent of autopilot action. The logical process leading to the selection of the Flight 278 compensation is outlined below, followed by a detailed description of the 278 autopilot functions.

The use of a lead compensation such as that employed for the CSM alone is not suitable for the CSM-LM because of the need to gain stabilize the higher order bending modes. The lead stabilization diminishes the slope of the gain drop-off beyond the main 0 db crossover frequency. With this reduced slope, it is necessary to lower the crossover frequency very drastically in order to achieve the required attenuation at the bending modes. It can be shown that the required crossover frequency is unacceptable, regardless of whether the first bending mode is phase-lead or gain stabilized.

If the first bending-mode frequency were appreciably higher than its presently estimated value of 1 cps - of the order of 2 cps - then a modification of the CSM - alone lead function would be possible that would phase compensate the first bending mode, gain compensate the higher modes and allow the lead compensation of the slosh mode to be retained. This modification would involve an appreciable but tolerable reduction in the 0 db crossover frequency and an accompanying reduction in the break frequency in the numerator of the lead compensation function. The modification would replace the single order pole in this function by two underdamped, complex pole pairs whose natural frequencies occur between the slosh and first bending mode frequencies. The added poles would produce a very rapid change in the phase angle between the slosh and bending resonances. By the proper choice of natural frequencies and damping ratios for the two pole pairs it is possible to achieve almost any desired phase angle as required to phase compensate the first bending mode resonance. Furthermore, the drastic increase in the rate of gain drop off produced by these poles facilitates the gain compensation of the higher order bending modes. The shape of the first bending mode is such that a positive excursion in phase angle of almost +180 degrees is produced by the zero-pole combination resulting from this mode. The phase stabilization of this mode may be said to require that the resulting open loop phase angle come no closer than + 35 degrees to 180 degrees. This requirement means that the phase angle

just prior to the bending zero-pole combination must be between -35 degrees and -145 degrees. Assuming that the open loop phase angle just following the slosh frequencies is $-180^{\circ} + 35^{\circ} = -145^{\circ}$, the needed phase change for first bending mode compensation ranges from -250° to 360° . This range would seem to give ample leeway for the selection of the compensation pole pairs. However, this compensation approach offers one main difficulty: the undesirable peaks in magnitude resulting from the fact that the compensation poles are underdamped. If the slosh and bending frequencies are closer to each other, a more rapid change in phase versus frequency change is required, necessitating smaller damping ratios in the poles. The presently specified value of 1 cps for the first bending mode is not considered sufficiently separated from the slosh region for adequate stability margins to be produced by this compensation approach. That is, the resulting resonance peaks between the slosh and bending frequencies would be too close to 0 db. This compensation approach might be worth reconsidering if the new estimations give a first bending mode frequency near 2 cps.

It should be pointed out that one other approach exists for producing a rapid negative phase change between the slosh and first bending mode frequencies. This approach employs an added complex zero pair with a positive real part, in conjunction with a complex pole pair having a negative real part. This alternative approach offers the possibility of avoiding large resonance peaks in producing a large phase change. However, the compensation does not provide the needed increase in gain drop-off rate required for gain stabilizing the higher order bending modes, and therefore was rejected for Flight 278.

The foregoing discussion has covered the various methods of compensating the bending modes that would not alter the CSM-alone approach of lead compensating the 0 db crossover and the slosh modes. All of these methods have been rejected on the basis of present bending mode data.

The next logical step in compensation design is to consider the possibility of altering the slosh mode compensation. The present state of the uncertainties in the bending mode data tends to rule out all but one such possibility. This approach involves a drastic reduction in both gain and phase prior to the slosh mode, produced by two underdamped, complex pole pairs. The damping ration of 0.5 is employed in these pole pairs to provide the maximum rate of change in the open-loop phase angle consistent with a requirement of no peaking in the open-loop gain. This compensation produces an open-loop phase angle of ~ -35 degrees in the slosh frequency region, thereby phase stabilizing the slosh modes. It also produces an attenuation of roughly -30 db in the slosh region, which may be sufficient

to gain stabilize the slosh modes. The very rapid drop-off in gain above the slosh frequency is more than sufficient to gain stabilize any bending mode occurring at 1 cps and above. The filter function even guards against the possibility of a first bending mode less than 1 cps by providing a phase stabilization of such a bending mode between 0.5 cps and 1 cps. Unfortunately, the added phase angle at low frequencies produced by these compensation poles requires a reduction in the 0 db crossover frequency (to $f = 0.05$ cps) and an accompanying reduction in the break frequency of the single zero that provides the phase lead at the main crossover frequency. These reductions decrease both the bandwidth and d-c gain of the compensation filter to the point that the filter is no longer capable of compensating for the effects of an initial thrust misalignment. Thus, the d-c gain of the filter implementing this approach is only ~ 0.03 for a 42% full CSM-LM yielding a steady-state attitude error of ~ 33 degrees per degree misalignment of the thrust vector. However, a method to compensate for this deficiency has been developed. This method employs a computer program to generate an estimated correction to the initial gimbal trim signal, as shown in Figure 3-15. The correction is computed and inserted approximately 2-3 seconds after thrust initiation (after thrust has reached a steady-state condition and after one period of slosh oscillation has elapsed.)

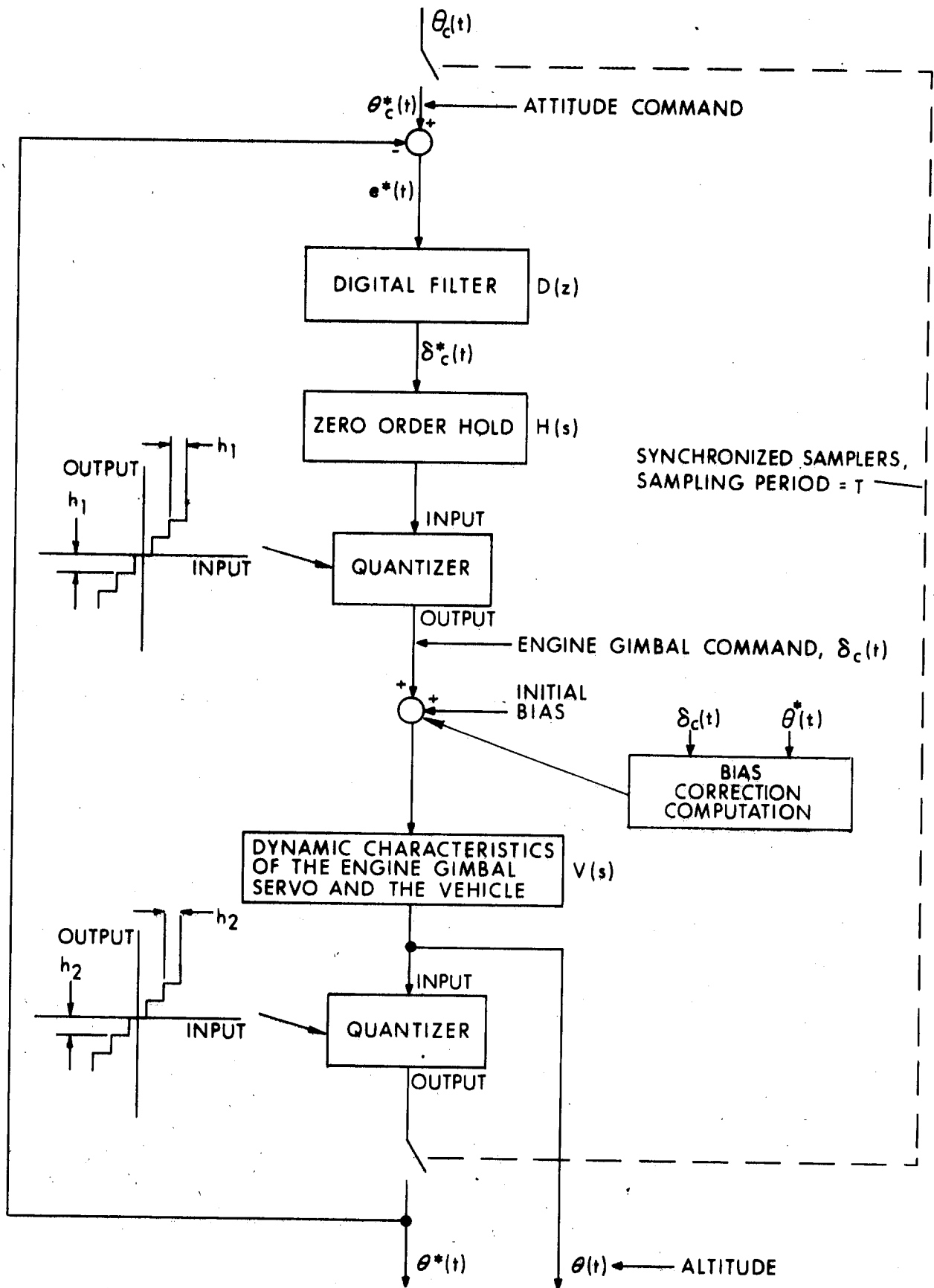


Fig. 3-15 Simplified Schematic Block Diagram of One Channel of the CSM-LEM Pitch-Yaw Autopilot

The trim or gimbal bias correction computation is based on the double integration of a simplified rigid-body equation of motion:

$$I \ddot{\Theta} = T l_x [\delta'_c(t) + \delta_{bc}]$$

in which

- I = moment of inertia about the appropriate axis
- $\ddot{\Theta}$ = vehicle angular acceleration about the appropriate axis
- T = engine thrust
- l_x = moment arm (from hinge - point to c. g.)
- $\delta'_c(t) = \delta_c(t - \tau)$
- τ = approximate time delay for engine gimbal servo
- $\delta_c(t)$ = engine gimbal command supplied by autopilot filter
- δ_{bc} = initial offset of the thrust vector (to be computed as bias correction).

Integration of the rigid-body equation gives

$$\Theta(t) = \dot{\Theta}(0)t + K \int_0^t \phi(t) dt + \left[K \frac{t^2}{2} \right] \delta_{bc} + \Theta(0)$$

where

$$\phi(t) = \int_0^t \delta'_c(x) dx$$

x = dummy variable of integration

K = T l_x/I

The evaluation of this relationship at t = 0, t = T₀ and t = 2T₀ yields

$$\delta_{bc} = \frac{\Theta(2T_0) - 2\Theta(T_0) + \Theta(0)}{K T_0^2} - \frac{\int_{T_0}^{2T_0} \phi(t) dt - \int_0^{T_0} \phi(t) dt}{T_0}$$

This expression is evaluated by the CMC from the measured autopilot system behavior over a 2T₀ sec. period.

The effects of propellant slosh were not included in the foregoing derivation. However, it can be shown that these effects can be reduced to an acceptable level if a good estimate of the period of the predominate slosh mode is available. This minimization is accomplished by making T₀ = slosh mode period, resulting in a δ_{bc} computation time of two slosh periods.

Slosh effects can also be reduced by averaging two computations of δ_{bc} taken over the first and second halves of the slosh cycle, where T₀ = (1/4) x (slosh period). This latter approach is planned for Mission 278.

The bias correction scheme effectively neutralizes the initial thrust misalignment. The low-bandwidth autopilot achieves the following:

1. phase stabilizes the slosh mode at 0.5 cps,
2. phase stabilizes the first bending mode also, out to 2 cps, and
3. gain stabilizes any bending modes occurring above 2 cps.

The filter function, $D(z)$, of the Mission 278 autopilot for the CSM-LM vehicle is as follows:

$$D(z) = \frac{K_c \prod_{i=1}^{i=7} (z-p_i)}{\prod_{i=1}^{i=7} (z-g_i)}$$

where $K_c = 1.638 \times 10^{-3}$

$T =$ sampling time $= 0.08$ seconds.

and where the zeros and poles of $D(z)$, and their corresponding factors, are as follows:

Zeros:

$z = 0.61088$
 $z = -0.9920$
 $z = +0.9920$
 $z = +0.4279 \pm j 0.6821$
 $z = +0.7521 \pm j 0.4858$

Corresponding Factors:

$(z - 0.61088)$
 $(z + 0.992) (z^2 - 0.9841)$
 $(z - 0.992)$
 $(z^2 - 0.8558z + 0.6483)$
 $(z^2 - 1.5042z + 0.8016)$

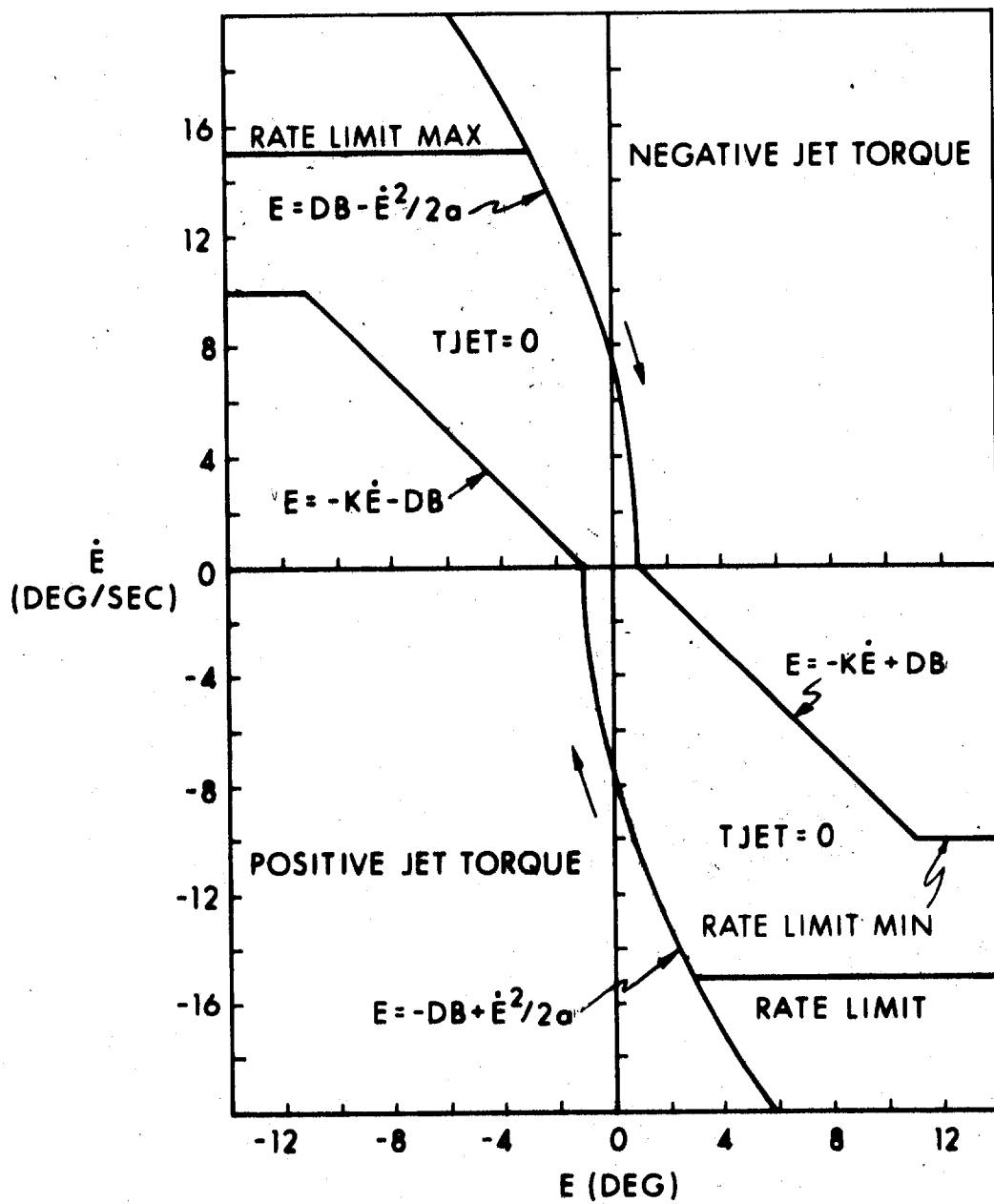
Poles:

$z = 0.000$	z
$z = 0.5385$	$(z - 0.5385)$
$z = 0.5385$	$(z - 0.5385)$
$z = 0.9257 \pm j 0.1129$	$(z^2 - 1.8515z + 0.8698)$
$z = 0.9257 \pm j 0.1129$	$(z^2 - 1.8515z + 0.8698)$

3.3.4. Roll Autopilot

During thrust vector control using the SPS engine, "roll control" is effected by maintaining the outer gimbal angle (OGA) close to a preselected value. Prior to ignition the astronaut may roll the vehicle to a preferred orientation, if desired. The OGA corresponding to the orientation at ignition will be maintained throughout the powered maneuver. It is expected that under nominal conditions the inner and middle gimbal angles will be near zero at the start of a major powered maneuver. As a result OGA control is equivalent to roll control. With a sizeable initial MGA (e. g., 45°) some roll motion will occur but this is not considered significant.

The roll autopilot is an adaptation of the LM p-axis control as documented in Chapter III of R-499, 7/65. The phase plane switching curve is shown in Figure 3-16 for convenience. The slope of the straight line is chosen at $K = -0.2/\text{sec/degree}$ which is a good compromise between fuel



RATE LIMIT MAX = 5°/SEC
 RATE LIMIT MIN = 1°/SEC
 DB = 5°

Fig. 3-16A Roll Autopilot Phase Plane Logic

12-477
57-239-204

3-44-40

7/15/54
FIT

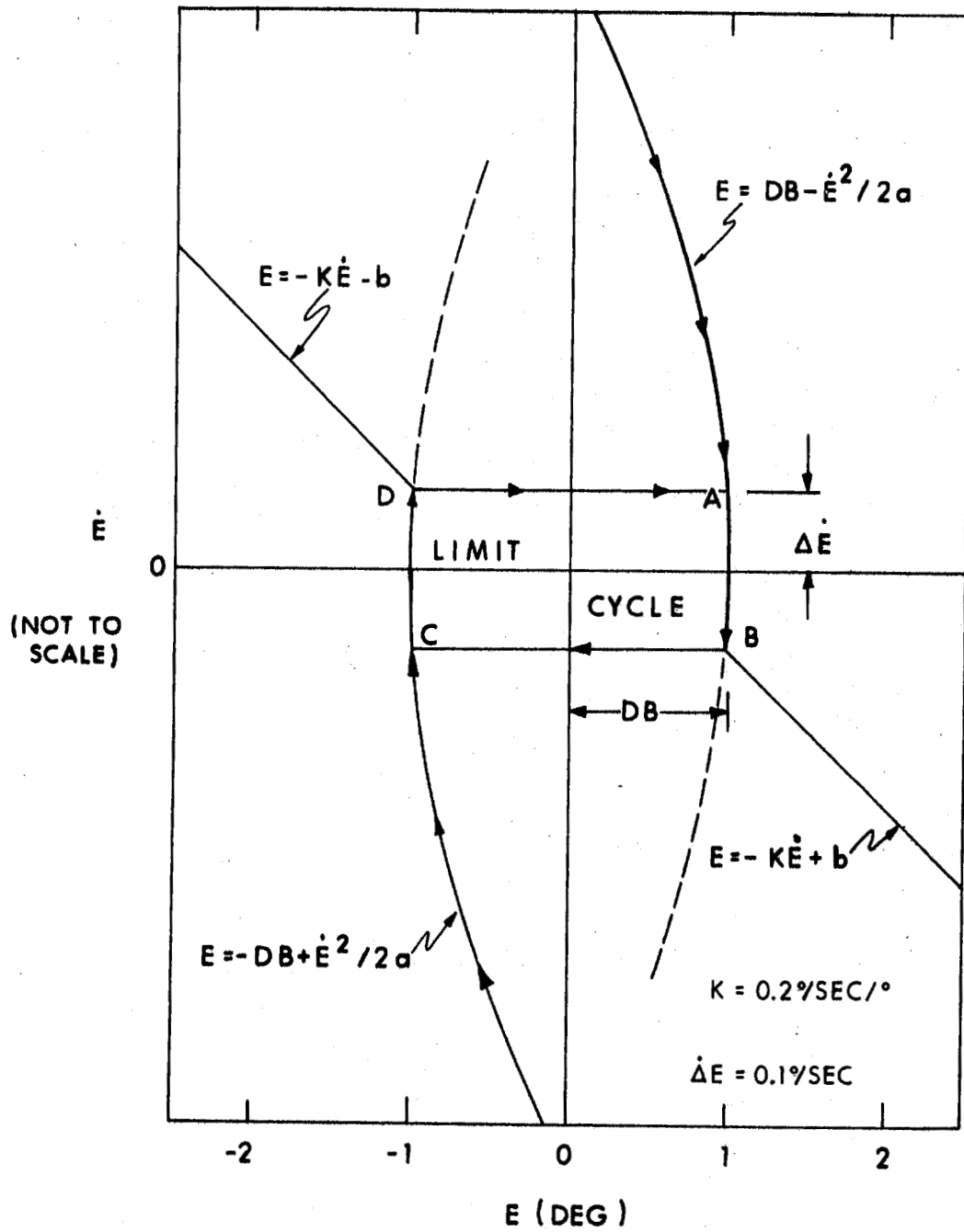


Fig. 3-16B Expanded View of Fig. 16A in Limit Cycle Region

usage and speed of response.

Since the autopilot operates in a thrusting environment, subject to disturbing torque generated by actuator limit-cycling and cross-coupled inertias, minimum impulse performance is unlikely. Two-jet firing is assumed and the roll inertia is continually recomputed during a firing. A limit cycle rate of $0.1^\circ/\text{sec}$ yields satisfactory fuel economy for an undisturbed flight. Since disturbances will be significant any attempt to constrain the rate to a smaller value would be futile. By sampling every $1/2$ second and simply deriving the OGA rate by differencing, the theoretical accuracy due to quantization is $.0222^\circ/\text{sec}$. Thus at this sampling rate $.1^\circ/\text{sec}$ can be detected quite easily. The deadband has been set at $\pm 5^\circ$ which is adequate for this mode.

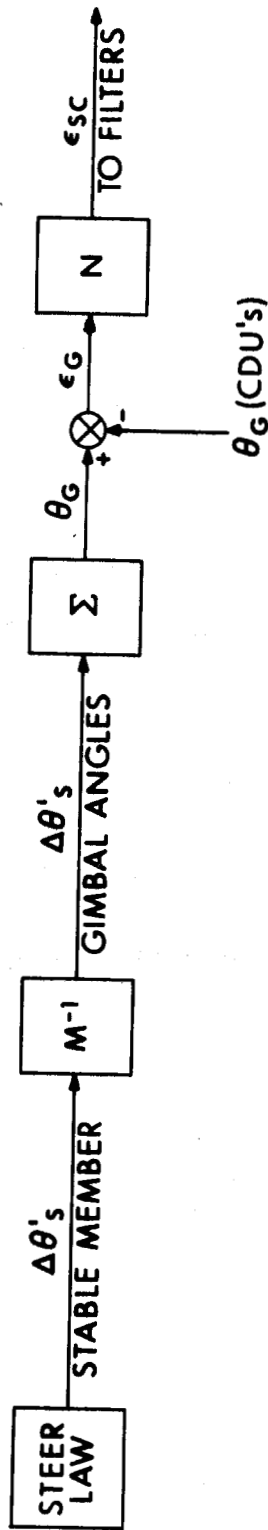
Since roll control during TVC is not a precise function the design philosophy, correspondingly, has been kept simple. However in order to increase reliability during this automatic sequence; i. e., the astronaut cannot exercise manual control in the primary mode, the following features have been included in the roll autopilot:

- (1) the maximum firing time for any one firing is set at 2.5 sec.
- (2) following any firing, there is a delay of at least $1/2$ sec. before the next firing. This delay enhances the rate estimation and breaks up long maneuvers into 2.5 sec. firings and at least $1/2$ sec. measurements.
- (3) Each jet pair fires alternately. That is, if two consecutive positive roll firings are required, these will consist of separate jet-pairs. Roll control can remain operative under a combination of jet failures.

3.3.5. The TVC Digital Autopilot Program and Associated Guidance Equations.

The connection between the guidance equations and the digital autopilots is illustrated in Figure 3-17. The gimbal angle commands are updated every 2 seconds. The filter inputs are updated each filter iteration period (each 40 ms or each 80 ms). The gimbal angle commands are interpolated between updates in order to realize a smoother command.

From a programming point of view a digital filter is a difference equation (or set of equations) in which old outputs and inputs are processed through appropriate gain coefficients. The Laplace transform, of a delayed unit impulse is simply e^{-sT} or $1/z$. Regarding the sampled data as mathematical impulses, the resulting polynomials in z represent a difference equation involving present and past, inputs and outputs.



STABLE MEMBER TO GIMBAL CONVERSION

$$M^{-1} = \begin{bmatrix} \cos \theta & \sec \psi & 0 & -\sin \theta & \sec \psi \\ -\cos \theta & \tan \psi & 1 & \sin \theta & \tan \psi \\ \sin \theta & 0 & 0 & 0 & \cos \theta \end{bmatrix}$$

GIMBAL ANGLES (CDU's) TO SPACECRAFT AXES CONVERSION

$$N = \begin{bmatrix} 1 & \sin \psi & 0 \\ 0 & \cos \phi \cos \psi & \sin \phi \\ 0 & -\sin \phi \cos \psi & \cos \phi \end{bmatrix}$$

$\phi, \theta, \psi = 0, 1, M$ gimbal angles

Fig. 3.17 TVC Autopilot Interfaces within the CMC

3.3.5.1. Time Variable Parameters

The control loop gains are made time-variable to offset the variation of control effectiveness (Tl_x/I_{yy}). In particular, the desired gain:

$$K_p(t) = \frac{[K_p(Tl_x/I_{yy})] \text{ DESIGN}}{[Tl_x/I_{yy}] \text{ CURRENT}}$$

Analysis shows that $K_p(t)$ can be approximated by a linear function of elapsed time for a particular burn:

$$K_p(t) = K_p(0) - \dot{K}_p(t - t_0)$$

The start burn value, $K_p(0)$, is computed on the basis of nominal gain and keyed in values of Tl_x and I_{yy} . \dot{K}_p is a stored constant.

Mechanization of variable K_p within the CMC requires a discrete form of the equation:

$$K_p(nT) = K_p((n-1)T) - \Delta K_p$$

where $\Delta K_p = T(\dot{K}_p)$, and the initial $K_p(0)$ is as defined above.

The constants differ significantly for LM on and LM-off burns. Two sets of these parameters are required to closely match the desired $K_p(t)$.

Empirical data is similarly employed to estimate the roll acceleration during a burn and the slosh period at engine ignition.

3.3.5.3. Computer Timing and Storage Estimates

For Flight 278 the LM-docked digital autopilot will operate at a basic interval of 80 ms. That is, the pitch and yaw filters are called, alternately, every 40 ms. Each filter requires an interrupt time of about 5 ms., thus the filters are expected to occupy .125 sec. every 1 sec. or 12.5% of main frame time. For LM-off, the interval is 40ms. with an interrupt time of 1.25 ms. or only 3%. The roll autopilot (described elsewhere) operates every 1/2 sec. and occupies an additional 1% of computer time. Thus for Flight 278, the autopilot functions are expected to take less than 15% of main frame time during a powered maneuver. Based on Block I experience for steering and matrix updating and taking into account the increased speed of the Block II interpreter, the steering equations for Flight 278 will be solved every 2 sec., occupying 0.5 sec. of computer time or 25%. Thus for guidance, steering and autopilot a powered maneuver can be expected to take 40% of main frame time.

Thus

$$D(z) = K_c \frac{z^r + N_1 z^{r-1} + \dots + N_i z^{r-i} + N_{r-1} z + N_r}{z^s + D_1 z^{s-1} + \dots + D_j z^{s-j} + D_{s-1} z + D_s}$$

or

$$D(z) = K_c \frac{\pi_i (z - z_i)}{\pi_j (z - p_j)}$$

For Flight 278, with LM attached the coefficients N_i , D_j are

$N_1 = -2.971$	$D_1 = -4.7798972$
$N_2 = -3.195$	$D_2 = 9.4452763$
$N_3 = -0.4096$	$D_3 = -9.8593475$
$N_4 = -2.518$	$D_4 = 5.7231811$
$N_5 = 2.963$	$D_5 = -1.7484750$
$N_6 = -1.510$	$D_6 = 0.21933335$
$N_7 = 0.3124$	

and the difference equation for the filter may be written

$$\delta_k = -[D_1 \delta_{k+1} + \dots + D_6 \delta_{k+6}] + K_z [E_k + N_1 E_{k+1} + \dots + N_7 E_{k+7}]$$

where

$E_k \equiv$ filter input

$\delta_k \equiv$ filter output

A schematic of this implementation is shown in Fig. 3-18. Note that the coefficients N_i are held in single precision while the D_j 's are double precision constants. The multiplications $E_k N_k$ are SP \times SP but the $D_k \delta_k$'s must be performed as DP \times DP.

For Flight 278, with LM off,

$$D(z) = K_c \frac{a_0 + a_1 Z^{-1}}{b_0 + b_1 Z^{-1}}$$

where

$a_0 = 1$	$b_0 = 1$
$a_1 = -0.98$	$b_1 = -.64$

The filter gains for both LM on and off autopilots are time varying quantities reflecting the torque to inertial ratio of the vehicle during SPS burn. The selection of the gains and their variations are commented upon in the next section.

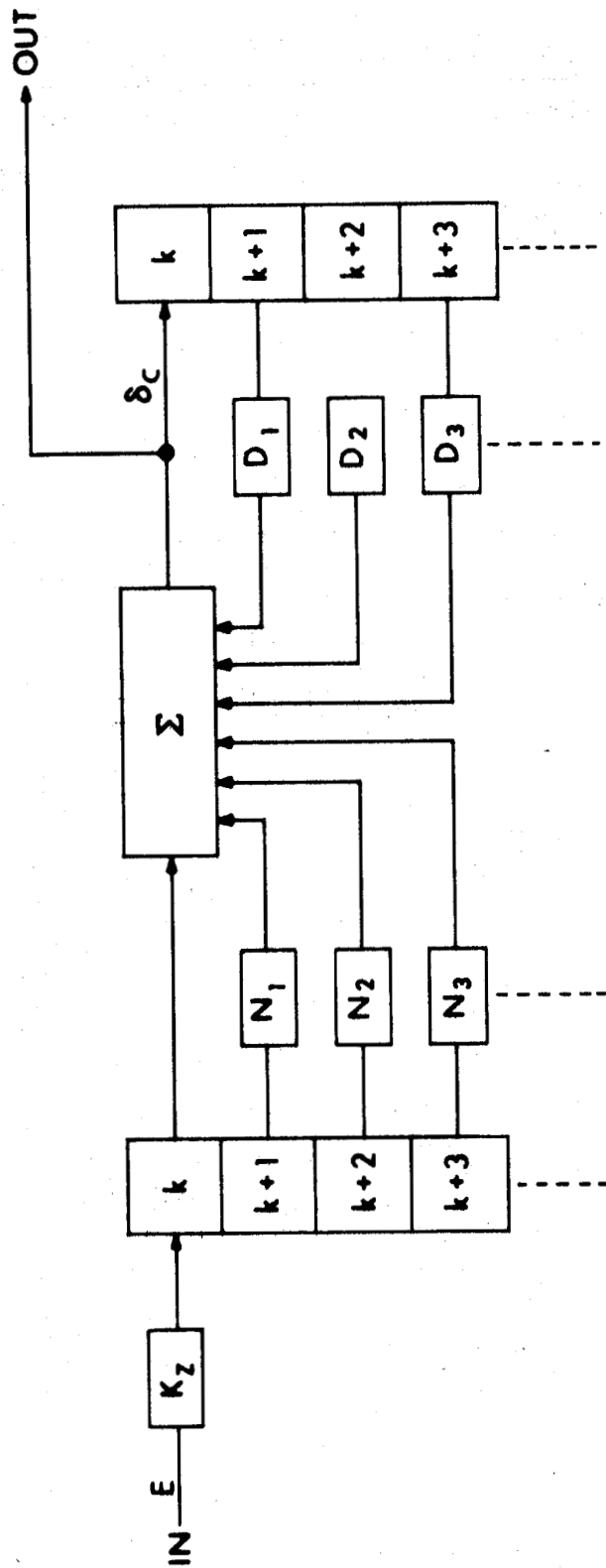


Fig. 3-18 Filter Implementation

The filters (LM on and off) and roll control require approximately 1500 fixed locations. The filter gains, coefficients and roll control acceleration estimate are carried in erasable. In addition, provision is made for the astronaut to key in the pitch and yaw actuator trim angles before thrust. The total erasable load will be close to 110 registers.

3.3.3.6 The Stroking Test

For Mission 278, the TVC autopilot includes a means for rigorously exciting the bending modes of the vehicle through lateral thrust excursions in order to definitively evaluate those modes. The basic STROKER program provides for a sequence of as many as four different strokes. Each stroke is characterized by N cycles of saw-tooth commands to the SPS pitch engine actuator of period T. All strokes command sawtooth ramp slopes of approximately 0.1/rad/sec. The STROKER test is expected to be initiated after approximately 5 seconds of SPS burn by means of V74E through the DSKY. It may be terminated at any time by V75E. A full four strokes would involve approximately 12 seconds of excitation.

3.4 Entry Autopilots

The CM body attitude control during the entry phase commences 5 sec. after CM-SM separation and continues until drogue chute deployment. During this interval, several tasks must be performed.

- $g < 0.05$
1. Provide attitude hold from 5 sec. after separation until crew input of entry roll attitude.
 2. Initiate and perform maneuver to bring CM from separation attitude to entry trim attitude.
 3. Hold entry attitude with respect to relative velocity vector.
- $g > 0.05$ *
4. Follow roll commands issued by Entry Guidance and perform coordinated turns with rate damping.
 5. Maintain attitude hold and rate damping at end of final phase when the velocity drops below 1000ft/sec. until autopilot is disabled.

These tasks require several distinct autopilot control modes.

Further, the autopilot is required to provide a display presentation to the FDAI needles as follows:

Extra Atmospheric DAP-The three attitude errors.

roll $R_c - R$, yaw $\beta_c - \beta$, and pitch $\alpha_c - \alpha$ are presented each 0.1 second.

Atmospheric DAP- The only presentation is roll error, corrected for shortest angular path, on a 0.1 second basis. The pitch and yaw needles are not driven.

Regarding modes, the Entry DAP does not recognize any mode except automatic. Manual take-over by the pilot will not affect DAP action, nor its display presentation. The disabling of DAP jet discrettes is effected by hardware outside the CMC.

When SM-CM separation occurs, adequate clearance between CM and SM is needed before initiating the CM reorientation maneuver. In the interval while clearance is being established, CM attitude control disable will prevent any firing that may cause re-contact. After the interval, the entry conditions are established as commanded attitude angles: Roll attitude as was specified by keyboard entry, zero beta, and trim angle of attack. The extra atmospheric DAP performs the control according to the above requirements. Specifically, these are Tasks numbered 1, 2, and 3 above, occurring for $g < 0.05$. For $g > 0.05$, the atmospheric DAP is in control and does Task 4 and 5, as described below.

* Although damping commences at 0.05 g, roll commands will not be issued until 0.2 g.

The terminal phase of extra-atmospheric return to the earth at a specified landing point is achieved by Entry Guidance, utilizing atmospheric aerodynamic lift. The guidance equations determine proper orientation of the lift vector relative to the trajectory plane as the means of control in achieving the desired landing point. The component of lift in the plane of the relative velocity and the position vector controls the down range flight. Cross range is controlled by the out-of-plane component of lift. By rolling the CM about the velocity vector, orientation of the lift vector is achieved such that the desired in-plane component obtains. The out-of-plane component of lift causes lateral drift of the vehicle. This sidewise motion is used for plane changing, if any is needed. Otherwise lateral drift is an unwanted by-product of the steering, and is constrained by causing the CM to roll so as to reverse the sign of the out-of-plane component of lift. Since the in-plane component is the fundamental controlled quantity, it is important that its sign be unchanged during lateral reversals or switchings. In effect this demands that the CM roll predominantly through the smaller of the two possible angles at lateral switching time. In an exceptional and infrequent case Entry Guidance insists on rolling over the top without regard for the angle size, and the switch LATSW is set to inform DAP. Thus Entry Guidance provides a single output quantity, commanded roll angle Roll C, to be achieved by the CM.

Within the atmosphere the CM is aerodynamically stable, a property that simplifies the autopilot design. In pitch and yaw, since stability is no problem, simple rate dampers are indicated. Furthermore, aerodynamic forces can be utilized to do most of the work during a coordinated turn. The roll axis torque of the CM is mostly inertia, having negligible damping and cross-coupling terms. A simple predictive autopilot utilizing the phase plane is used.

Table 3-XIII summarizes the major entry events that effect the DAPs.

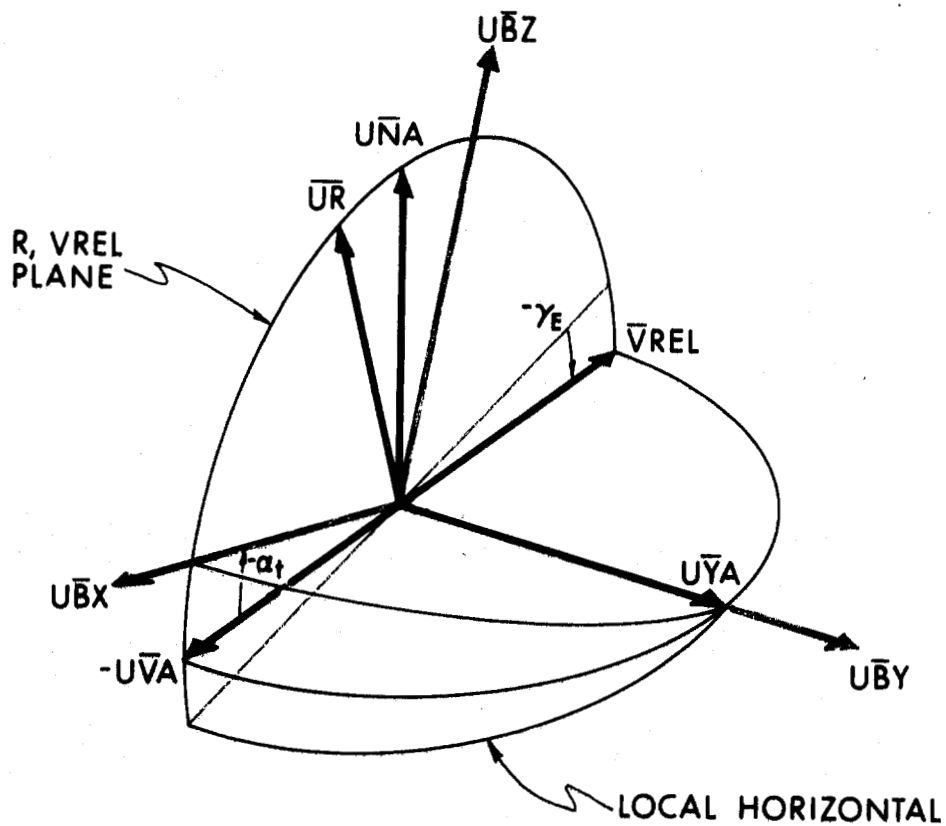
3.4.1. Coordinate System

Trajectory Triad

The Inertial Measurement Unit is the source of input data for Entry Guidance and the autopilots. Accelerations in the form of velocity increments are provided by the PIPAs, and the gimbal angle values are communicated by the CDU's. The coordinate system used during Entry is defined in Figure 3-19. During entry the axis of symmetry of the CM is pointed backward along the trajectory and the triad used by the autopilots is -UVA, UYA, UNA. In the figure, the body axis set UBX, UBY, UBZ is shown for ROLL C = 0 (corresponding to lift up) and for $\alpha = \alpha_t$ (corresponding to trimmed flight).

TABLE 3-XIII OUTLINE OF ENTRY EVENTS

<u>EVENT</u>	<u>CONTROLLING ACTION</u>	<u>DAP FUNCTION</u>
<u>Separation + 5 sec</u>	Load β_c, α_c with β, α	Roll Damping β, α Attitude Hold
<u>Establish</u> <u>Entry conditions</u>	Set R_c : Specified By Key Board $\beta_c = 0$ $\alpha_c = \alpha_t$ (trim)	$|\alpha| > 135$ Roll Damping (p) β, α Attitude Control (r, q)
		$45 < |\alpha| < 135$ R, β, α Attitude Control (r, p, q)
		$|\alpha| < 45$ R, β, α Attitude Control (p, r, q)
$g > .05$	R_c given By Entry Guidance	R Attitude Control q, r Damping (coord.)
$V < 1000$ Ft/S	R_c Remains Constant	R Attitude Control q, r Damping (coord.)
Drogue		Disable DAP



BODY AXES DRAWN FOR LIFT UP $ROLLC = 0$

$$\begin{aligned} \bar{U}R &= \text{UNIT}(\bar{R}) \\ \bar{V}REL &= \bar{V} - \bar{\omega}_E \times \bar{R} \\ \bar{U}VA &= \text{UNIT}(\bar{V}REL) \\ \bar{U}YA &= \text{UNIT}(\bar{U}VA \times \bar{U}R) \\ \bar{U}NA &= \bar{U}YA \times \bar{U}VA \end{aligned}$$

Fig. 3-19 Entry Autopilot Coordinate Triads

Body Triad

The body axis triad of the CM is defined relative to the platform axis set in Figure 3-20 in terms of the three gimbal angles. When all three gimbal angles are zero, the body set UBX, UBY, UBZ and the platform set UPX, UPY, UPZ coincide. At other times the body set is obtained from the platform set by using the Euler gimbal sequence; inner, middle, outer, abbreviated I, M, O. These rotations are pictured in Figure 3-20 along with the transformation equations, (I). With these, the autopilot determines the CM unit body triad UBX, UBY, UBZ expressed in platform coordinates, (II).

Angular Velocity Measurement in CM Body Axes

The body angular velocities, roll p , pitch q , and yaw r are measured in the positive sense about the respective axes UBX, UBY, UBZ and are obtained from the gimbal angle rates using the sequence I, M, O of Figure 3-20. When the gimbal angles are zero, body axes coincide with platform axes and the rate p, q, r are equal to the respective gimbal rates O, I, M . When the gimbal angles are not zero, the body rates are obtained from equations (III) of Figure 3-20.

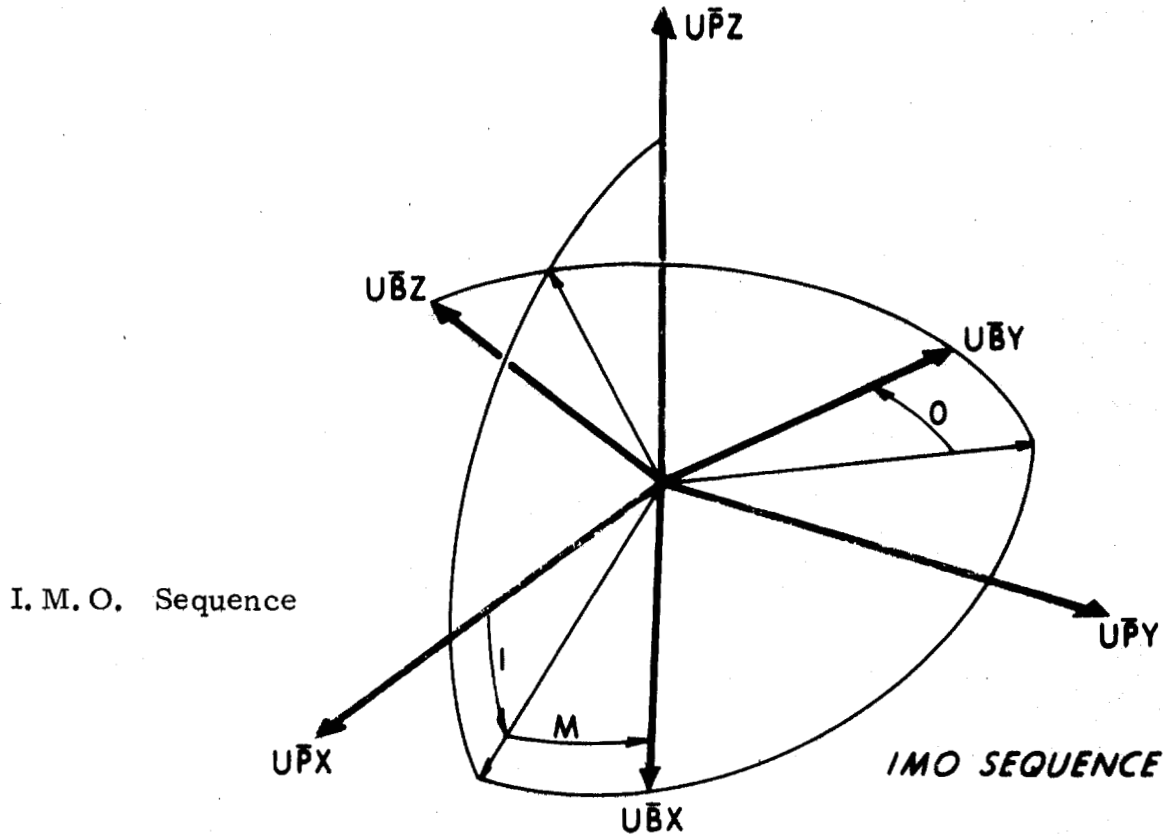
Measurement of the gimbal rates, and hence of the body rates is not continuous, but occurs at regular time intervals as indeed do all calculations done by the AGC. The basic computation cycle for Navigation and Guidance is 2 seconds. Body rates must be determined more frequently, and a computation cycle of 0.1 second is used. Thus each interval $\tau=0.1$ second, the gimbal angular rates required by (III) are measured as CDU angle differences in the manner

$$\dot{O}\tau \approx \Delta O = O_k - O_{k-1}$$

and is illustrated in detail in Figure 3-32. Using the measured gimbal differences $\dot{O}\tau, \dot{I}\tau, \dot{M}\tau$, (III) yield body rates as differences $p\tau, q\tau, r\tau$. These differences represent body rates that are exact only if the angular accelerations are zero. A better estimate is obtained from the measured $p\tau, q\tau, r\tau$ by the simple algorithm

$$\dot{\theta}\tau \approx \Delta\theta = \Delta\theta_1 + \frac{\Delta\theta_1 - \Delta\theta_0}{2}$$

where the subscript 0 refers to the previous value of a difference and 1 refers to the present value. For each body rate in turn, substitute the present difference and the previous difference in place of the thetas, as shown in Figure 3-33. By previous difference, the previous result of (III) is meant, not the previous average. This fact is not made explicitly in the referenced figure.



$$\begin{pmatrix} \bar{U}BX \\ \bar{U}BY \\ \bar{U}BZ \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & CO & SO \\ 0 & -SO & CO \end{pmatrix} \begin{pmatrix} CM & SM & 0 \\ -SM & CM & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} CI & 0 & -SI \\ 0 & 1 & 0 \\ SI & 0 & CI \end{pmatrix} \begin{pmatrix} UPX \\ UPY \\ UPZ \end{pmatrix} \quad (I)$$

BODY TRIAD EXPRESSED IN PLATFORM COORDINATES

$$\bar{U}BX = (CM \ CI, \quad SM, \quad -SI \ CM)$$

$$\bar{U}BY = (-CO \ CI \ SM + SO \ SI, \quad CO \ CM, \quad CO \ SI \ SM + SO \ CI) \quad (II)$$

$$\bar{U}BZ = (SO \ CI \ SM + CO \ SI, \quad -SO \ CM, \quad -SO \ SI \ SM + CO \ CI)$$

BODY ANGULAR VELOCITIES

$$p = \dot{O} + \dot{I} \ SM$$

$$q = \dot{I} \ CM \ CO + \dot{M} \ SO$$

$$r = -\dot{I} \ CM \ SO + \dot{M} \ CO$$

Where SM = SIN M ETC.

(III)

Fig. 3-20 Platform to Body Transformation

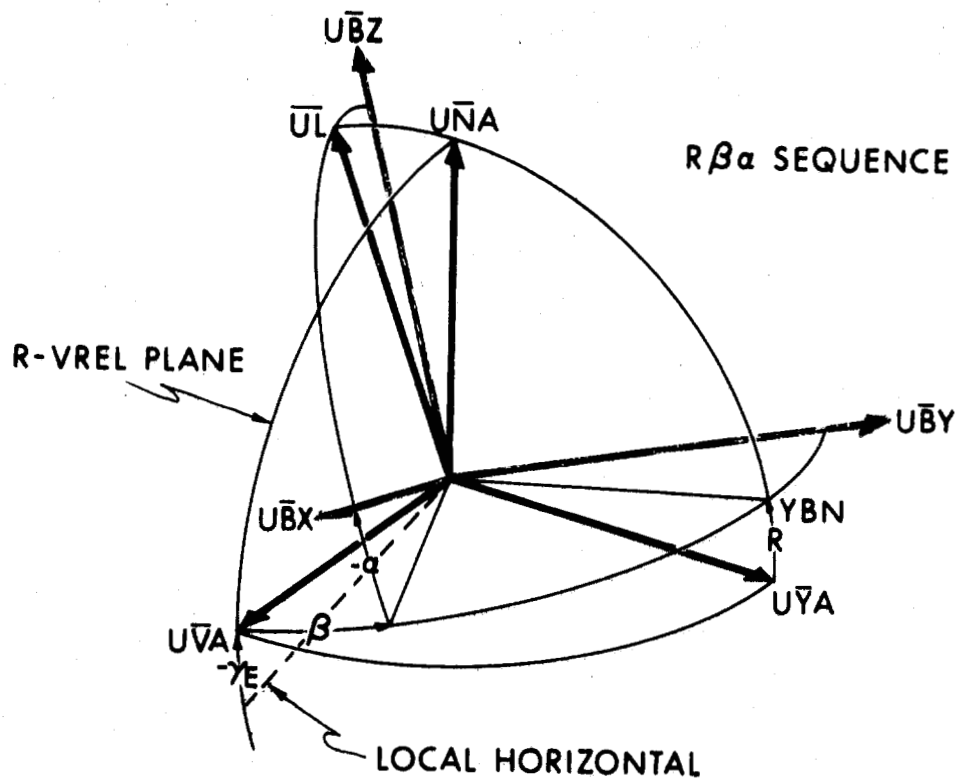
CM Body Attitude

The CM attitude angles are defined relative to the trajectory triad -UVA, UYA, UNA and the body triad UBX, UBY, UBZ. Both are expressed in platform coordinates. The defining Euler sequence R, β, α is pictured in Figure 3-21 along with the transformation equations (I). When all angles are zero, UBX points along the negative relative velocity vector away from the heat shield, and UBY lies along the normal to the trajectory plane. UBZ lies in the trajectory plane and points along the lift vector. The condition $R = 0$ corresponds to positive lift or lift up. Rotation of the body triad by rolling about UBX (-UVA) through the angle R , causes the lift to have a component out of the trajectory plane. The direction of UBZ can be called UL since it points in the direction of the lift vector. The direction of UBY can be called YBN since for any R it points in the nominal direction for Y body. That is, it is normal to the relative velocity, lying in the UNA, UYA plane. The second rotation is yaw about UL through the angle β . The last rotation is pitch about UBY through the angle α , shown negative in the picture. The result of the final rotation is to locate the actual CM unit body triad UBX, UBY, UBZ relative to the trajectory triad -UVA, UYA, UNA in terms of the Euler attitude angles R, β, α . The equations for calculating the angles R, β, α and also their derivatives are summarized in Figure 3-22.

For the approximations involved in mechanizing the attitude rate equations, see the block diagram, Figure 3-33.

The equations of Figure 3-22 neglect the effect of $\dot{\gamma}_E$. In cases where γ_E changes rapidly, $\dot{\gamma}_E$ can be of the order of 2 to 3 $^{\circ}/\text{sec}$ for a short period of time (of order 20 sec) and occur for relatively large γ_E . Approximate inclusion of the effect of $\dot{\gamma}_E$ is done with the equations of Figure 3-23. By correcting the body rates and then using the corrected values wherever required in DAP, control of CM with respect to the velocity vector is maintained. The level above which $\dot{\gamma}_E$ correction is applied is set arbitrarily at $1/2^{\circ}/\text{sec}$.

The application of equations of Figure 3-21 through Figure 3-23 is diagrammed in Figure 3-24 and 3-25. Program CM/POSE is called by Entry Guidance to establish afresh the CM attitude angles R, β, α . Since CM/POSE requires position and velocity, it is called at some time after navigation is completed and thus at roughly 2 second intervals. The attitude angles which are calculated (in the figure: NEW R , NEW β , NEW α) were valid at the time at which position and velocity were valid: at the PIPA read time. To obtain the present attitude angles, the NEW angles must be corrected for any increment accrued in the interval between PIPA read time



$$\begin{pmatrix} UBX \\ UBY \\ UBZ \end{pmatrix} = \begin{pmatrix} C\alpha & 0 & -S\alpha \\ 0 & 1 & 0 \\ S\alpha & 0 & C\alpha \end{pmatrix} \begin{pmatrix} C\beta & S\beta & 0 \\ -S\beta & C\beta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & CR & SR \\ 0 & -SR & CR \end{pmatrix} \begin{pmatrix} -UVA \\ UNA \\ UYA \end{pmatrix} \quad (I)$$

Fig. 3.21 CM Body Attitude Angles - Definition

Combine matrices in Fig. 3-21 into single matrix. Calculate Attitude angles as for CALCGA. Obtain body angles from

$$\bar{U}L = \text{Unit} (-U\bar{V}A \times \bar{U}BY)$$

$$CR = \bar{U}L \cdot \bar{U}NA, SR = -\bar{U}L \cdot \bar{U}YA$$

$$S\beta = U\bar{V}A \cdot \bar{U}BY$$

$$C\alpha = \bar{U}L \cdot \bar{U}BZ, S\alpha = -\bar{U}L \cdot \bar{U}BX$$

For updating angles R, β, α between matrix calculation, integrate the rate equations

$$C\beta \dot{R} = p C\alpha + r S\alpha$$

$$\dot{\beta} = -p S\alpha + r C\alpha$$

$$\dot{\alpha} = q + \dot{R} S\beta$$

Thus

$$R \leftarrow R + \dot{R}\tau$$

$$\beta \leftarrow \beta + \dot{\beta}\tau$$

$$\alpha \leftarrow \alpha + \dot{\alpha}\tau$$

Fig. 3-22 Computation of CM Body Attitude Angles

To approximately correct for $\dot{\gamma}_E$ in rate control relative to relative velocity vector, use

$$p_{rel} = p - S\alpha SR \dot{\gamma}_E$$

$$q_{rel} = q - CR \dot{\gamma}_E$$

$$r_{rel} = r + C\alpha SR \dot{\gamma}_E$$

With these, the attitude rate equations keep the same form

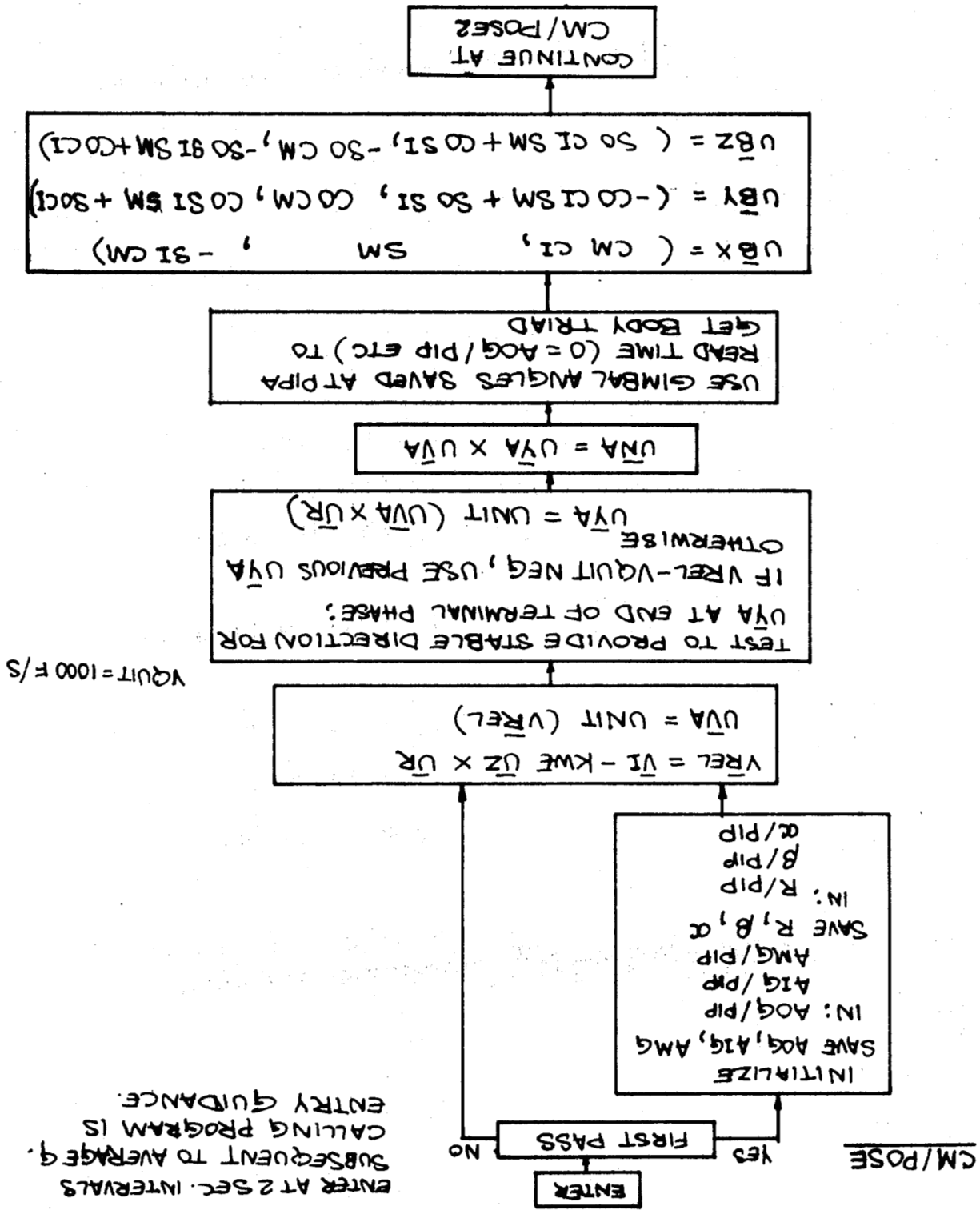
$$C\beta \dot{R} = p_{rel} C\alpha + r_{rel} S\alpha$$

$$\dot{\beta} = -p_{rel} S\alpha + r_{rel} C\alpha$$

$$\dot{\alpha} = q_{rel} + \dot{R} S\beta$$

Fig. 3-23 Gamma Dot Correction to CM Body Rates

Fig. 3-24 Calculation of Attitude Angles



CONT'D

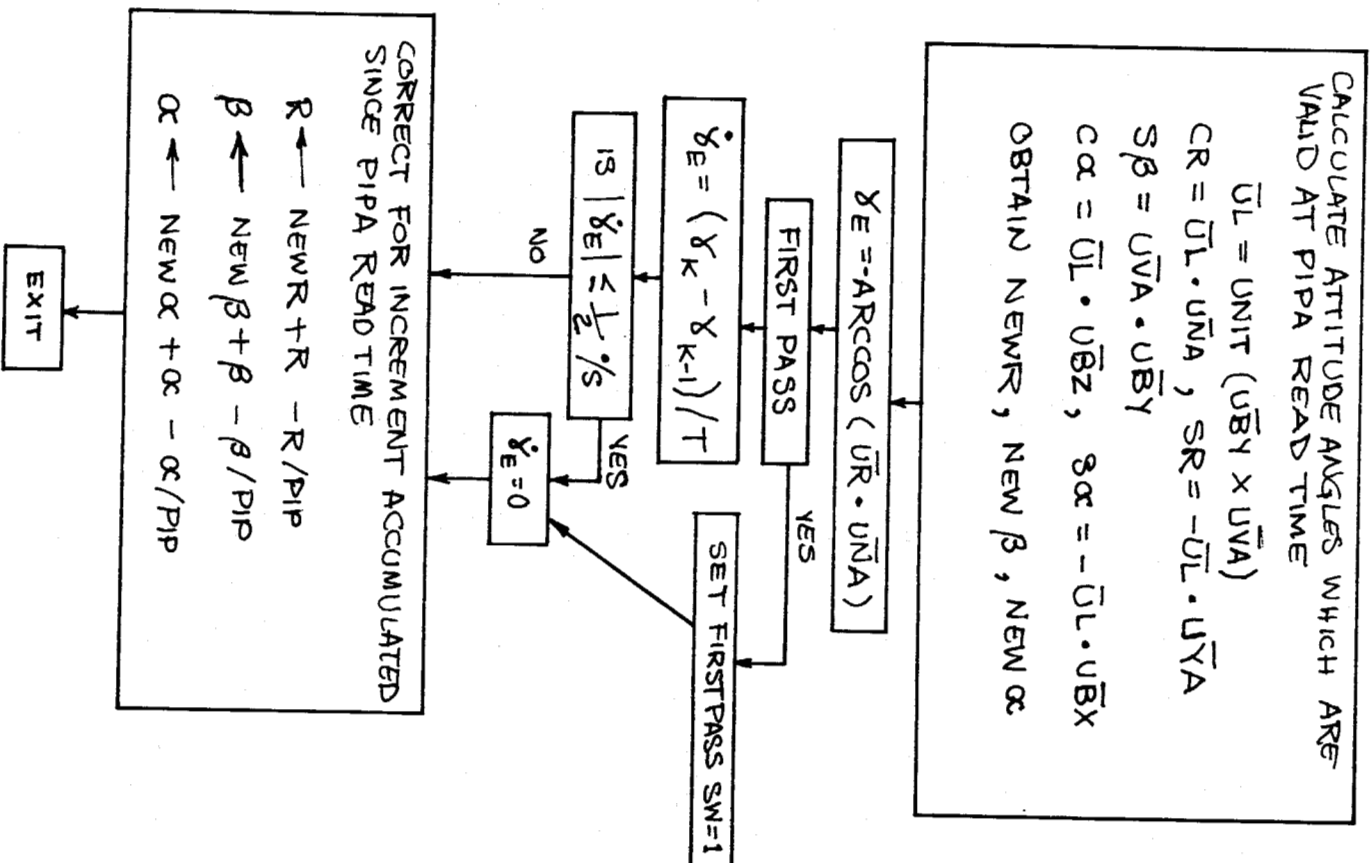


Fig. 3-25 Attitude Calculation, Cont'd

to the present. This is easily done since an independent integration of attitude rates is done each 0.1 second to maintain R, β, α . When the NEW values are corrected, they replace R, β, α . Thus CM/POSE prevents accumulation of error in attitude resulting from integration by providing a fresh reference roughly each 2 seconds.

Two comments are made concerning CM/POSE. The test to see if V is less than 1000 ft/sec provides warning that subsequent calculations of UYA will be unreliable because UR and UVA approach co-linearity. The error committed in using an old value of UYA affects only the measure of roll, and is not important at this stage. The other comment is that the calculation for $\dot{\gamma}_E$ is chosen to be more accurate in the region where $\dot{\gamma}_E$ is of possible interest.

3.4.2. Extra Atmosphere DAP

The CM autopilot function outside the atmosphere is fundamentally attitude control in all axes. Inside the atmosphere, attitude control is used only for roll, and rate damping is used for pitch and yaw. To minimize the size of the DAP software, multiple use is made of program logic where ever permissible.

It is convenient to categorize DAP action outside the atmosphere in terms of the size of α , as is suggested by the attitude rate equations of Figure 3-22. By quadranting α relative to 45° , the attitude rates can be considered as being controlled by a single body rate. In β for example, if $|\alpha| > 135^\circ$ then r is the predominant term and β error can be assigned to the yaw axis. Of course, this breaks down if p is several times greater than r , or if α is near 135° . However, the technique has merit. In Figure 3-26 the assignment of the Euler attitude errors to body axes in this manner is summarized. The region $|\alpha| > 135^\circ$ (case 1) corresponds to the initial phases of separation maneuver. It is desirable to enforce rate damping in roll in this region since it keeps p small. Besides, there will be ample time to complete a roll maneuver in the other regions. The attitude system used for β and α is intended to execute maneuvers at $2^\circ/\text{sec}$. However, cross coupling between thrusters makes an upper bound necessary. For this, $4^\circ/\text{sec}$ is used. In the interval $45^\circ < |\alpha| < 135^\circ$ (case 2), roll error and β error interchange axes. All three axes are now attitude controlled and obey the same phase plane logic. The rates when not in dead zone can be more than $2^\circ/\text{sec}$ but less than $4^\circ/\text{sec}$. In the interval $|\alpha| < 45^\circ$ (case 1 again), roll error and β error return to their proper axes. Control of q and r is the same as was described above. But here, roll control returns to the 2 sec predictive attitude system. A test must be made to recognize

SUMMARY OF CM BODY ATTITUDE ANGLE CONTROL BY ASSIGNMENT
OF ATTITUDE ERRORS TO BODY AXIS DAP

1. IF $|\cos \alpha| > \cos (45^\circ)$

r Axis YAW ERROR = $\text{SGN}(C\alpha) (\beta_C - \beta)$

p Axis ROLL ERROR = $\text{SGN}(C\alpha) (R_C - R)$

(However, if α negative, do rate damping only in roll. Set
ROLL ERROR = 0)

2. IF $-\cos (45) < \cos \alpha < \cos (45)$

r Axis YAW ERROR = $\text{SGN}(S\alpha) (R_C - R)$

p Axis ROLL ERROR = $\text{SGN}(-S\alpha) (\beta_C - \beta)$

3. FOR ALL CASES

q Axis PITCH ERROR = $(\alpha_C - \alpha)$

Fig. 3-26 Extra Atmosphere Attitude Error Assignments

the transition of $|\alpha|$ across the 45° boundary and to assure that the p jets are off. This is necessary since the time interval until the next 2 second update is not known. It is interesting to note that in general β will be essentially zero by this time, so any remaining roll error will be nulled in a coordinated manner... a desirable feature as the CM nears the atmosphere.

The attitude commands for the extra atmospheric phase of flight were discussed earlier, and are outlined in Table 3-XIII.

Before progressing further, a description of the sampled attitude DAP is helpful. Discussion of the predictive 2 second DAP is included in the atmospheric section, even though its services are used outside the atmosphere.

The logic for the sampled attitude DAP is common to all those axes operating at the $\tau = 0.1$ second interval. The basic phase plane logic is given in Figure 3-27a. To be specific, let $X = \alpha_c - \alpha$ be the error and $V = q$ be the velocity.

Both X and V are to be kept within specified limits: the range $(-V_z, V_z)$ for V and the range $(-X_z, X_z)$ for X . Within the area bounded by these limits, jet thrusters are turned off. If $|X| < X_z$, but $V > +V_z$, negative jets are desired and are indicated by the minus sign. Similarly, if V exceeds the lower bound, positive jets are required. If $|V| < +V_z$, and $X > +X_z$, positive jets are required to establish a positive velocity to reduce the error X . As indicated, the positive jets remain on until at a sample interval V has exceeded V_z , when all jets are turned off. The positive velocity causes the point (X, V) to drift leftward. At a subsequent sample instant, X is observed to be less than X_z but $V > +V_z$ and negative jets are actuated. In this manner arbitrary initial conditions (X, V) of reasonable value are caused to enter the central box. If these were the only jet thrusters or if there were no cross coupling, this would be the whole story. However, coupling from thrusters on other axes causes the velocity to increase above V_z by an undesirable margin. The addition of the upper bound at $2V_z$ constrains V to have acceptable values.

In actual operation both X and V are separately tested against limits. A tag is set to zero if the limit is not exceeded, and to ± 1 bit depending on the sign of the limit exceeded. In Figure 3-27b the pairs of signs refer to the result of both tests, where the two tags are shown in the order (X, V) . The tags are combined in a "logical or" using ones complement arithmetic to generate a single tag. The resulting tag is used to select the proper jet code from a list for the axis being controlled. When a jet code is executed, only the jets designated by the code are fired or are left on if

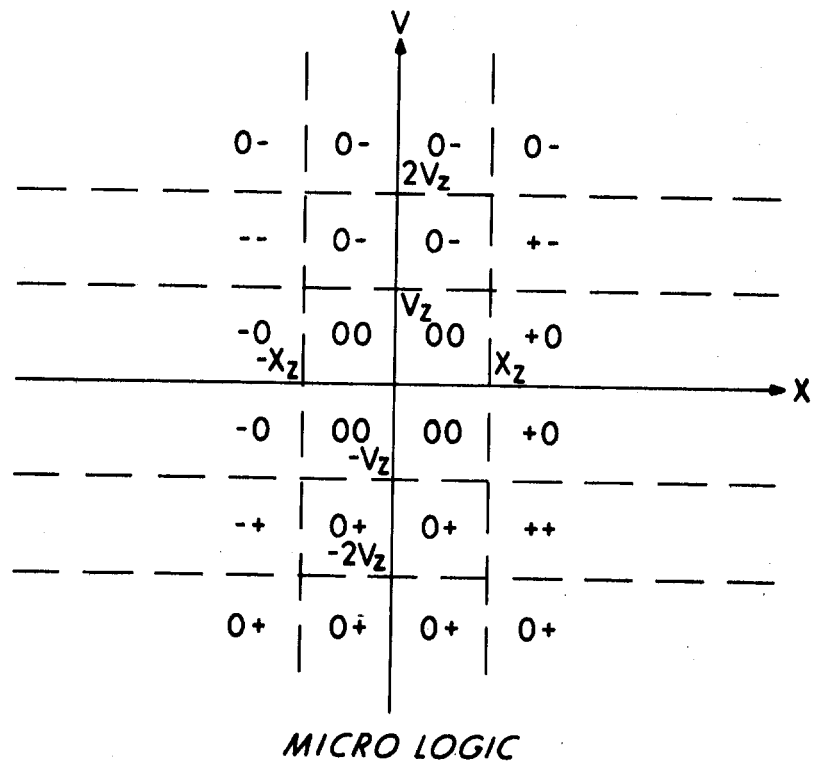
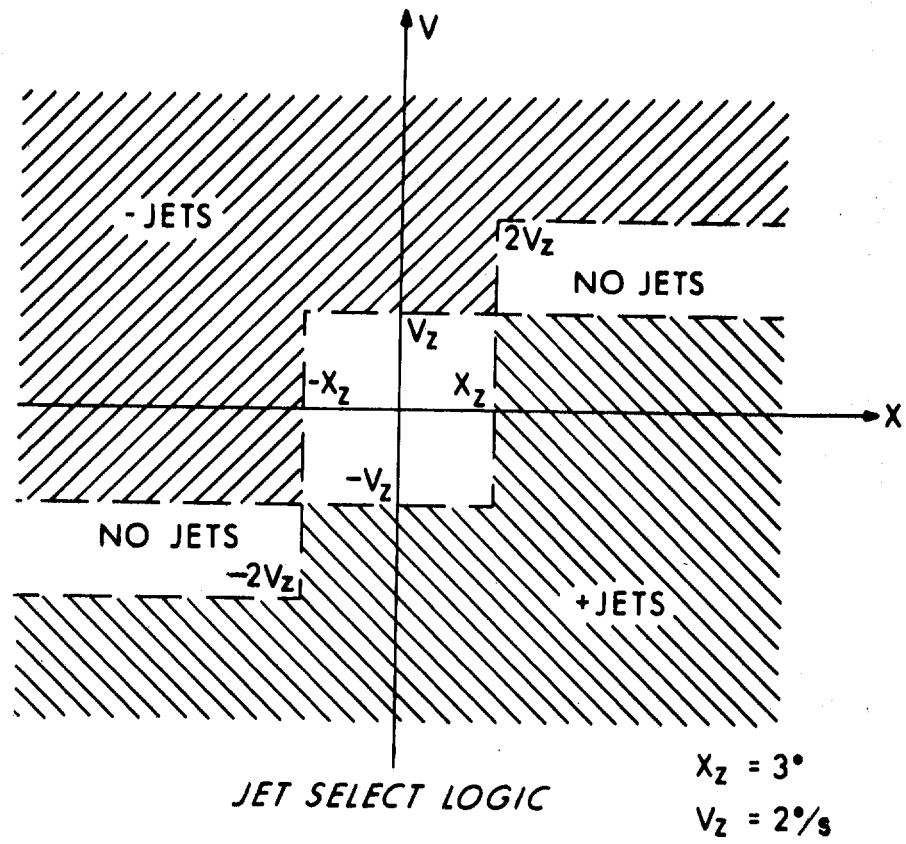


Fig. 3-27 Phase Plane Logic for CM Attitude DAP

already firing. All other jets are quenched. A tag of value zero quenches any jets that might be firing.

The flow diagrams that apply to the extra atmospheric DAP are Figure 3-32 through Figure 3-35. Subsequent figures also apply, but are not discussed yet.

3.4.3. Atmospheric DAP

Before entering the atmosphere, all attitude errors will be at null or nearly so, and the DAP mode characterized by $|\alpha| < 45^\circ$ (case 1) in Figure 3-26. When the 0.05 g level is sensed by Entry Guidance, a switch is set. The DAP observes the switch and changes the q and r control to pitch and yaw dampers. The roll system is already activated and performing and is ready to accept commands when issued by Entry Guidance. Later on, when the kepler phase is entered, the DAP slips easily back into the mode of case 1 and as easily out again.

3.4.3.1. Functional Behavior of Atmospheric Autopilots

In Entry Guidance, control is based on the components of lift in and normal to the trajectory plane, components that are specified in terms of an angle defined the same as R but having value ROLL C. If the CM is to achieve the desired lift direction, then the Y body axis must lie along YBN. This condition is met when $\beta = 0$. Thus one property of Entry autopilot is to keep $\beta = 0$ and another is to have the actual vehicle roll angle R agree with the desired value ROLL C.

Within the atmosphere, aerodynamic forces tend to keep β essentially zero, and α assumes a trim value $\alpha_t \cong -22^\circ$ so that attitude control is required only in roll. As the CM rolls, UBY should remain normal to UVA. When $\beta = 0$ and α is constant, such a maneuver causes UBX to describe a cone of angle 2α about -UVA while UBZ similarly describes a cone about +UVA. This condition of rolling about the velocity vector, or making a coordinated roll, is equivalent to requiring that the CM angular velocity vector lie along -UVA. In the atmosphere then, coordinated roll maneuvers are enforced by the angular rate autopilots already required to damp pitch and yaw body rates caused by dynamic behavior of the CM.

Figure 3-21 shows that for the nominal case, $\beta = 0$, only roll and yaw rate are present if the body angular velocity is to lie along -UVA. Further, this angular velocity is equal to the rate of change of roll angle R. A third property of the atmospheric autopilot is that it enforce the proper proportionality between yaw and roll rate necessary to produce coordinated roll.

3.4.3.2. Pitch and Yaw Digital Autopilot

In the atmospheric mode, rate damping is used to maintain pitch and yaw angular velocities within prescribed limits. The digital autopilots perform this function in a discontinuous manner by producing a control action each time new input data are available. Thus, the pitch and yaw autopilots are exercised each .1 second immediately following the measurement of angular velocity.

Pitch Damper DAP

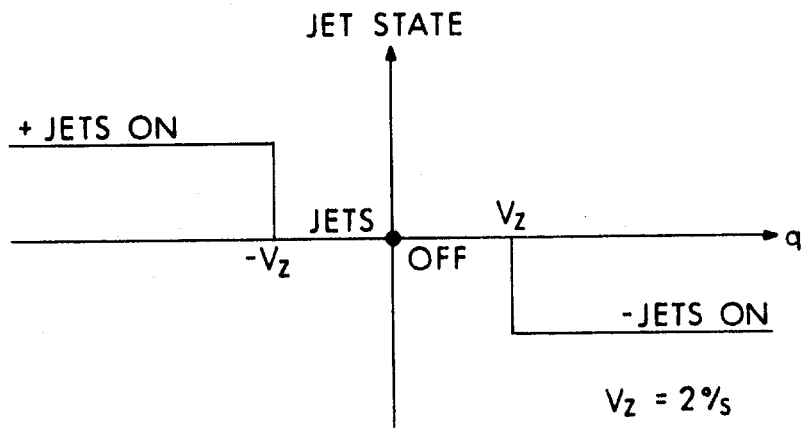
The pitch axis autopilot for the CM performs rate damping action using the simple logic of Figure 3-28, which is the single axis representation of Figure 3-27. As long as sampled pitch rate is less than $2^{\circ}/\text{sec.}$, no action is taken and the jet thrusters are off. Whenever sampled pitch rate exceeds $2^{\circ}/\text{sec.}$, the jet thrusters are activated to produce opposing torque. The jets remain firing until the pitch rate is observed to be less than $2^{\circ}/\text{sec.}$ Because of the digital nature of rate measurement, jet switching is based on the value of the rate at the time of measurement, which in general will not be exactly $2^{\circ}/\text{sec.}$ Hysteresis, a result of the .1 sec. interval between control actions, is present at the nominal $2^{\circ}/\text{sec.}$ switching discontinuity and prevents the formation of high frequency limit cycles in presence of pitch acceleration. The hysteresis zone is of variable width and can be as large as twice the total ΔV achievable by the jets in one sample time (Figure 3-28).

Yaw Damper DAP

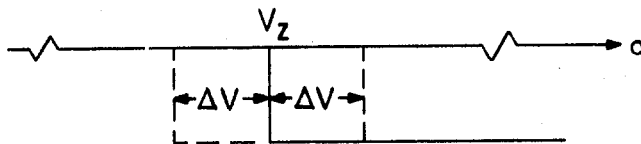
The yaw axis requirements are somewhat different than pitch. The CM must roll about the velocity vector in order to maintain nominal trim attitude and to keep the stagnation point in a fixed region on the heat shield. Figure 3-29 illustrates the situation in the UBX, UBZ plane. The UBY component of VREL is kept essentially zero by the aerodynamic force so that the velocity shown can be considered to be the total velocity VREL. In the coordinated turn illustrated, the angular velocity vector lies along $-VREL$ if the angular velocities in yaw and roll are related by

$$r = -p \tan |\alpha_t|$$

if pitch angular velocity $q = 0$. Even when the latter condition is not exactly fulfilled, the equation is still useful.

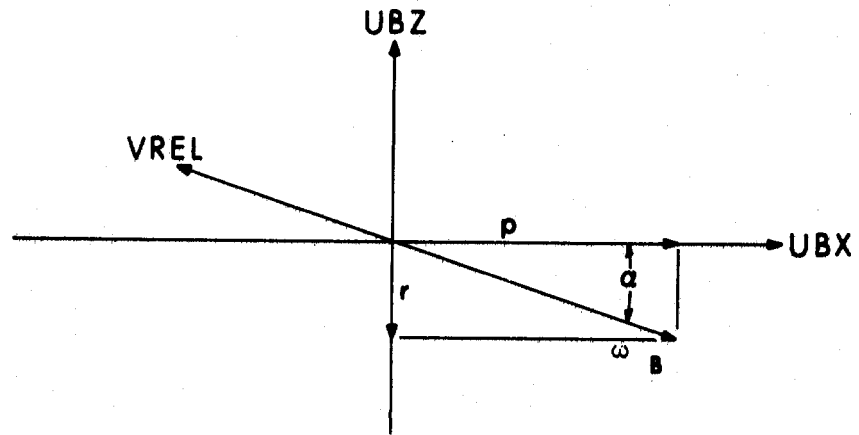


a. *PITCH RATE DAMPER*



b. *HYSTERESIS EFFECT*

Fig. 3-28 CM Pitch Rate Autopilot



Coordinated Roll

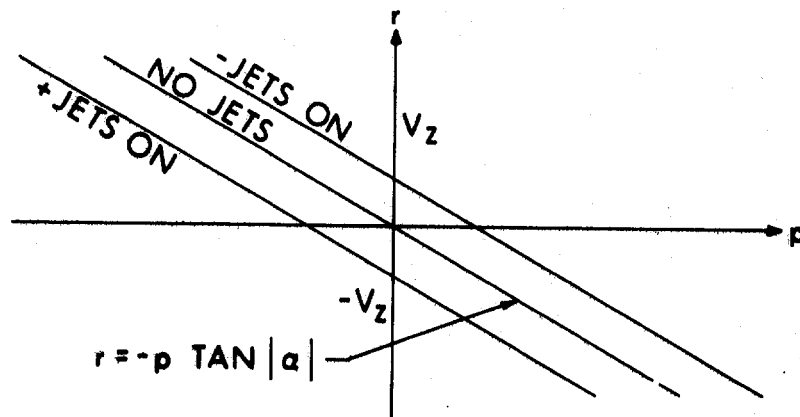


Fig. 3-29 CM Yaw Rate Autopilot

During periods of angular acceleration in roll, a corresponding acceleration in yaw is quickly established and supported by aerodynamic forces. We utilize these forces to encourage the CM to make a coordinated turn. The bulk of the work is done by the aerodynamics with the yaw jet thrusters operating only as needed according to Figure 3-29. The jets fire when necessary to keep the vehicle within the central band. This allows r to be proportional to p and at the same time keeps yaw oscillations damped to within $\pm 2^\circ/\text{second}$.

The yaw damper operates at the .1 second sample interval established by the angular velocity measurements and exhibits the same switching boundary hysteresis as the pitch damper.

The flow diagrams that apply to the atmospheric (damping) DAP for q and r are in Figure 3-32 through Figure 3-34.

3.4.3.3. Roll Attitude Control

Every 2 seconds during the entry phase, Entry Guidance provides a roll command ROLL C. It examines vehicle current position and velocity and also landing point position, decides on the proper orientation of the lift vector, and generates the commanded roll attitude of the CM necessary to achieve that orientation. The roll autopilot uses the command ROLL C, the present roll attitude R and roll rate p to generate firing times for the jet thrusters. In general, there are three time intervals generated each 2 seconds. Two are thrust durations, and one is quiescent duration. Having obtained the time intervals, there remains the bookkeeping task of implementing the result of the calculations.

Bookkeeping consists of maintaining a short list containing pairs of entries: a jet thruster selection code and a time duration. The jet code specifies which jets are to be turned on or off and the time duration specifies the interval until the next change in jet activity occurs. Bookkeeping is carried out with the aid of the TIME 3 preset timer (WAITLIST) in the AGC. The list contains only entries which can be executed within a single two second interval.

3.4.3.4. Logic In Phase Plane with Control Line

The roll model for the CM is a simple inertia which makes the phase plane an attractive tool because motion is described by straight lines and parabolas. The (X, V) phase plane of Figure 3-30 is used where $X = \text{ROLLC} - R$ and $V = R$. When the CM has the commanded attitude, both X and V are zero and the point (X, V) representing the state of CM motion is at the origin. While not necessary to the understanding of the roll DAP

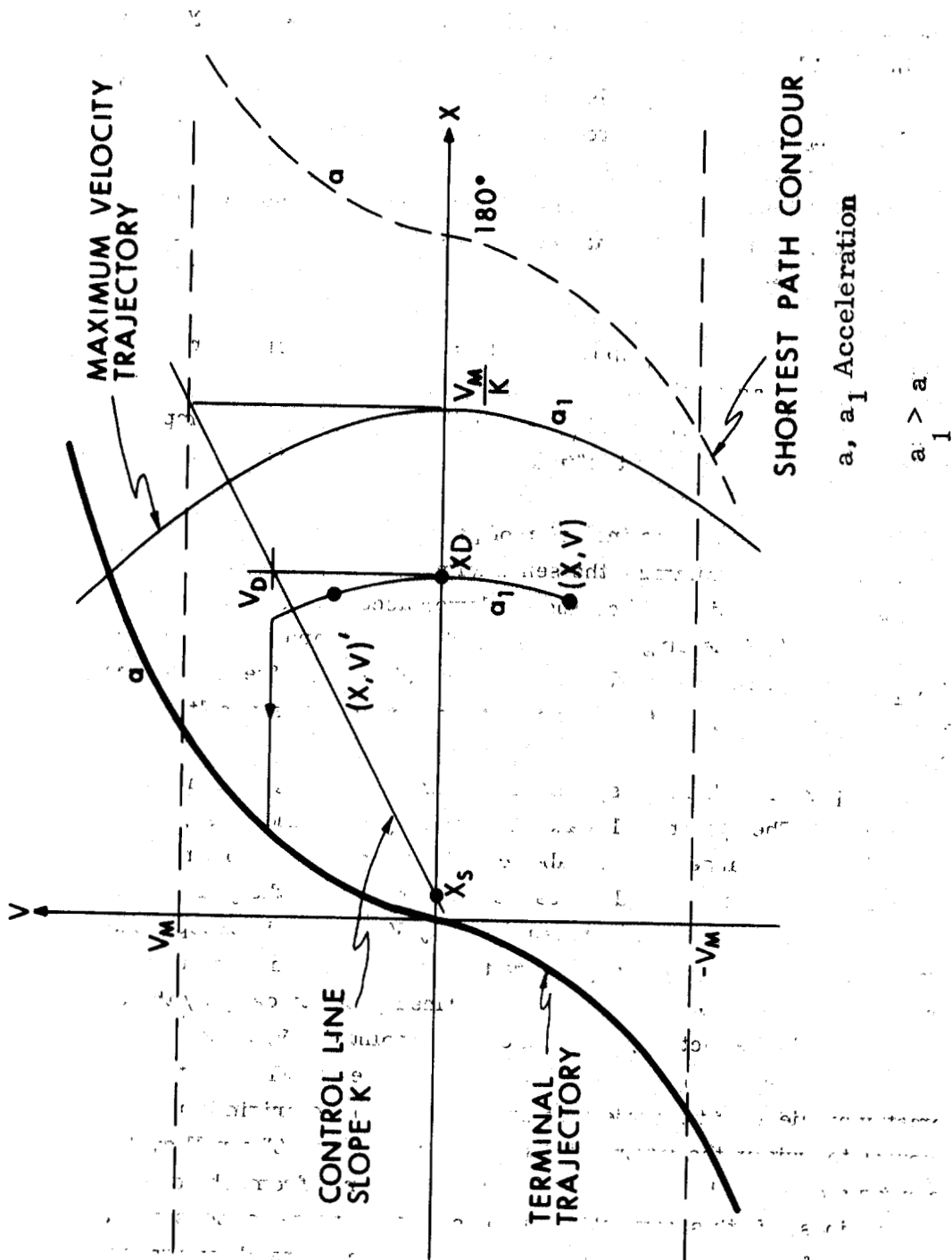


Fig. 3-30 Dual Gain Roll Attitude Phase Plane with Control Line

operation, bear in mind the fact that roll rate p is related to \dot{R} by $\cos \alpha$ in a coordinated roll. The DAP assumes coordinated roll obtains and the trim value $\cos \alpha_t$ is used to scale one axis of the phase plane so that velocity V and the change in error ΔX are compatible. Incompatibility results in overshooting the origin and costs fuel.

The salient feature of the control technique is the use of a line of slope K to determine the rate with which an error is reduced. This has several advantages. The fundamental and motivating one is that fuel consumption (ΔV) becomes somewhat proportional to error. The CM responds rapidly to large error and proportionately slowly for small error. The slope K is chosen as small as is consistent with the rate of response needed during Entry. A by-product is that the equations involved are simplified. Furthermore, this system will efficiently follow ramp inputs by establishing the necessary rate.

A second facet is the inclusion of parabolas of different acceleration, a gambit intended to minimize the sensitivity of the control system to actual jet thruster acceleration. Choosing the lower acceleration (a) to have a value near that of the single fuel system thrusters, and the larger acceleration (a_1) to have a value slightly less than that of the dual fuel system has the effect of providing good transient response with little penalty in fuel usage.

In operation, the roll system has initial values (X, V) , marked in Figure 3-30. The system will calculate the trajectory indicated. Positive jet acceleration a causes the parabolic path shown. Jets remain on until the specified drift velocity V_d is reached, at which time the jets are turned off. The trajectory drifts at constant velocity V_d until it intercepts the terminal trajectory. Negative jets are turned on and remain on until the origin is reached. The drift velocity is defined geometrically by the control line as shown in the picture. Were the initial point $(X, V)'$, the parabola would be extended back to the X axis to define XD , and the same geometry applied. If the trajectory from (X, V) to the origin is unable to be completed within the interval T , it does not matter. The roll system computes a completely new trajectory each T seconds from whatever (X, V) it finds. In this way, changes in command, noise in measurement, uncertainty of jet acceleration and other disturbances are always taken into account.

This behavior will of course occur if the first burn has acceleration a_1 and the second burn has acceleration a . However in the single fuel system case, let the actual jet acceleration be a and let $a_1 = 2a$.

The control logic will predict VD, and specify a burn time. But the actual jet acceleration is only half of that of a_1 so that at the end of the burn, the velocity will be half way between V and VD. If K is suitably chosen, the predicted total trajectory time will exceed T. When the next update occurs, the same process recurs and eventually the point (X, V) will be to the left of the control line. In this region there is no first burn, so the predicted trajectory and the actual trajectory will agree. The point will approach the origin without overshoot. On the other hand, let both fuel systems be active and have acceleration a_1 . Let $2a = a_1$. In this case the predicted trajectory and the actual trajectory will agree until the second burn starts. The higher acceleration will cause twice the ΔV and result in undershoot of the origin. However convergence is rapid.

The shortest angular path test consists of asking whether the point (X, V) lies inside the contours at ± 180 or outside of them. (Figure 3-30). In the nominal single fuel case, any point (X, V) inside the contours considers the origin as its terminal point. Points outside these contours should consider ± 360 as their origin. Such points X are shifted by $-360 \operatorname{sgn}(X)$ and thereby appear inside the contours so far as the phase plane logic is concerned. Such a shift is necessary since physically -360 , 0 , and 360 are the same CM attitude. Furthermore it is necessary that the contour dividing the regions of stable nodes be dynamic rather than geometric. Otherwise there exists a region between the dynamic contour and the geometric one where points will initially head for the origin as node, but the trajectory will carry across the geometric contour and then head for 360 as the proper node. This results not only in taking the longer path, but also in taking a longer time to do it. The acceleration associated with the shortest path contour of Figure 3-30 is that for the single fuel jets.

The dead zone utilized for the roll attitude is the parallelogram of Figure 3-31. The shape is chosen to provide a smaller limit cycle amplitude for a given zone width X_z . The effective dead zone on a $T = 2$ second basis is nearly rectangular since $X_z = V_z T$. The intercept V_I is intended to keep the limit cycling velocity at a value less than V_z and is used to specify control line intercept X_s .

Control policy is outlined in the three flow charts starting with Figure 3-36. In the first, roll error is established. Because of symmetry, the control equations are instrumented only for the rhp, where the plane is bisected by the terminal trajectory. To determine which half plane contains (X, V), evaluate the equation for the terminal trajectory at the initial point (X, V). If the point is in the lhp, reverse the sign of variables to reflect about the origin into rhp. If the point (X, V) is to the right of the maximum velocity trajectory through $X = VM/K$,

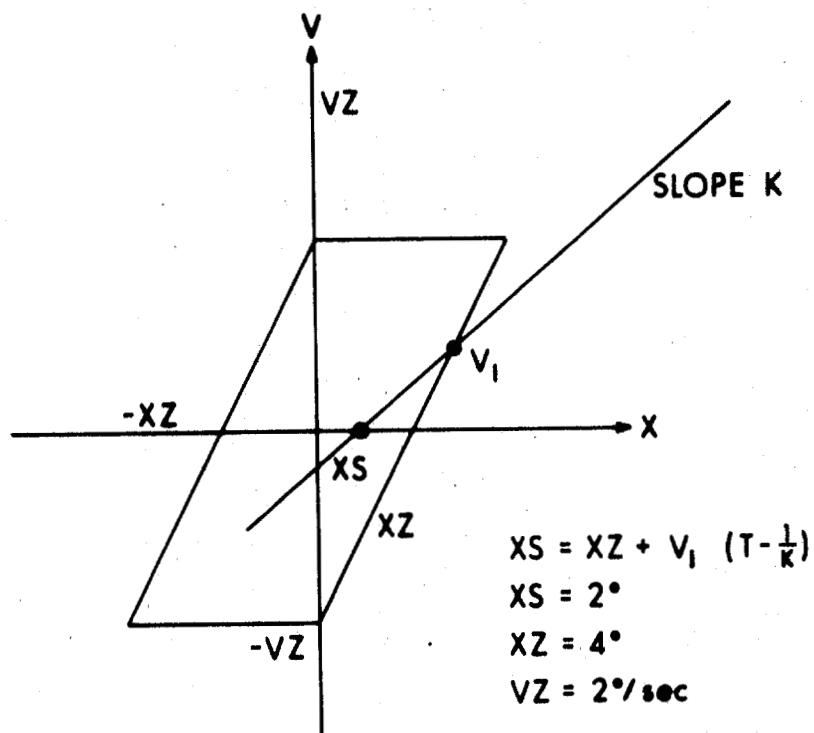


Fig. 3-31 Roll System Dead Zone

then thrust up (or down) to $V = V_M$. If the point is to the left, and below the control line, thrust up to V_d . But if the point is to the left and over the control line, keep the present velocity as the drift velocity if $V_d < V$. In all cases calculate the complete trajectory to the origin. The equations are summarized in the flow chart.

The result of the trajectory calculations are three time intervals:

ton1 the time to thrust from V to V_d (or V_M)
toff the time required to drift at V_d (or V_M)
ton2 the time to origin on terminal trajectory from V_d (or V_M)

Intervals ton1 and ton2 are firing intervals and toff is quiescent interval. The attitude system can generate three, two, one or none of the time intervals. None occurs if the point (X, V) lines within the deadzone at the origin. Jets are quenched, if on, and the program exits.

3.4.3.5. Timetest and Jetcall 1

The program portion named TIMETEST, Figure 3-39, examines the three possible time intervals and prepares to execute them in sequence if

1. no interval is less than two centiseconds
2. the sum of the intervals plus time used in computation is less than two seconds.

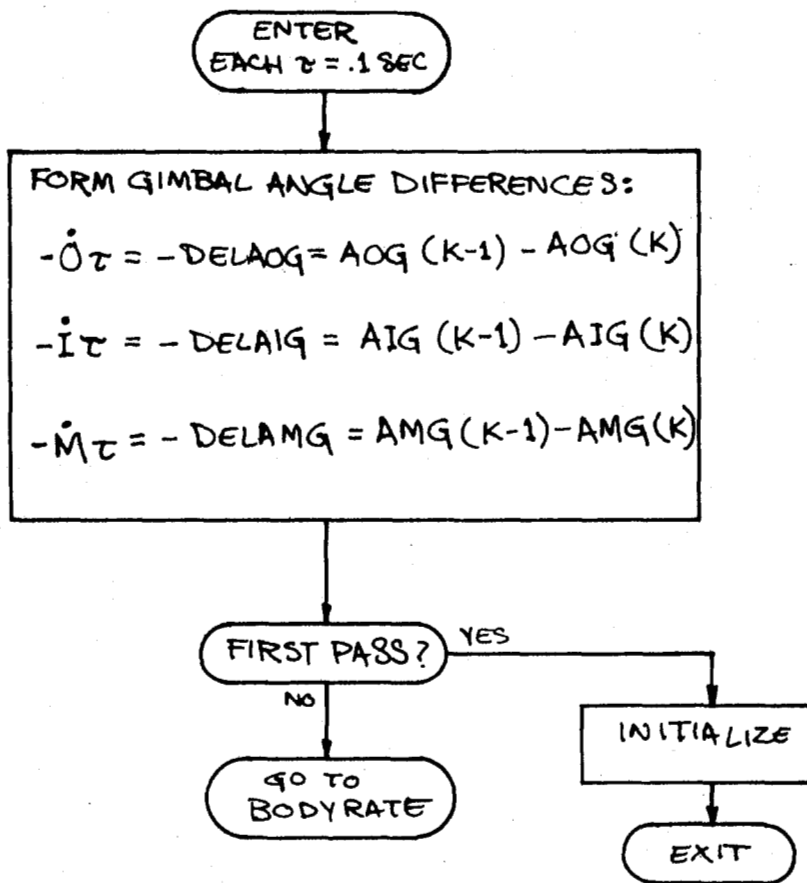
Time intervals which fail to meet the above requirements are ignored, and the jet codes corresponding to such intervals are appropriately executed.

The program portion named JETCALLL, Figure 3-40, performs the actual bookkeeping with the jet list, executing the jet codes and establishing WAITLIST calls as required.

3.4.4. DAP Flow Chart Summary

The Entry DAP is described by the flow charts starting with Figure 3-32 and continuing through Figure 3-40. This chain of event starts with gimbal angle readout and is followed by body rate calculation, attitude rate calculation and attitude angle integration. Immediately following rate determination the sampled DAP is entered. Covered in the next two figures are those autopilot functions that are implemented on the sampled 0.1 second basis. The 2 second predictive roll DAP starts with Figure 3-36 and continues through the processing of waitlist time calls, Figure 3-40. This set of diagrams is presented as a block since it represents the complete sequence of events associated with DAP updates. Of importance also are the calculations that are required to establish the body attitude Euler angles that appear in Figure 3-24 and Figure 3-25. The program for these

READGYMB



READ GIMBAL ANGLES VIA CDU'S
AND FORM FIRST DIFFERENCES

Fig. 3-32 Gimbal Angle Rates

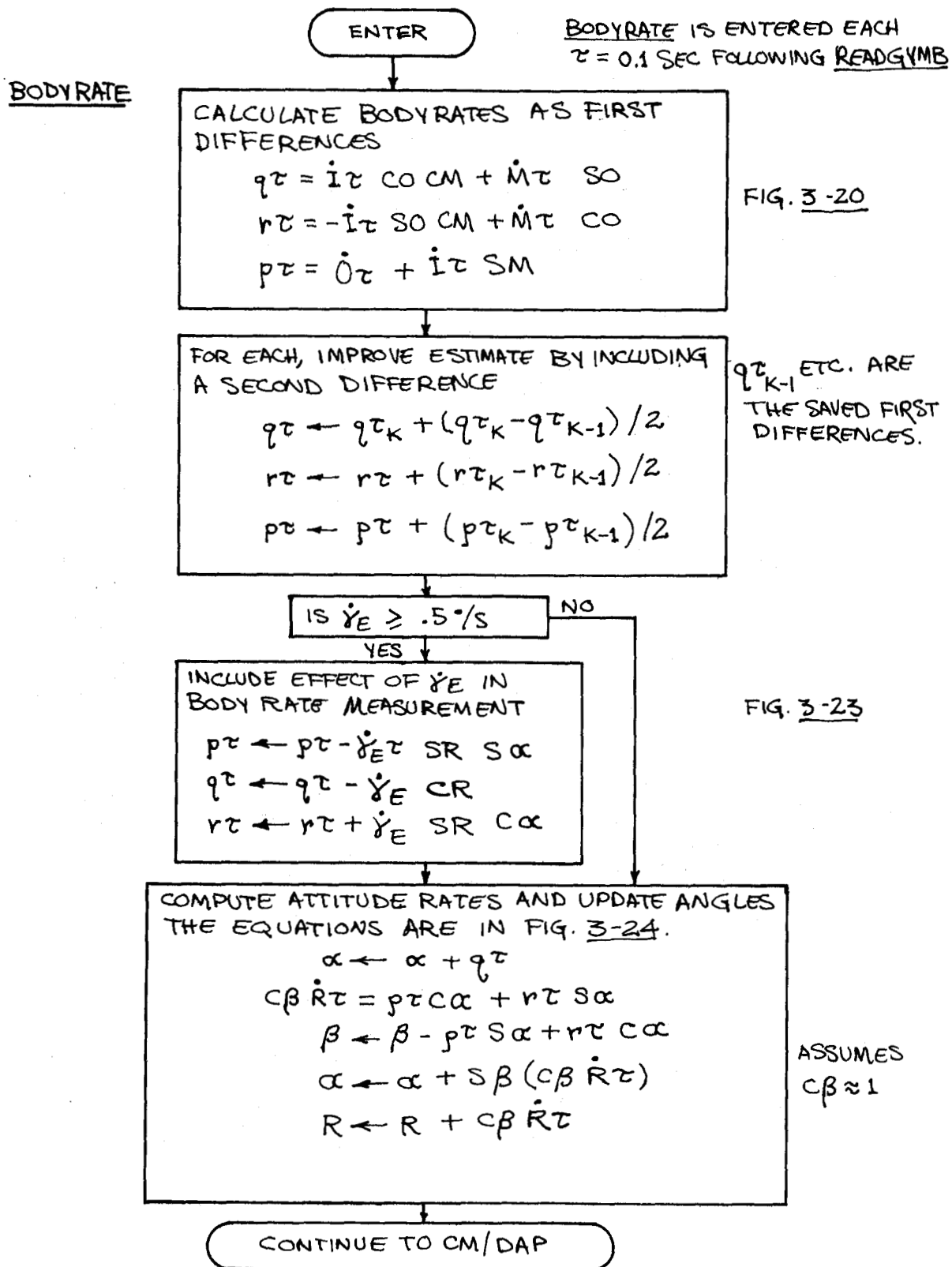


Fig. 3-23 CM Body Rates and Attitude Angles

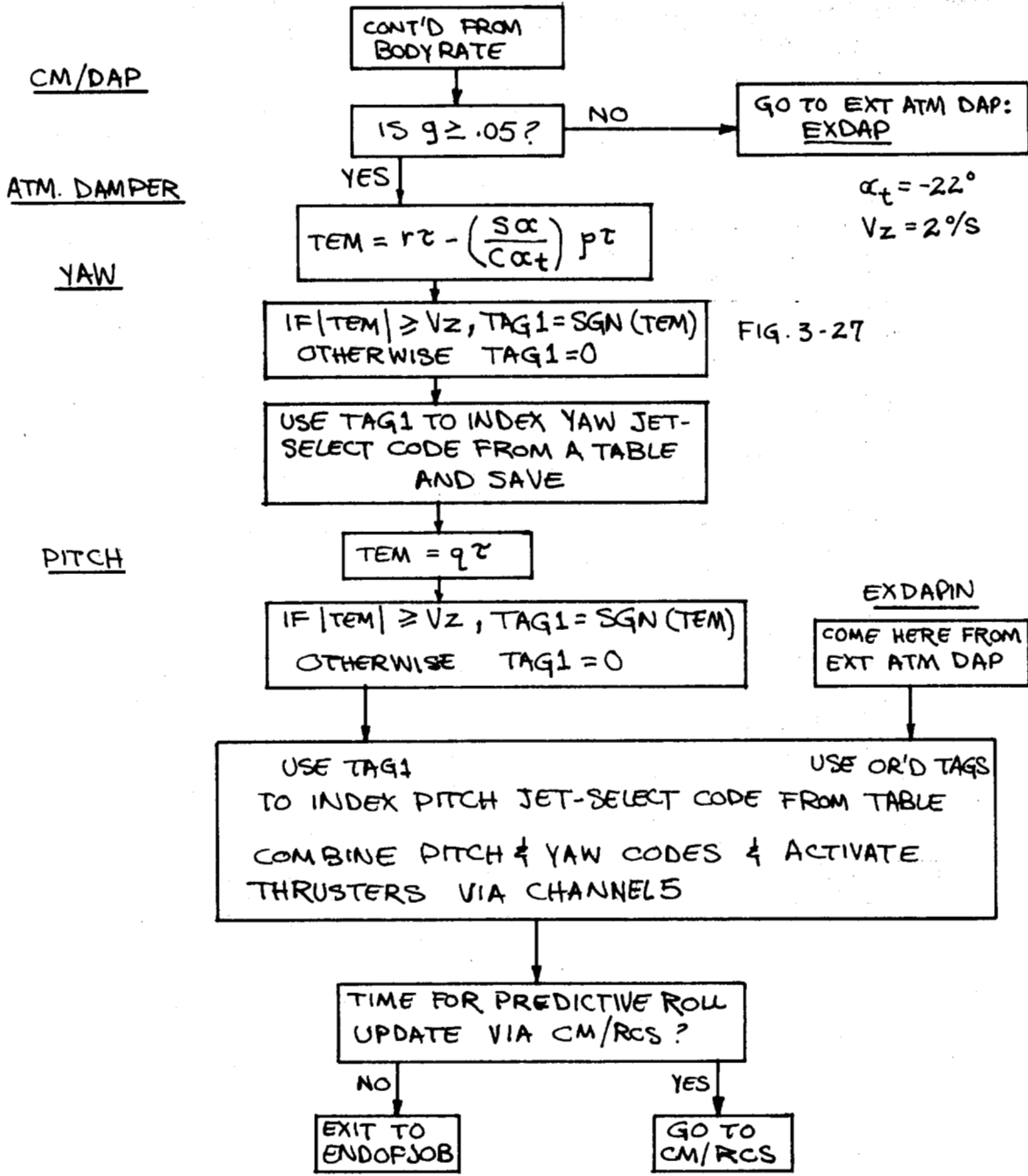


Fig. 3-34 CM Pitch and Yaw Dampers

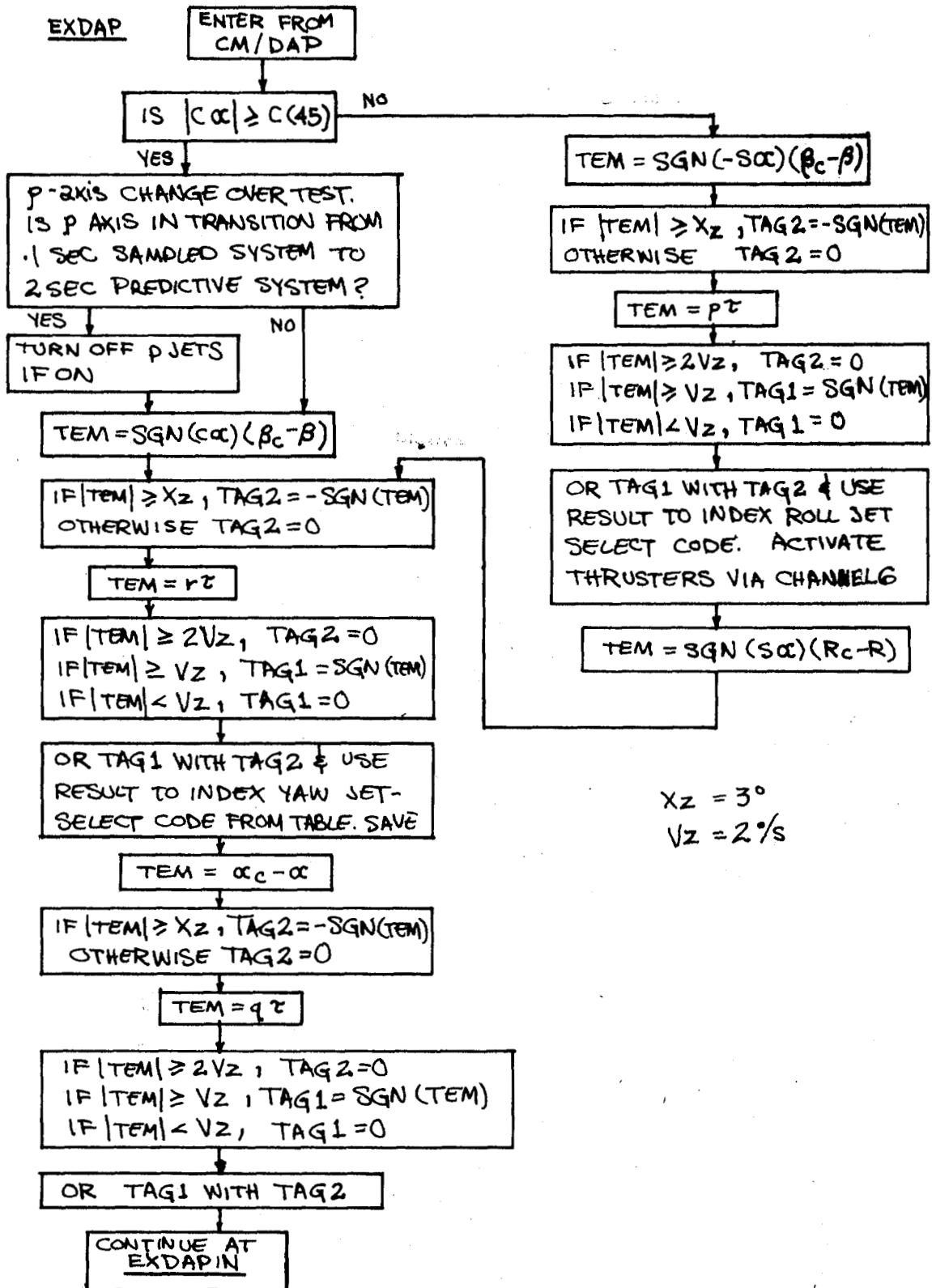


Fig. 3-35 Extra Atmospheric Attitude CM DAP

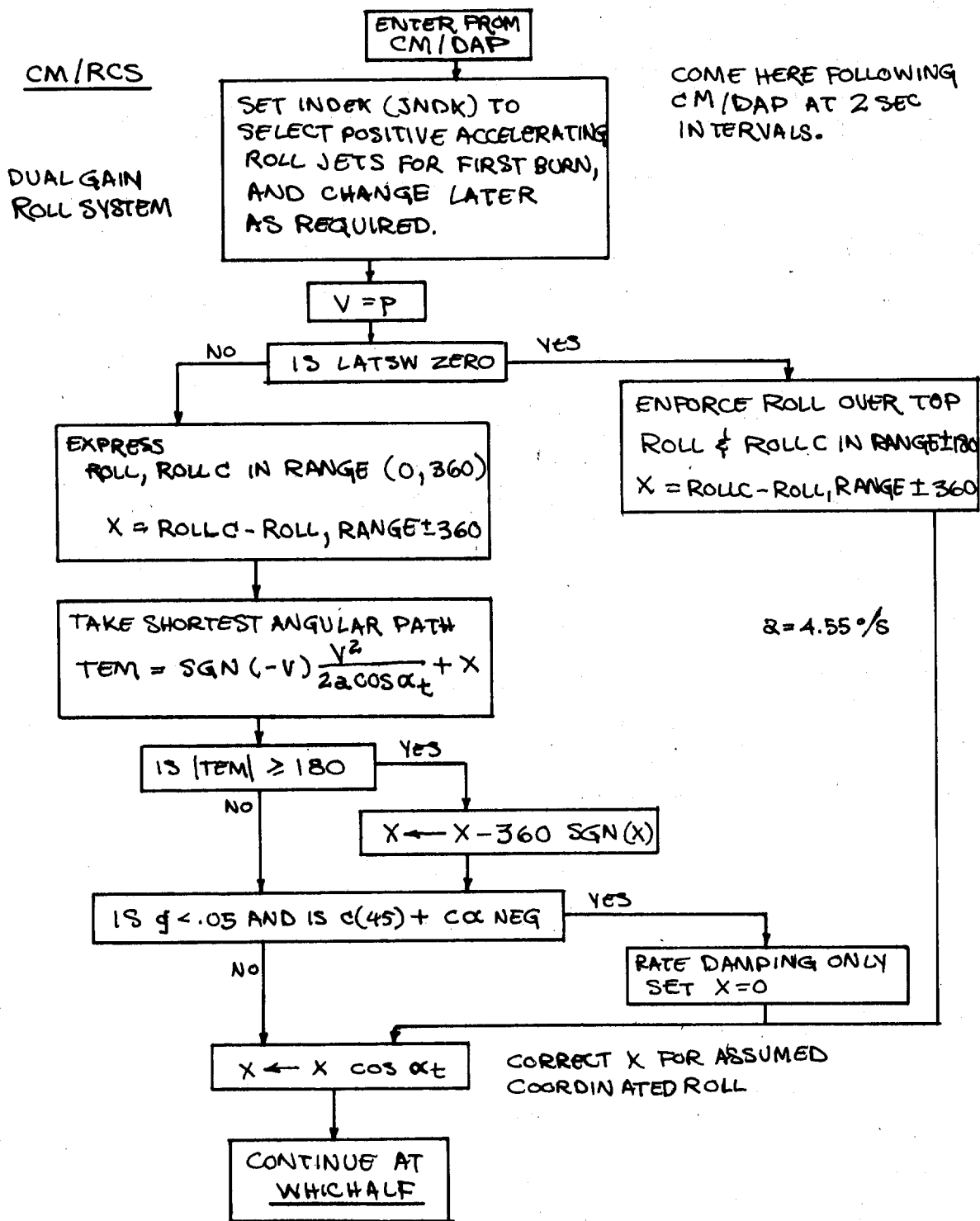


Fig. 3-36 Dual Gain Roll DAP - Error Calc.

WHICH HALF

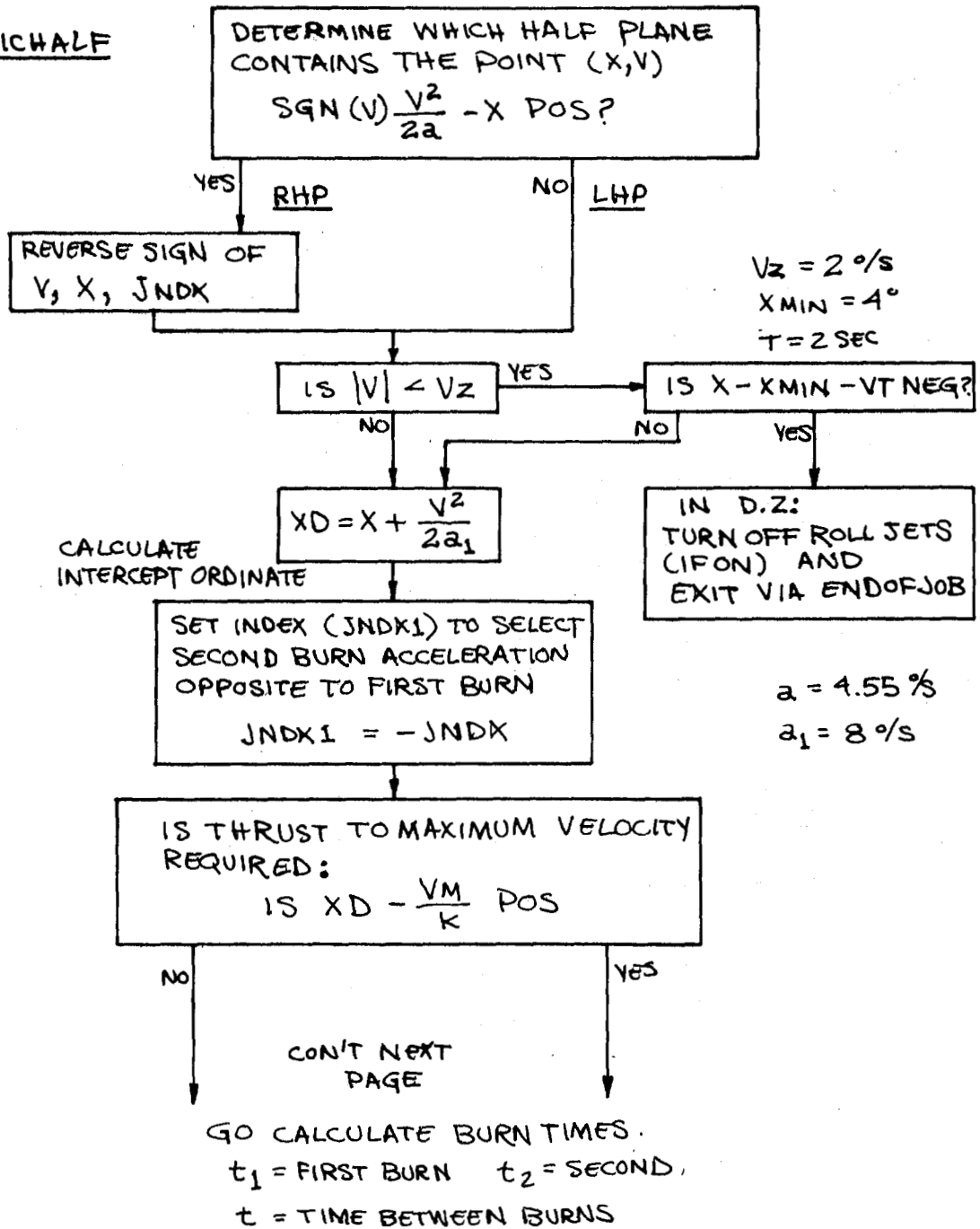


Fig. 3-37 Dual Gain Roll DAP - Preliminary Logic

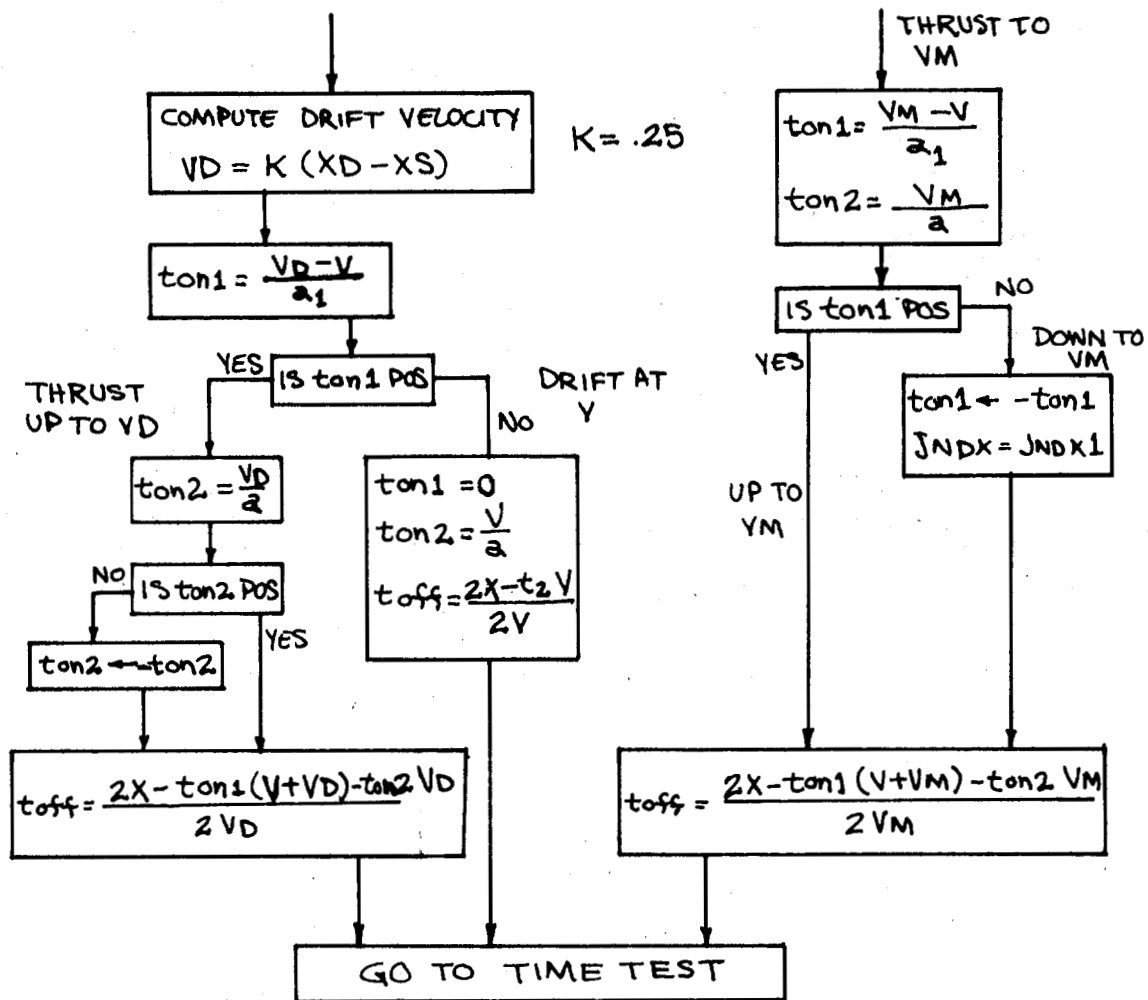


Fig. 3-38 Dual Gain Roll DAP - Burn Time Calc.

TIMETST

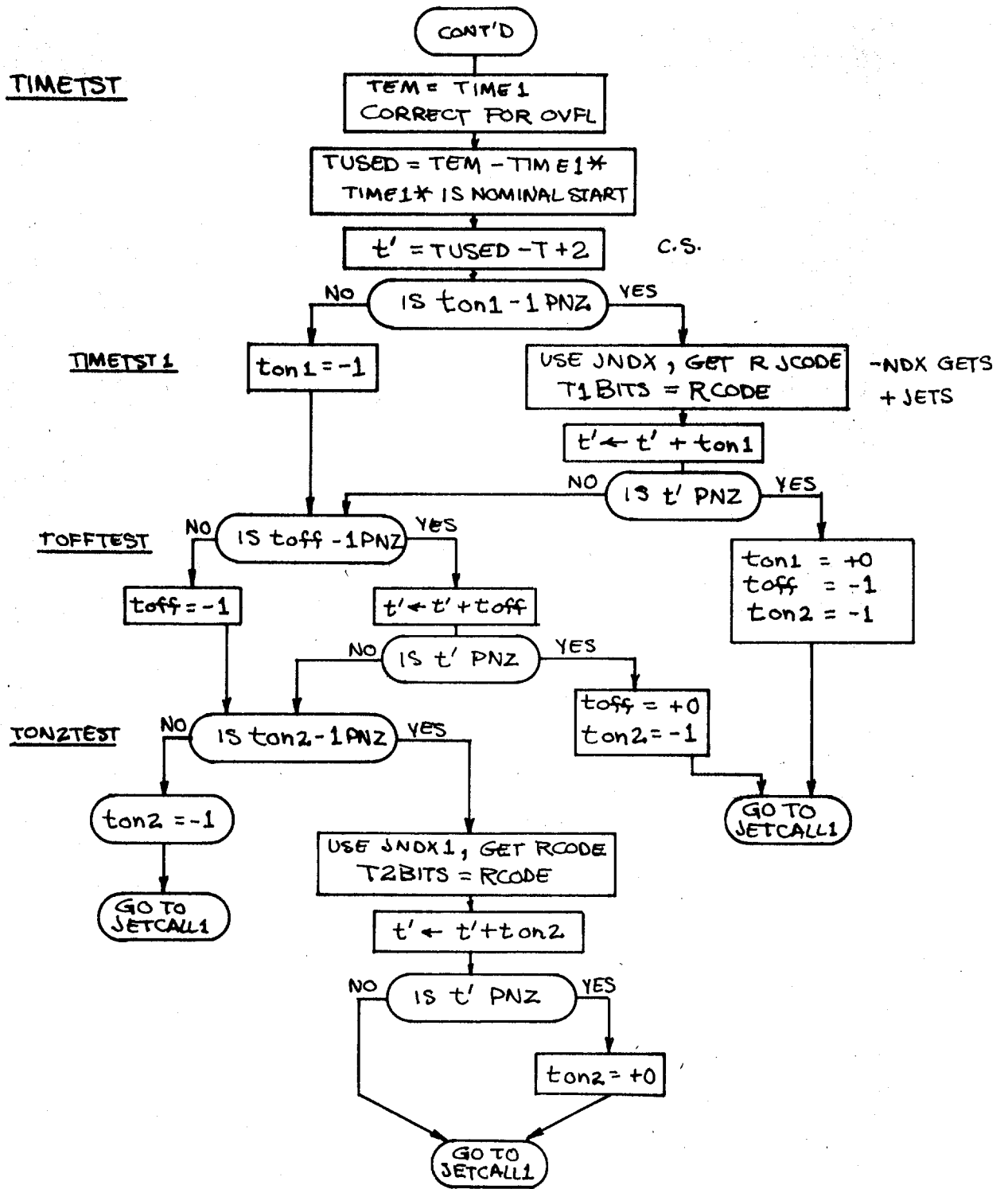


Fig. 3-39 Roll DAP - Time Interval Processing

JETCALL1

WAITLIST CALLS
COME HERE
JETCALL

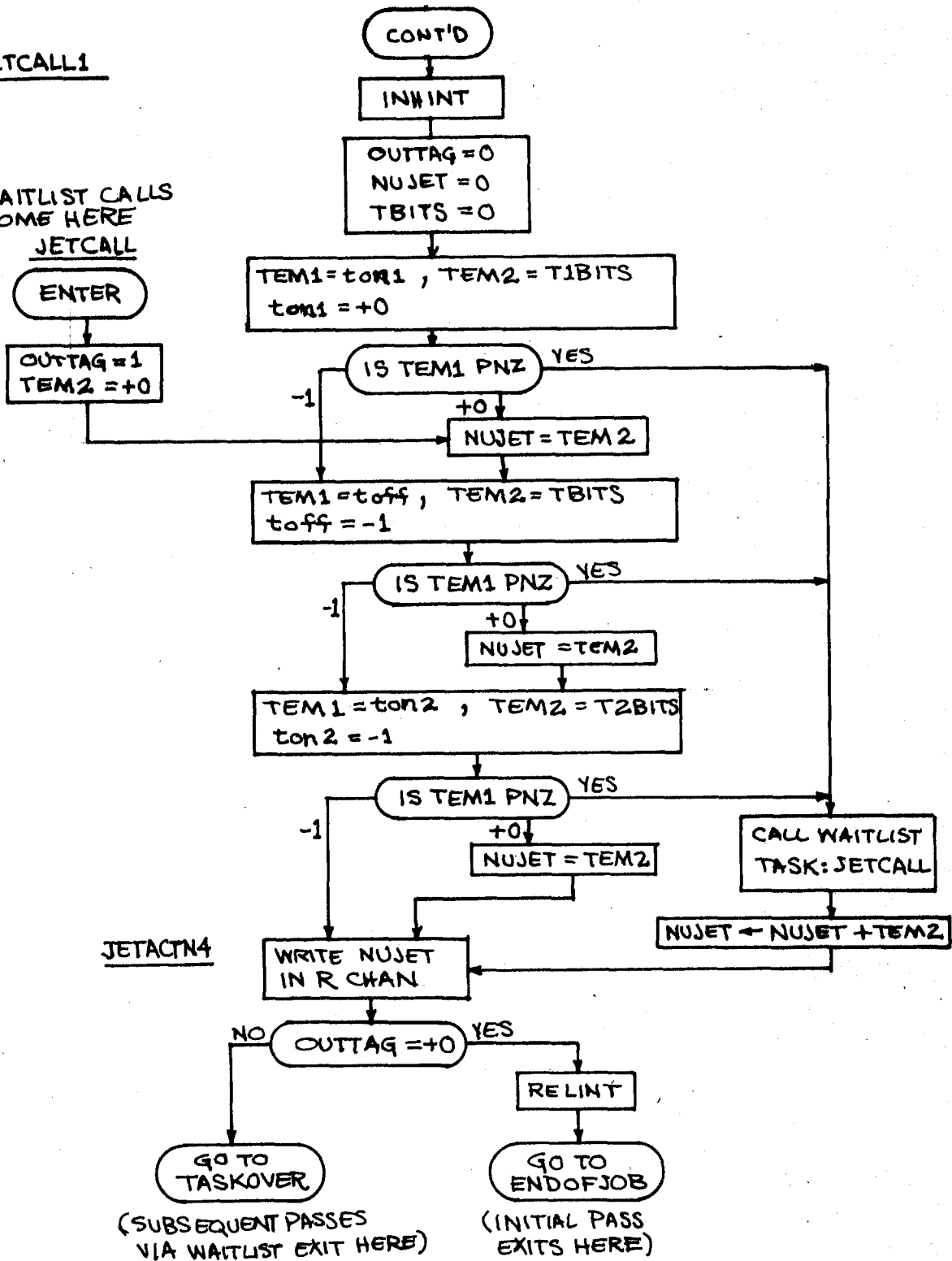


Fig. 3-40 Roll DAP - Time interval Execution Logic

calculations runs somewhat independently of the DAP.

3.5 Saturn Control Functions

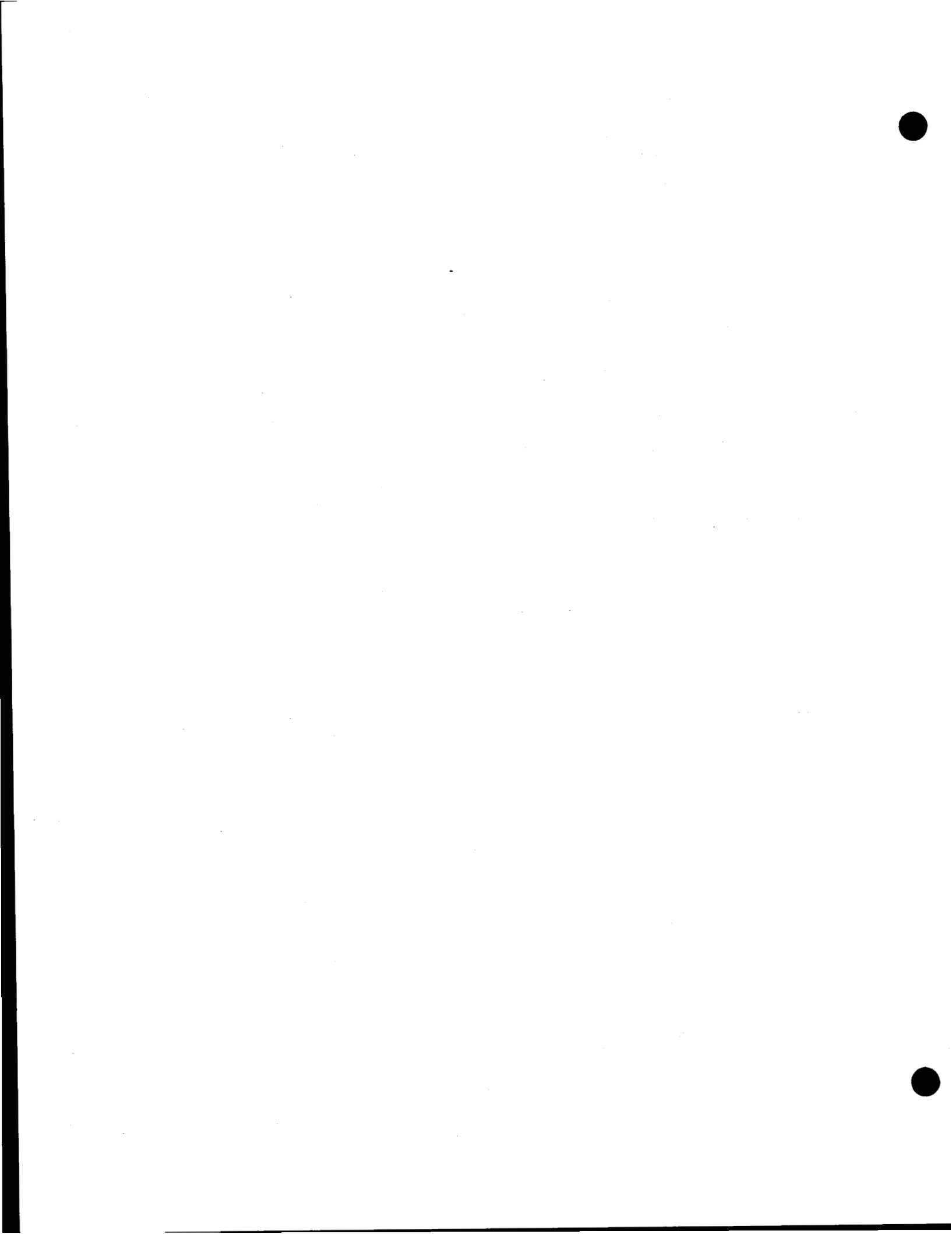
The GNC system provides rate command signals to the Saturn autopilot during the coast phase of earth orbit and, upon command, provides attitude error signals or rate command signals during second stage boost.

During all stages of boost* the CMC generates, by means of a stored, 6-th order polynomial, a nominal spacecraft attitude profile which is compared with spacecraft attitude and the difference displayed to the crew on the FDAI attitude-error needles. At any time after first-stage cutoff, the crew may energize the "Spacecraft Control of Saturn" discrete to the GNC and cause the attitude errors to be transmitted also to the Saturn autopilot. Thereafter, Saturn will exercise thrust vector control so as to null the errors.

The crew may override the polynomial by means of RHC activity. In order to render the CMC sensitive to RHC commands (and zero and disable the polynomial), the GNC A/P discrete must be transmitted. Thereafter, the CMC regards RHC commands as body-axis rate commands and transmits these commands to Saturn as d-c voltages. No RHC activity results in the command of zero rate. The value of the constant rate command is originally $0.5^{\circ}/\text{sec}$. It may be changed to $4^{\circ}/\text{sec}$, $0.2^{\circ}/\text{sec}$ or $0.05^{\circ}/\text{sec}$ by manipulation of the first octal digit of Noun ___ as described in Section 3.2.5.

The RHC control of rate during the coasting phase is identical. The error needles reflect the value of the rate command.

* It is presumed that the MSC supplied polynomial will cover the entire boost trajectory.



4. GNCS OPERATIONAL MODES

4.1 CMC Sequence Control

To efficiently coordinate the design of the CMC Sequences, as well as define the astronaut and ground control procedures with respect to the GNC system, it is necessary to define the operating inter-relationships between the GNC system, other S/C systems, the astronauts and the ground.

In primary GNC control modes the CMC can automatically compute required mission parameters and automatically command both GNC and CSM subsystems. Complete automation of this control throughout a mission is neither feasible nor desirable. For primary as well as secondary GNC control modes the astronauts and/or the ground must be capable of INITIATION, MODIFICATION (to a limited degree), or INTERRUPTION of automatic CMC sequences. These procedures must be thoroughly defined to design the CMC sequence logic for astronaut/ground participation.

4.1.1 CMC Sequence Initiation

4.1.1.1 CMC PROGRAMS

Due to the random time sequencing of many of the CMC tasks the design of "building blocks" of sequences which can be utilized at varied times and in varied circumstances offers the best method of accomplishing these tasks. These "building blocks" must incorporate sufficient logic to clearly define the particular time and/or application for which they are used. They must also standardize astronaut/CMC communication procedures, ground/CMC communication procedures and GNC and SCS Mode determination.

A logical establishment of these building blocks has been made using the PROGRAM capability of the CMC, supplemented by simpler routines not requiring identification as a PROGRAM. The PROGRAMS, their associated routines and the crew checklist are outlined in detail in Section 4.4.

PROGRAMS in process in the CMC are identified by the PROGRAM light on the Keyboard and Display panels. During the display of this PROGRAM number, the CMC can be programmed to do anything within its total capability. The CMC will be pre-programmed, however, to display a PROGRAM number only in response to the initiation of a specific mission task and will continue this display and the pre-programmed sequence of computations and displays for the specific task until PROGRAM completion or termination.

PROGRAMS may always be initiated by manual DSKY keyboard entry (Astronaut) or by CMC UPLINK Command (ground). In certain cases PROGRAM initiation is automatically done by the previous PROGRAM. The diagrams of Section 4.4, however, show PROGRAM selection as it should occur nominally.

4.1.1.2 Special CMC Routines

The CMC Sequences include many routines and subroutines not specifically identified with a PROGRAM. The majority of these are automatically performed in a particular computation or control sequence and involve no notification to the "outside world" that they are in process. While they may occasionally be referred to in this document their large number alone requires that detailed descriptions be restricted to special CMC program documents.

Several special routines are described in detail herein, however, because of one or more of the following characteristics:

- (a) The routine involves CMC communication with the astronaut.
- (b) The routine is of importance in understanding the PROGRAMS.
- (c) The routine involves significant sequences of CMC/Astronaut action but could be performed while certain PROGRAMS are in process.

These routines are normally called by the CMC. If the routine requires CMC/Astronaut communication, it will start with a particular display which acts as a key to the astronaut that the CMC has automatically entered the routine. The majority of these routines may not be initiated by DSKY entry or by CMC UPLINK command; however, there are exceptions to this rule.

4.1.2 CMC Sequence Modification

Modification of a "normal" CMC sequence associated with a particular PROGRAM or routine is possible, but only in a limited sense. When Astronaut action is implied by CMC request, he sometimes has the alternative of not completing this action and so notifying the CMC. The CMC sequence will proceed; however, the result is usually system operation in a less than optimum configuration.

During certain CMC calculation procedures the astronaut/ground is given the opportunity to modify/change the inputs to a certain specific calculation to force desired results.

4.1.3 CMC Sequence Termination

Once an automatic sequence has been initiated the astronaut always has the capability to end it at any time. This can be done by a DSKY entry selecting a new PROGRAM (for instance CMC IDLING PROGRAM (P00): DSKY entry "VERB 37 ENTER 00 ENTER") which will terminate all displays and control sequences associated with the previous PROGRAM, and start the new PROGRAM. In certain cases (described below) a PROGRAM may be terminated by a special DSKY entry (for instance "TERMINATE"; VERB 34 ENTER).

4.2 CMC/Astronaut/Ground Communications

4.2.1 CMC / Ground Communications

The CMC/Ground Communications are via the CMC UPLINK and DOWNLINK and are described in detail in Section 2.

4.2.2 CMC/Astronaut Communications

The Display and Keyboard logic in the CMC processes information exchanged between the CMC and the computer operator. This information is exchanged via the Display and Keyboards (DSKYS) of which there are two, one at the Main Display Console (MDC) and one at the Lower Equipment Bay (LEB).

The modes of operation are basically:

- (a) Display of Internal Data - This includes simple displays and periodically updated displays of data; and displays of requests for operator action required by the CMC.
- (b) Loading of External Data - the process of inserting data into the CMC via the DSKY.
- (c) PROGRAM or ROUTINE Calling - Initiated by operator action via the DSKY.

The following paragraphs and Table 4-1 provide a limited description of the DSKY and the crew/DSKY operating procedures. They are included herein to facilitate the reader's understanding of the PROGRAM logic in Section 4.4 and do not comprise a complete instruction manual for the use of the DSKY. For detailed DSKY operating instructions refer to other MIT documents.

4.2.2.1 The DSKY (Refer to Fig. 4-1)

- (a) UPLINK ACTY LIGHT - Is energized by the first character of a DIGITAL UPLINK message received by the CMC. If the light is not extinguished by the UPLINK transmission it should be extinguished by crew use of the RSET or KEY REL buttons when the UPLINK transmission is complete.
- (b) NO ATT LIGHT - Is energized when the CMC is in operate mode and there is no inertial reference; i. e. the ISS is off, caged, or in the coarse align mode.
- (c) STBY LIGHT - Is energized when the CMC is in standby mode. Is deenergized when the CMC is in operate mode.
- (d) KEY REL LIGHT - Is energized when an internal sequence attempts to use the DSKY, but finds it busy due to independent operator action (any keyboard depression except RSET). Until the operator releases the DSKY (by pressing the KEY REL button) the internal sequence may be forced to hold.

- (e) TEMP LIGHT - Is energized when the stable member temperature is outside the design limits (126.3°F to 134.3°F).
- (f) GIMBAL LOCK LIGHT - Is energized when the middle gimbal angle exceeds $\pm 70^\circ$ from its zero position. When the middle gimbal angle exceeds $\pm 85^\circ$ from its zero position the CMC automatically commands the coarse align mode in the ISS to prevent gimbal oscillation. The NO ATT light will then be energized (see(b) above).
- (g) PROG LIGHT - Is energized when a PROGRAM ALARM occurs. Refer to paras. 4.3.3 (d) and 4.3.4.
- (h) RESTART LIGHT - Is energized when a RESTART occurs. Refer to para. 4.3.1 (j).
- (i) TRACKER LIGHT - This light is inoperative on the CMC DSKYS.
- (j) OPR ERROR LIGHT - Is energized when the DSKY operator performs an improper sequence of key depressions. The light is de-energized by pressing the RSET button. Refer to para. 4.2.2.11.
- (k) COMP ACTIVITY LIGHT - Is energized when the CMC is occupied with any internal sequence. It is not an indicator of whether the operator may use the DSKY or whether the CMC is not capable of handling further computation.
- (l) Display Panel - Consists of 24 electroluminescent sections arranged as in Figure 4-1. Each section is capable of displaying any decimal character or remaining blank, except the 3 sign sections (R1S, R2S, R3S). These display a plus sign, a minus sign, or a blank. The numerical sections are grouped to form 3 data display registers, each of 5 numerical characters; and 3 control display registers, each of 2 numerical characters. The data display registers are referred to as R1, R2, R3. The control display registers are known as VERB, NOUN, and PROGRAM.

At maximum activity, two display characters and a sign may be updated on the Display Panel approximately every .1 second.

- (h) KEYBOARD - Contains the following buttons:
 - VERB - Pushing the button indicates that the next two numerical characters keyed in are to be interpreted as the Verb code.
 - NOUN - Pushing the button indicates that the next two numerical characters keyed in are to be interpreted as the Noun Code.

+ and - SIGN KEYS - Used for sign convention and to identify decimal data.

NUMERICAL KEYS (0 thru 9) - Self explanatory.

CLR (CLEAR) - Used during a data loading sequence to blank the data display register (R1, R2, R3) being used. It allows the operator to begin loading the data word again.

STBY - Used to put the CMC in standby and operate mode. Pushing button always changes present mode. STBY LIGHT (see above) indicates present mode.

KEY REL. - Gives the operator's permission for internal sequences to use the DSKY. It is recommended that the operator release the DSKY by pushing this button whenever he is temporarily finished with the DSKY.

ENTR (ENTER) - Is used in two ways:

- (1) To execute the Verb/Noun now appearing on the Verb and Noun lights.
- (a) To accept a data word just loaded.

RSET (RESET) - Turns off alarm conditions on the DSKY providing the alarm condition has been corrected.

4. 2. 2. 2 Verbs and Nouns

The basic language of communication between the operator and the DSKY consists of the Verb and Noun. The Verb Code indicates what action is to be taken (operation): The Noun Code indicates to what this action is applied (operand).

Verb Noun codes may be originated either by manual operation or by internal CMC sequence.

The standard procedure for manual keyboard operation consists of a sequence of 7 key depressions:

VERB V₁ V₂ NOUN N₁ N₂ ENTR

The VERB key depression blanks the Verb lights on the Display Panel (VD 1 and VD2), and clears the Verb Code register within the computer. The next two numerical characters punched in are interpreted as the Verb Code (V₁, V₂). Each of these characters is displayed in the Verb lights on the Display Panel as it is punched in. The NOUN key operates similarly for the NOUN lights and Noun Code register.

The depression of the ENTR key causes the performance of the Verb-

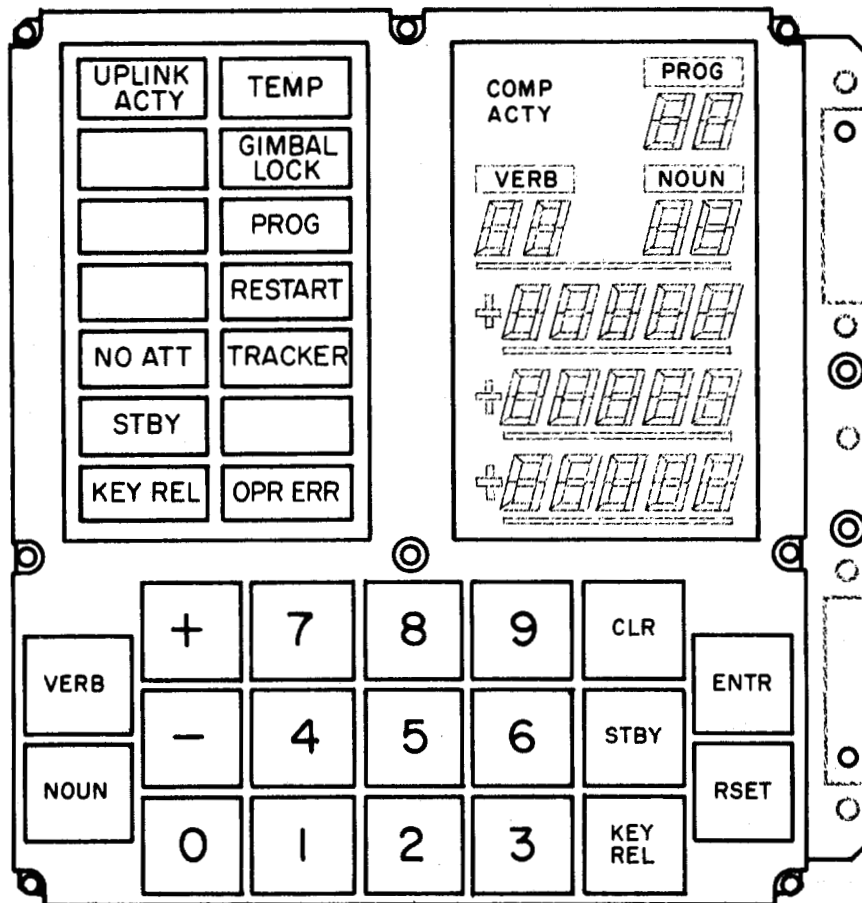


Fig. 4-1 Display and Keyboard Assembly

Noun combination appearing in the lights at the time of depression. Thus it is not necessary to follow any order in punching in the Verb or Noun Code. They may be done in reverse order, or an old Verb or old Noun may be used without repunching it.

No action is ever taken in performing the Verb-Noun combination until ENTER is pressed. If an error is noticed in either the Verb Code or the Noun Code before the ENTER is pressed, correction is simple. Merely press the VERB or NOUN key and repunch the originally intended code, without necessarily changing the other. Only when the operator has verified that the desired Verb and Noun Codes are in the lights, should he press the ENTER key and execute the Verb-Noun combination.

A Noun Code can refer to a group of computer erasable registers, a group of counter registers, or may serve merely as a label. A label Noun refers to no particular computer register, but conveys information by its Noun Code number only. The group of registers to which a Noun Code refers may be a group of 1, 2, or 3 members. These are generally referred to as 1-, 2-, or 3- component Nouns. The component is understood as a component member of the register group to which the Noun refers. The machine addresses for the registers to which a Noun refers are stored within the computer in Noun Tables.

A single Noun Code refers to a group of 1-, 2-, or 3- component members. It is the Verb Code that determines which component member of the Noun group is operated on. Thus, for instance, there are 5 different Load Verbs. Verb 21 is required for loading the first component of whatever Noun is used therewith; Verb 22 loads the second component of Noun; Verb 23, the third component; Verb 24, the first and second components of the Noun; and Verb 25 loads all three components of the Noun. A similar component format is used in the Display and Monitor Verbs.

When the Decimal Display Verb is employed, all the component members of the Noun being used are scaled as appropriate, converted to decimal, and displayed in the data display registers.

Decimal data is identified by a + or - sign preceding the 5 numerical characters. If decimal is used for loading data of any component of a multi-component Load Verb, it must be used for all components of that Verb. Thus no mixture of decimal and octal data is permitted for different components of the same Load Verb. (If this is violated, the Operator Error alarm is turned on.)

There is a class of Verbs called Monitor Verbs which display data every one second. Once a Monitor Verb is executed, the data on the Display Panel continues to be updated until the Monitor is turned off.

The Monitor is turned off by; Proceed/Proceed without data (V33E), Terminate (V34E), and internal program initiation of the Keyboard and Display System Program, or by a Fresh Start of the CMC.

Monitor action is suspended (but not ended) by the depression of any key, except Reset. This turns on the KEY REL LIGHT immediately. Monitor action continues after the Keyboard and Display System is released. Thus it is possible to suspend a monitor while the operator loads some data, or requests another display; and to return to the original monitor when his intervention is concluded.

After any use of the DSKY, the numerical characters (verb, noun and data words) remain visible until the next use of the DSKY. If a particular use of the DSKY involves fewer than 3 data words, the data display registers (R1, R2, R3) not used remain unchanged unless blanked by deliberate program action.

The DSKY procedures above were described for manual operation, however the principles described remain the same for DSKY operation by the internal CMC sequences.

As outlined in the Mission PROGRAMS (section 4.4) the majority of DSKY operations are originated by the internal programs.

The most commonly used CMC originated verbs in the Mission PROGRAMS are of the following categories:

- (a) DISPLAY - To display data to the operator. DISPLAY verbs present data computed by the mission program.
- (b) LOAD - To request a data load as described in detail below.
- (c) PLEASE PERFORM - To request an action from the operator who then notifies the CMC that he has complied as described in detail below.
- (d) PLEASE MARK - To request the operator to push the "MARK" button for an optics sighting.

CMC initiated Verb/Noun combinations are either statically displayed or flashed. If static they identify data displayed only for operator information requiring no response from him. If the Verb/Noun is flashing, appropriate operator response is required as dictated by the Verb/Noun combination. In this case the internal sequence is interrupted until the operator responds appropriately, then the Verb/Noun flash is terminated and the internal sequence

is resumed.

It is important to respond to a flashing Verb/Noun with only one of the proper responses or else the internal sequence that called the display may never be resumed.

An appropriate operator response to a flashing Verb/Noun should be an ENTER, Recycle (V32E), Proceed/Proceed without Data (V33E), or a Terminate (V34E). The internal sequence response to any one of these operator responses varies according to the Verb/Noun flashing and the PROGRAM in process as described below and in Section 4.4.

4.2.2.3 Acceptance of Keys

The numerical keys, the CLR key, and the sign keys are rejected if struck after completion (final ENTER) of a data display or data load Verb. At such time, only the Verb, Noun, Enter, Reset, or Key Release are accepted. Thus the data keys are accepted only after the control keys have instructed the program to accept them.

Similarly the plus (+) and minus (-) keys are accepted just before the first numerical character of R1, R2, or R3 is punched in, and at no other time.

The 8 or 9 key is accepted only while loading a data word into R1, R2, or R3 which was preceded by a plus or minus sign. (If this is violated, the Operator Error Alarm is turned on.)

If more than two numerical characters are punched in while loading the Verb, Noun, or Program code, or more than five numerical characters while loading a data word, the excess characters are not accepted.

4.2.2.4 Release of Keyboard and Display System

The Keyboard and Display System Program can be used by internal computer programs. However, any operator keyboard action (except Reset) makes the Keyboard and Display System Program busy to internal routines. The operator has control of the Keyboard and Display System until he wishes to release it. Thus he is assured that data he wishes to observe will not be replaced by internally initiated data displays. In general, it is recommended that the operator release the Keyboard and Display System for internal use when he has temporarily finished with it. This is done by pressing the Key Release button.

If an internal program attempts to use the Keyboard and Display System, but finds that the operator has used it and not yet released it, the Key Release

light is turned on. When the operator finds it convenient, he should strike the Key Release button to allow the internal program to use the Keyboard and Display Panel.

4.2.2.5 DISPLAY - Verb/Noun Flashing

This is an internally initiated action. The appropriate operator response to a flashing DISPLAY Verb/Noun combination is:

- (a) Correct the data (See Section 4.2.2.6 below.) Perform the appropriate load verb sequence. Upon the final ENTER, the internal sequence proceeds normally.
- (b) Recycle (V32E) - This causes the program to return to a previous location.
- (c) "Proceed/Proceed Without Data" (V33E). This indicates acceptance of the displayed data, and a desire for the internal sequence to continue normally.
- (d) "Terminate" (V34E). The operator wishes the internal sequence to cease operation.

Note: That only three responses are legal for any given Verb/Noun Flash.

4.2.2.6 LOAD - Verb/Noun Flashing

Whenever any data is to be loaded the Verb/Noun flashes. The flash occurs whether the data load is initiated by CMC or by the operator. The appropriate data display register (R1, R2, or R3) is blanked in anticipation of the data load. Data is loaded in 5-character words and is displayed character-by-character; in one of the 5-position data display registers as it is keyed in.

Numerical data is considered decimal if the 5-character data word is preceded by a plus or a minus sign; if no sign is supplied it is considered octal. The plus and minus keys are accepted only when they precede the first numerical character of the data word; they are ignored at any other time. Decimal data must be loaded in full 5-numerical-character words (no zeros may be suppressed); octal data may be loaded with high order zeros suppressed. If decimal is used for any component of a multi-component Load Verb, it must be used for all components of that Verb. No mixing of octal and decimal data is permitted for different components of the same Load Verb; it must be used for all components of that Verb. No mixing of octal and decimal data is permitted for different components of the same Load Verb. (If this principle is violated, the Operator Error Alarm is turned on.)

The ENTER key must be pressed after each data word. This tells the program that the numerical word being punched in is complete. The flash is turned off after the last ENTER of a loading sequence is pressed.

As data is loaded, it is temporarily stored in intermediate buffers. It is not placed into its final destination, as specified by the Noun Code, until the final ENTER of the load sequence is punched in.

If an attempt is made to key in more than 5 numerical characters in sequence, the sixth and subsequent characters are simply rejected. If the 8 or 9 key is punched during an octal load (as identified by lack of a sign entry), it is rejected and the Operator Error Light is turned on.

In multi-component load situations, the appropriate single component Load Verbs are flashed one at a time. The computer always instructs the operator through a loading sequence. For example, consider a three-component loading sequence. The operator (or the internal program) initiates the sequence by selecting VERB 25, "load 3 components of:" (any noun will do). E. The Verb Code is changed to 21, "load first component of:," and the flash is turned on. VERB 21 continues to be flashed as the operator punches in the first word of data. When the ENTER is pressed, the Verb Code is changed to 22. Flashing continues while the operator punches in the second data word. When ENTER is pressed, the Verb Code is changed to 23, "load third component," and again the flash continues while the third data word is punched in. When ENTER is pressed, the flash is turned off, and all three data words are placed in the locations specified by the Noun. Throughout the changing of the Verb Codes, the Noun Code was left unchanged.

The CLEAR Button is used during data loading to remove errors in R1, R2, or R3. It allows the operator to begin loading the data word again. It does nothing to the PROGRAM, Noun, or Verb lights. (The Noun lights are blanked by the NOUN key; the Verb lights, by the VERB key.) In the following discussions, the term Clearing Function will be used to mean: blanking the data display register of interest and placing +0 into the buffer storage register associated with that display register.

For single component Load Verbs the CLEAR button depression performs the Clearing Function on whichever register is being loaded, provided that the CLEAR is punched before the data ENTER. Once the ENTER is depressed, the CLEAR does nothing. The only way to correct an error after the data ENTER for a single component Load Verb is to begin the Load Verb again.

For the 2- or 3- component Load Verbs, there is a backing-up feature

of CLEAR. The first depression of the CLEAR key performs the Clearing Function on whichever register is being loaded. (The CLEAR may be pressed after any character, but before its ENTER.) Consecutive depressions of CLEAR perform the Clearing Function on the data display register above the current one, until R1 is cleared. Any attempts to back-up beyond R1 are simply ignored.

The backing-up function of CLEAR operates only on whatever data is pertinent to the Load Verb which initiated the loading sequence. For example, if the initiating Load Verb was a load second component only, no backing-up action is possible.

The appropriate operator response to an internally initiated Verb/Noun for LOAD therefore becomes:

- (a) The final ENTER of the Loading sequence, after which the internal sequence proceeds normally.
- (b) "Proceed/Proceed Without Data" (V33E). This indicates the operator will not load the requested data and desires the internal sequence to continue as best it can.
- (c) "Terminate" (V34E). The operator wishes the internal sequence to cease operation.

4.2.2.7 PLEASE PERFORM - Verb/Noun Flashing

This is always an internally initiated action, as operator response is always required to the "please perform" request, the verb-noun is always flashed, and the internal sequence is interrupted. The "please perform" verb (50) is usually used with the "checklist" noun (25) with an appropriate "checklist code" number in R1. The appropriate operator response is:

- (a) ENTER to indicate that the requested action has been performed. The internal sequence continues normally.
- (b) "Proceed Without Data" (V33E). The operator chooses not to perform the requested action, but desires the internal sequence to proceed as best it can.
- (c) "Terminate" (V34E). The operator chooses not to perform the requested action and desires the internal program to cease operation.

The "please perform" verb (50) is also used with "Change of PROGRAM" noun (07) and "Engine on Enable" noun (11). Its use in these cases is subject to the PROGRAM in process and is best described by referral to Section 4.4.

4.2.2.8 PLEASE MARK

The "please mark" verb (51) is flashed when the CMC is prepared to accept optical sighting data upon the pushing of the "MARK" button. The logic associated with the "please mark" function is completely described in Section 4.4.

4.2.2.9 Machine Address to be Specified

There is a class of Noun available to allow any machine address to be used. These are called "Machine Address to be Specified" Nouns. When the ENTER which causes the Verb-Noun combination to be executed senses a Noun of this type, the flash is immediately turned on. The Verb Code is left unchanged. The operator should load the 5-octal-character complete machine address of interest. It is displayed in R3 as it is punched in. If an error is made in loading the address, the CLEAR may be used to remove it. Pressing ENTER causes continuation in executing the Verb.

4.2.2.10 PROGRAM Selection

To change the PROGRAM the sequence is: VERB 37 ENTER. This causes the Noun display register to be blanked and the Verb Code to be flashed. The 2 character PROGRAM code should then be loaded. For verification purposes, it is displayed as it is loaded in the Noun display register. The ENTER causes 1) the flash to be turned off, 2) a request for the new PROGRAM to be entered, and 3) a new PROGRAM Code to be displayed in the PROGRAM display register.

4.2.2.11 Alarm Philosophy

The Operator Error Light is turned on when the operator performs some improper sequence of key depressions.

Illegal Verbs, Nouns, and Combinations

The simplest alarm situation is an attempt to use an undefined (or spare) Verb Code or Noun Code. The Alarm light is turned on when the ENTER is pressed that attempts to execute the Verb/Noun combination. No further action is taken.

It is possible to choose a Verb that is defined and a Noun that is defined, but have the combination of Verb and Noun be illegal (for example, the "decimal display" Verb used with a Noun which is restricted to be "octal only"). The alarm light is turned on at the ENTER that attempts to execute the Verb/Noun combination. No further action is taken.

Violation of the following principles causes the Operator Error to be

ASTRONAUT RESPONSE	DISPLAY OF INFORMATION		REQUEST FOR ASTRO ACTION	REQUEST FOR DATA LOAD	REQUEST FOR OPTICS MARK
		Type of information identified by V_N followed by up to three available registers of information, R1, R2, R3.		Request identified by V50 ("Please Perform"), N identifying a function to be performed or a check list, one register R1 identifying function on that check list.	Request identified by V and type of data by N. Loaded data appears in registers R1, R2, R3. At completion, key in "ENTER".	Request identified by V51. At completion of "MARK"s identify target (final entry is "ENTER")
	CMC Awaiting ASTRO Response V_N_Flashing	CMC Not Awaiting ASTRO V_N_Static	CMC Awaiting ASTRO Response V50N_Flashing	CMC Always Awaiting ASTRO Response V_N_Flashing	CMC Always Awaiting ASTRO Response V51 Flashing
Key in "ENTER"	No CMC Action	No CMC Action	CMC assumes ASTRO complied, terminates flashing Verb-Noun, and continues	CMC takes loaded data, terminates flashing Verb-Noun and continues	No CMC Action
Key in "PROCEED/ PROCEED w/o DATA" (V33E)	CMC assumes displayed data is correct, terminates flashing Verb-Noun, and continues	No CMC Action	CMC assumes ASTRO did not comply, terminates flashing Verb-Noun, and continues	CMC assumes no data available, terminates flashing Verb-Noun, and continues if possible	No CMC Action
Key in "TERMINATE" (V34E)	Varies with program in progress	No CMC Action	Varies with program in progress	Varies with program in process.	Program in progress is terminated.
Key in "RECYCLE" (V32E)	CMC returns to earlier point in sequence	No CMC Action	Incorrect Response	Incorrect response	No CMC action
Press "MARK" button (MARK)	If display is not in use will display V05N56 and the present 2 optics angles and time for a minimum of 10 secs.				CMC reads 2 optics angles, 3 CDU angles, and time, terminates flashing Verb-Noun if a suitable number of marks have been made and continues

ASTRONAUT RESPONSE TO DSKY DISPLAYS
AND CMC RESULTANT ACTION

Table 4-1

turned on. No further action is taken.

- 1) An undefined (or spare) Verb must not be used.
- 2) An undefined (or spare) Noun must not be used.
- 3) In octal display and monitor verbs and all load verbs, the component number of the verb must not exceed the number of components in the noun. (Note, all "machine address to be specified" nouns are considered 1 component, except noun 01 which may be used with any verb.)
- 4) The octal display and monitor verbs must not be used with a "decimal only" noun.
- 5) The decimal display and monitor verbs must not be used with an "octal only" noun.
- 6) The dp decimal display and monitor verbs (07,17) must not be used with mixed nouns (codes 55-77).
- 7) No load verb may be used with a noun restricted to be "no load". All nouns having the split MIN/SEC scale for any component are "no load" for the entire noun.
- 8) An input code other than those which are defined is received from the Keyboard.
- 9) The contents of the register used to determine which Display Panel character is to be lighted has exceeded its limit.

Illegal Data and Recycle

Many legal Verb/Noun combinations require the loading of additional data (either numerical or machine address). It is possible that the data supplied may itself be improper for the Noun selected. Examples are: (1) the numerical data exceeds the maximum value allowed by the scale factor associated with the Noun, and (2) decimal data is loaded into an "octal only" noun.

In general, the offense is detected at the final ENTER of the loading sequence. The alarm is turned on and a recycle is performed back to the beginning of the loading sequence. The flash is left on, and the data display register associated with the first data word in the sequence is blanked again. It is necessary for the operator only to supply the data again; he need not attempt to re-execute the Verb/Noun combination. (Note, if decimal data is supplied for the address of a "machine address to be specified" noun, the alarm and recycle are performed at the ENTER immediately following the address word.)

Violation of the following principles causes the Operator Error to be turned on, and a recycle to be performed.

- 1) The address keyed in for a "machine address to be specified" noun must be octal.
- 2) In multi-component load verbs, no mixing of octal and decimal data is permitted. All the data words loaded for a given noun must be either all octal or all decimal.
- 3) Octal data must not be loaded into a "decimal only" noun.
- 4) Decimal data must not be loaded into an "octal only" noun.
- 5) Decimal data loaded must not numerically exceed the maximum permitted by the scale factor associated with the appropriate component of the noun.
- 6) Negative decimal data must not be loaded using the Y optics scale.
- 7) All 3 words must be loaded for the Hours, Minutes, Seconds scale.
- 8) When loading with the Hours, Minutes, Seconds scale, the minutes must not exceed 59; the seconds must not exceed 59.99; the total number must not exceed 745 hours, 39 minutes, 14.55 seconds.
- 9) Two numerical characters must be supplied for the PROGRAM Code under V37.

Operator Error and Key Rejection

There are two situations which cause the Operator Error light to be turned on and the offending key depression to be simply rejected. These are:

- 1) An attempt to ENTER a decimal data word having fewer than 5 numerical characters. The ENTER is simply rejected. The flash is left on and the Verb Code is not advanced. Thus it is possible to supply the remaining numerical characters and to press ENTER again for the same data word. Or the CLEAR key may be used if the operator wishes to begin loading the offending data word again.
- 2) An 8 or 9 is punched while loading a word which was not preceded by a plus or minus sign. The 8 or 9 is simply rejected. The remaining characters may then be supplied or the offending word removed and its loading begun again.

4.3 GNCS Failure Monitor

The GNCS performance and operational readiness are self-monitored and caution and warning information are displayed to the crew. Two warning (red) lamps are actuated by the GNCS on the Caution/Warning Panel: CMC Warning indicates computer failure; ISS warning indicates failure of the inertial subsystem. Also a GNCS Caution (amber) lamp is actuated to indicate non-critical problems in the system. Further detail regarding the caution items is displayed by means of the DSKY event lamps and the DSKY data registers (in the event of a program alarm). The failure monitor mechanization is shown in Figure 4.2.

4.3.1 CMC Warning

A CMC warning alarm is generated in the event of CMC power failure, scaler failure of either of two types, restart or counter fail during CMC operate or in response to an alarm test program. As is shown in Figure 4-2 a scaler fail or prime power fail results in immediate alarm indication whereas the other inputs are buffered by a filter so as to prevent momentary transient disturbances which recover from causing a warning alarm. In this subsection the various inputs and conditions associated with CMC warning are defined.

- (a) SCAFAL - Occurs if scaler stage 17 (1.28 sec period) fails to produce pulses. This provides a check on the timing for all logic alarms.
- (b) COUNTER FAIL - Occurs if counter increments happen too frequently or else fail to happen following an increment request "Too frequently" means continuous counter requests and/or incrementing for from .0625 ms to 1.875 ms.
- (c) SCADBL - Occurs if the 100 pps scaler stage operates at a pulse rate of 200 pps or more.
- (d) PARITY FAIL - Occurs if any accessed word in fixed or erasable memory whose address is octal 10 or greater contains an even number of "ones".
- (e) RUPT LOCK - Occurs if interrupt is either too long or too infrequent. The criterion for "too long" is phase dependent

varying from 140 ms to 300 ms. Likewise the criterion for "too frequent" varies from 140 ms to 300 ms.

- (f) TC TRAP - Occurs if too many consecutive TC or TCF instructions are run or TCF instructions are too infrequent. The criterion for "too many" varies from 5 ms to 15 ms duration. The criterion for "too infrequent" varies from 5 ms to 15 ms absence.
- (g) NIGHT WATCHMAN - Occurs if the computer should fail to access address 67 within a period whose duration varies from .64 sec to 1.92 sec.
- (h) V FAIL - Occurs if the CMC voltages (28, 14, 4) are out of limits. This signal produces STRT 1 if it stays on for a period of between 157 and 470 μ sec. If the computer is in the STANDBY mode, an input to the CMC WARNING FILTER is generated simultaneous with STRT 1. The following criteria apply for V FAIL:

14 V Supply	> 16V
4 V Supply	> 4.4V
4 V Supply	< 3.65V
14 V Supply	< 12.5V
28 V Supply	< 22.6V
- (i) STANDBY - This is a signal which turns on RESTART and turns off the switchable +4 and +14 voltage, thus putting the CMC into a low power mode where only the scaler, timing signal, and a few auxiliary signals are operative. STANDBY is initiated by first setting the ENABLE STANDBY outbit (CH13 B11), and then pressing the STANDBY button on the DSKY for a time which varies from .64 sec to 1.92 sec, at the end of which time the STANDBY LIGHT is turned on. (All CMC alarms are inhibited during the standby mode with the exception of CMC Warning, which can be caused by VOLTAGE FAIL or SCALER FAIL; and TEMPERATURE CAUTION, which can be caused by TEM ALARM.) Normal operation is resumed by pressing the STANDBY button on the DSKY again, time of depression same as above.

- (j) RESTART - RESTART occurs at next time 12 following occurrence of any one or more of the parameters shown in Figure 4-2 except OSCILLATOR FAIL.

RESTART occurs immediately and forces time counter to 12 upon occurrence of OSCILLATOR FAIL. (See paragraph "1" below.)

RESTART causes the computer to transfer control to address 4000 as soon as it disappears. It sets a flip-flop which lights the RESTART CAUTION lamp in the DSKY. The Flip-flop is reset either by the ALARM RESET hard-wired signal or by the CAUTION RESET outbit CH 11 B 10. ALARM TEST operates the lamp but not the flip-flop.

- (k) WARNING FILTER - This circuit is used to operate the CMC WARNING output following repeated or prolonged occurrence of parameters shown in Figure 4-2. All occurrences of these signals are stretched so that no more than one input to the filter is generated in each 160 millisecond period. Approximately six consecutive stretched pulses cause CMC WARNING to turn on for about 5 seconds. Non-consecutive stretched pulses may also cause CMC WARNING after an interval dependent on the frequency of the pulses. The output will not occur if input pulses occur at a frequency of less than 0.9 pps; and the output will remain on if pulses occur at a frequency of 0.7 pps or more. The threshold of the filter resumes its normal level with a time constant of many seconds after the filter has received inputs. An immediate reset of the CMC FAIL due to a WARNING FILTER output is therefore not possible.
- (1) OSCILLATOR FAIL - Occurs if the oscillator stops. Has nominal 250-millisecond delay to keep signal present after the oscillator starts. Also occurs when CMC is in STANDBY because of loss of power to front end of circuit. This gives 250-millisecond delay in starting when CMC comes out of STANDBY into OPERATE. Causes immediate restart without waiting for time pulse 12.

4.3.2 ISS WARNING

The ISS WARNING signal is the logical "OR" of the following parameters, any one of which will cause an ISS WARNING under the following conditions:

(a) IMU Fail

- (1) IG Servo Error - greater than 2.9 mr for 2 sec
- (2) MG Servo Error - greater than 2.9 mr for 2 sec
- (3) OG Servo Error - greater than 2.9 mr for 2 sec
- (4) 3200 cps - decrease to 50% of normal level
- (5) 800 wheel supply - decrease to 50% of normal level

These parameters are generated in the Inertial Subsystem. However, the "FAIL" signal itself is under CMC program control. It is ignored by the CMC program when the GNC system is in the Coarse Align Mode and during the 5 second interval following Coarse Align. During this mode the servo errors normally exceed the above criteria.

(b) PIPA FAIL

Occurs if no pulses arrive from a PIPA during a 312.5 μ sec period, or else if both plus and minus pulses occur, or if a "long time" elapses without at least one plus pulse and at least one minus pulse arriving. By "long time" is meant a period of between 1.28 sec and 3.84 sec.

This FAIL signal is generated totally within the CMC and thus is completely under CMC program control. Its generation is enabled by the CMC only during CMC controlled translation or thrusting maneuvers.

(c) ISS CDU FAIL (Monitored for each of 3 CDU's)

- (1) CDU fine error - in excess of 1.0V rms
- (2) CDU coarse error - in excess of 2.5V rms
- (3) READ COUNTER limit cycle - in excess of 160 cps
- (4) $\text{Cos}(\theta - \phi)$ - below 2.0V
- (5) +14 DC Supply - decrease to 50% of normal level

These parameters are generated in the Inertial Subsystem. However, the "FAIL" signal itself is under CMC program control. It is ignored by the CMC program when the G&N System is in the CDU Zero Mode. During this Mode the CDU errors normally exceed the above criteria.

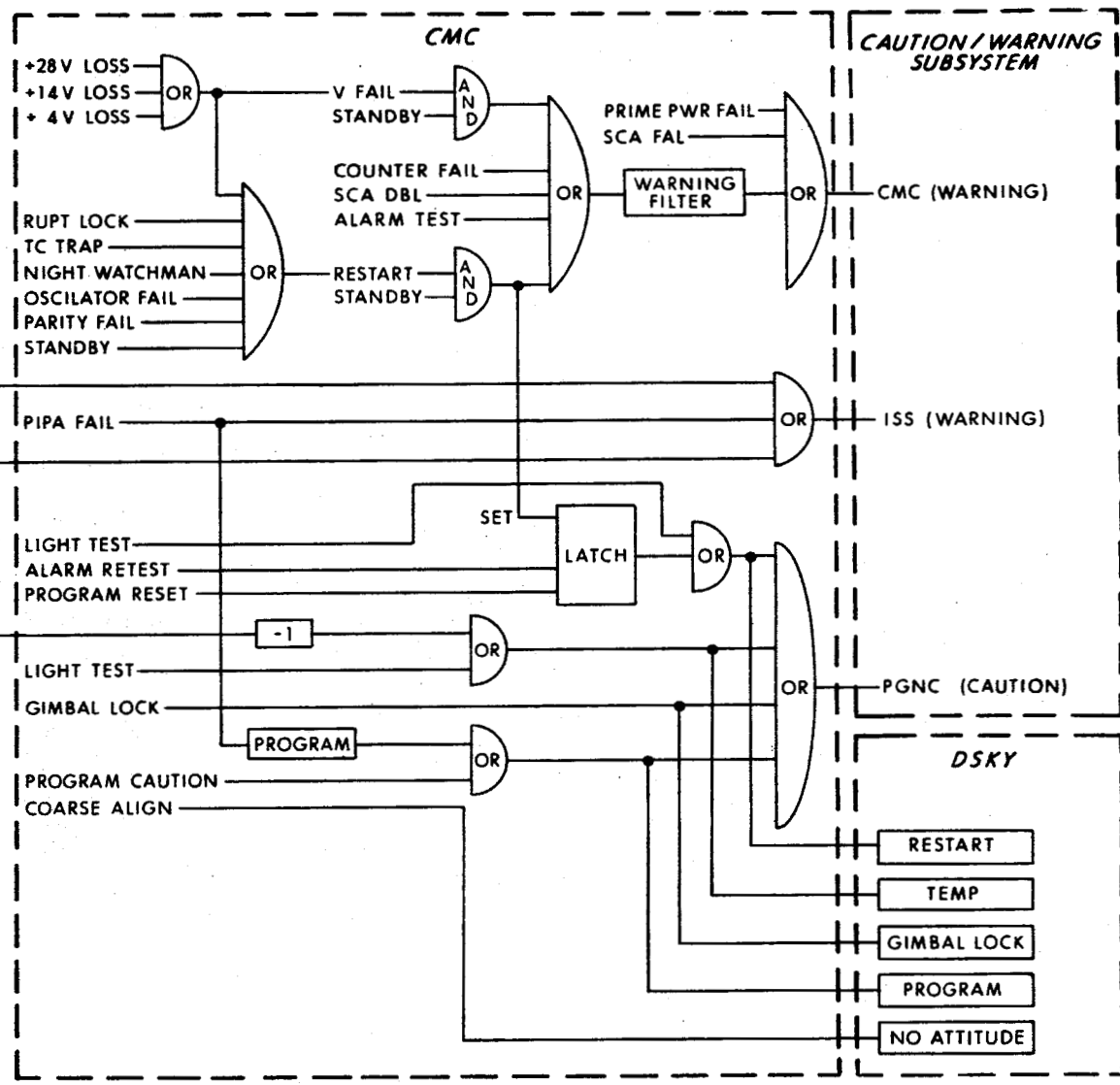
4.3.3 GNCS Caution

The GNCS Caution lamp is actuated by the following undesirable but non-critical events:

- (a) CMC Restart during Operation. In the event of Restart during operate a latch is set in the CMC which maintains the GNCS Caution alarm and the RESTART lamp on the DSKY until the latch is reset by program or until the latch is manually reset by ALARM RESET. For further detail see section 4.3.4.
- (b) Temperature out of Limits. The CMC receives a signal from the IMU when the stable member temperature is in the range 126.3°F to 134.3°F. In the absence of this signal, the Caution alarm and the TEMP lamp on the DSKY are actuated.
- (c) Gimbal Lock. When the CMC determines that the middle gimbal angle (MGA) of the IMU is greater than 70°, the Caution alarm and the Gimbal Lock lamp on the DSKY are actuated. When MGA exceeds 85° the ISS is downmoded to Coarse Align and the No Attitude lamp on the DSKY is actuated.
- (d) Program Alarm. Under a variety of situations a program alarm is generated. Figure 4-2 illustrates one example, that of PIPA fail when the vehicle is not in a thrusting mode. Under program control the CMC inhibits this alarm for 10 sec after system turn-on. The program alarm actuates the Caution alarm and the Program lamp on the DSKY. For further information see section 4.3.4.

4.3.4 Restart and Program Alarms

When the Restart or Program Alarm lamps are illuminated on the DSKY, either V 05 N 31 will automatically appear on the DSKY with a key to the source of the alarm displayed in R1 or by astronaut call up from the DSKY this information can be made available. This allows the astronaut to identify and normally correct the alarm condition. The listing of program alarms is included in Section 4.4.



GNCS Failure Monitor
Figure 4-2

4.4 Logic/Timeline/Checklist Diagrams

These diagrams outline the detailed logic of the inter-relationship between the CMC/Crew/Ground. For ease of correction and reproduction the diagrams have been incorporated on IBM cards and are presented as a computer printout.

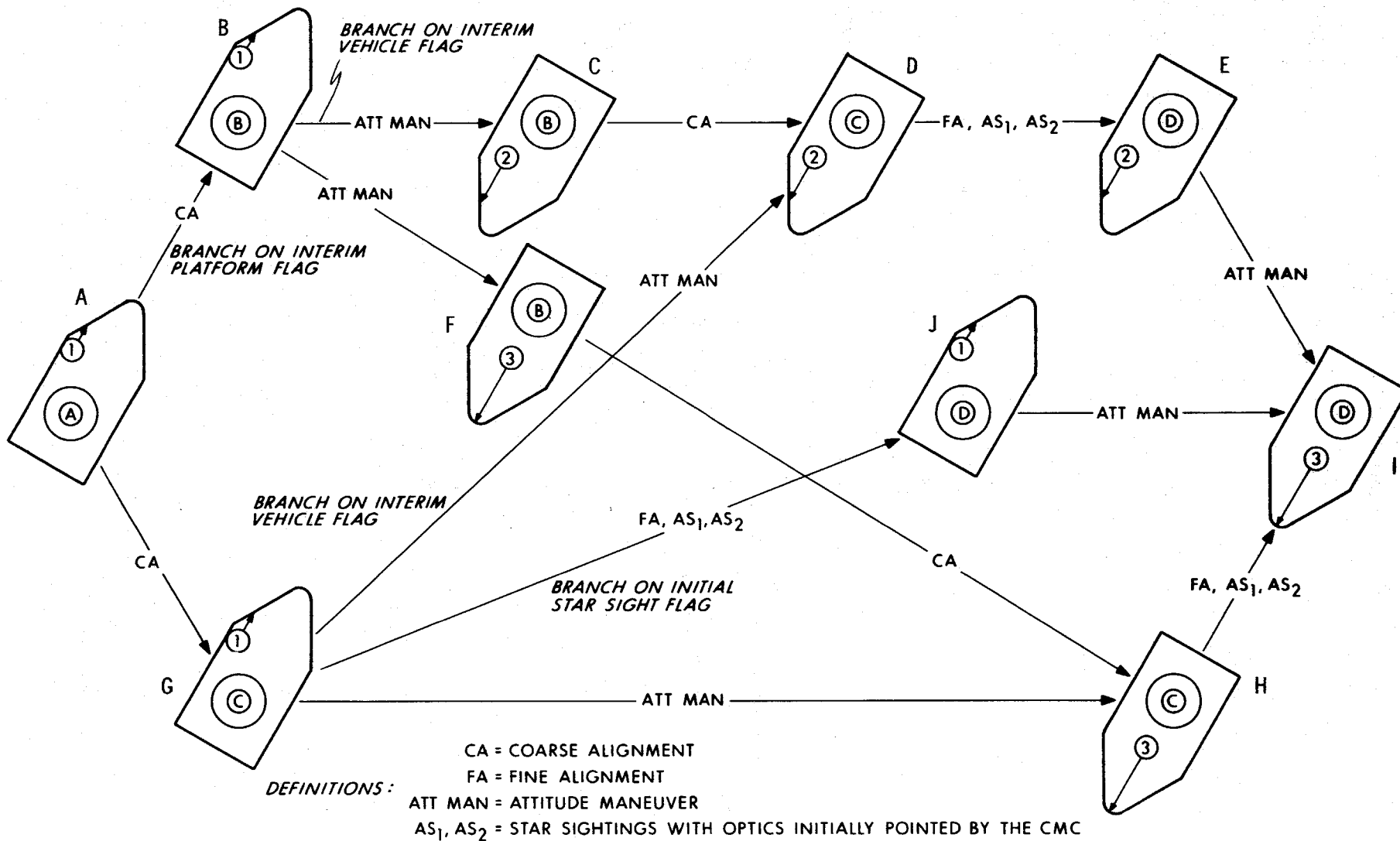
The diagrams contain seven columns:

- (1) Program Control
- (2) CMC } The sequence logic and interface
- (3) Ground } relationships of the CMC/ground/crew
- (4) Crew }
- (5) Crew Checklist - A checklist corresponding to the crew activities of (4) above.

- (6) Time - The time required to perform the individual sequences described in (2), (3), (4) above.
- (7) Total Time - The time required to perform a PROGRAM or ROUTINE.

To effectively construct a nominal mission timeline columns (6) and (7) must be completed for each PROGRAM or ROUTINE.

FIG. 4-3 INFLIGHT ALIGNMENT LOGIC - CSM/IMU ALIGN PROGRAM (P53)



APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

PROGRAM - ROUTINE INDEX

REV 5 11/02/66

4 5329

MISSION 278 - CMC PROGRAMS AND ROUTINES

PHASE	PROGRAM NUMBER	PROGRAM TITLE
PRE-LAUNCH AND SERVICE	00	CMC IDLING
	01	PRELAUNCH INITIALIZATION **
	02	GYRO COMPASSING **
	03	OPTICAL VERIFICATION OF AZIMUTH **
	04	INERTIAL REFERENCE **
	05	GNCS START UP
	06	GNCS POWER DOWN
	07	SYSTEMS TEST (NON-FLIGHT) **
BOOST	10	-----*
	11	EARTH ORBIT INSERTION MONITOR
	12	-----*
	13	-----*
	14	-----*
	15	-----*
	16	-----*
	17	-----*
COAST	20	RENDEZVOUS NAVIGATION
	21	GROUND TRACK DETERMINATION
	22	ORBITAL NAVIGATION
	23	CISLUNAR MIDCOURSE NAVIGATION

24 -----*
25 -----*
26 LGC INITIALIZATION
27 CMC UPDATE

30 PRE-
31 THRUSTING
32 -----*
33 -----*
34 TRANSFER PHASE INITIATION (TPI)
35 TRANSFER PHASE (MIDCOURSE)
36 TRANSFER PHASE (FINAL)
37 -----*

40 THRUSTING
41 -----*
42 -----*
43 -----*
44 -----*
45 -----*
46 -----*
47 THRUST MONITOR

50 ALIGNMENT
51 IMU ORIENTATION DETERMINATION
52 IMU REALIGN
53 CSM/IMJ REALIGN
54 -----*

4 5925

	55	-----*
	56	-----*
	57	-----*
ENTRY	60	-----*
	61	MANEUVER TO CM/SM SEPARATION ATTITUDE
	62	CM/SM SEPARATION AND PRE-ENTRY MANEUVER
	63	ENTRY INITIALIZATION
	64	POST 0.05G
	65	UPCONTROL **
	66	BALLISTIC **
	67	FINAL PHASE
ABORT	70	-----*
	71	-----*
	72	-----*
	73	-----*
	74	LM TRANSFER PHASE INITIATION (TPI) TARGETING
	75	LM TRANSFER PHASE (MIDCOURSE) TARGETING
	76	-----*
	77	-----*

ROUTINE	REV-DATE	ROUTINE TITLE
1		PROGRAM SELECTION CHECK
2		IMU STATUS CHECK
3		-----*

4

4 -----*
5 -----*
6 -----*
7 -----*
8 -----*
9 -----*
10 -----*
11 -----*
12 -----*
13 -----*
14 -----*
15 -----*
16 -----*
17 -----*
18 -----*
19 -----*
20 -----*

21 RENDEZVOUS TRACKING SIGHTING MARK
22 RENDEZVOUS TRACKING DATA PROCESSING

23 -----*
24 SXT SEARCH **
25 -----*
26 -----*
27 -----*
28 -----*
29 -----*

30 ORBIT PARAMETER DISPLAY
31 RENDEZVOUS PARAMETER DISPLAY

4 5827

32	TARGET DELTA V
33	-----*
34	-----*
35	-----*
36	-----*
37	-----*
38	-----*
39	-----*
40	-----*
41	-----*
42	-----*
43	-----*
44	-----*
45	-----*
46	-----*
47	-----*
48	-----*
49	-----*
50	COARSE ALIGN
51	FINE ALIGN
52	AUTO OPTICS POSITIONING
53	SIGHTING MARK
54	STAR DATA TEST
55	GYRO TORQUING
56	-----*
57	-----*
58	-----*
59	-----*

60	ATTITUDE MANEUVER
61	PREFERRED TRACKING ATTITUDE
62	-----*
63	-----*
64	-----*
65	-----*
66	-----*
67	-----*
68	-----*
69	-----*
70	SPS ENGINE THRUST FAIL
71	-----*
72	-----*
73	-----*
74	-----*
75	-----*
76	-----*
77	-----*
78	-----*
79	-----*

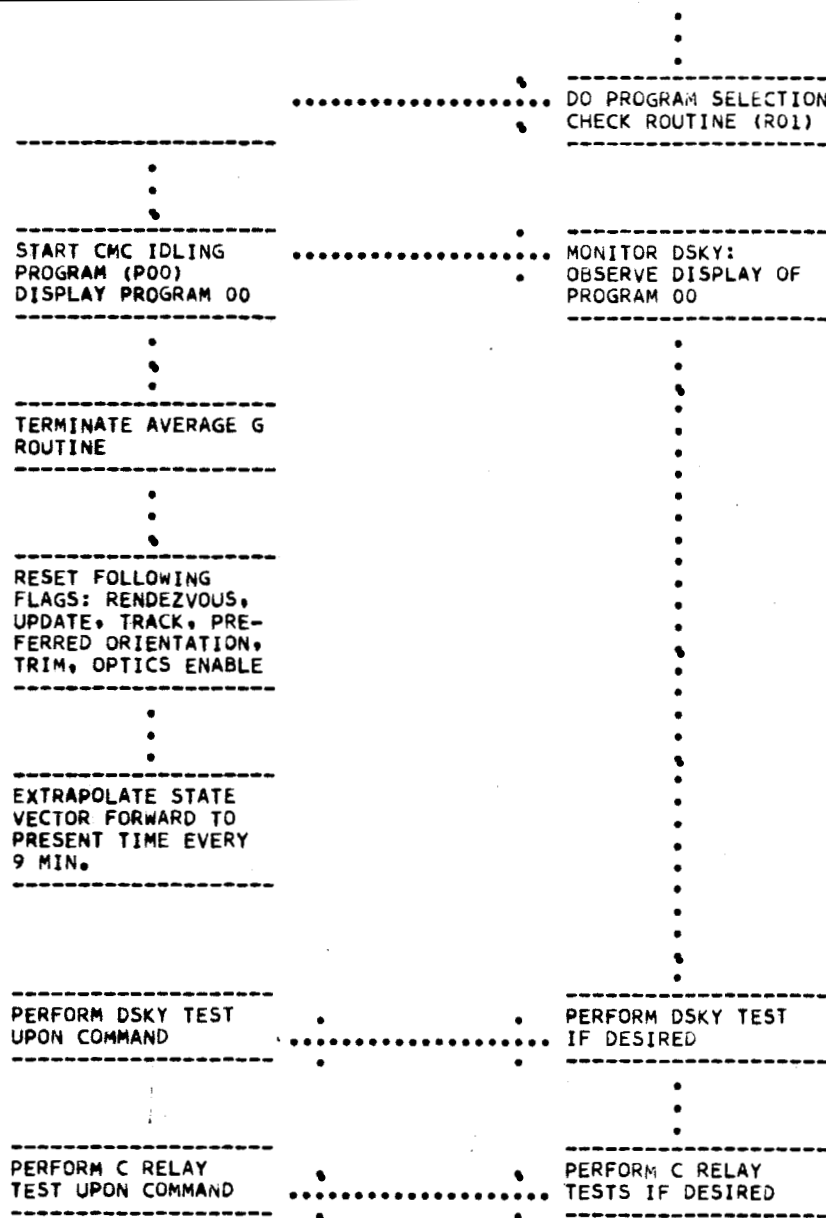
* THIS PROGRAM OR ROUTINE DOES NOT EXIST FOR MISSION 278

** THIS PROGRAM OR ROUTINE IS NOT DOCUMENTED AT THIS TIME

END OF RUN

4 3926

8



II PERFORM PROGRAM SELECTION CHECK ROUTINE (R01)

#30

CHECKLIST NOTES:

- 1. GNCS ATTITUDE CONTROL IS AVAILABLE BY MEANS OF STANDARD RCS DAP PROCEDURES. #40
- 2. ORBIT PARAMETERS WILL BE DISPLAYED BY SELECTION OF R 30 (V64E).
- 3. GNCS DATA WILL BE DISPLAYED BY MEANS OF STANDARD DSKY PROCEDURES.

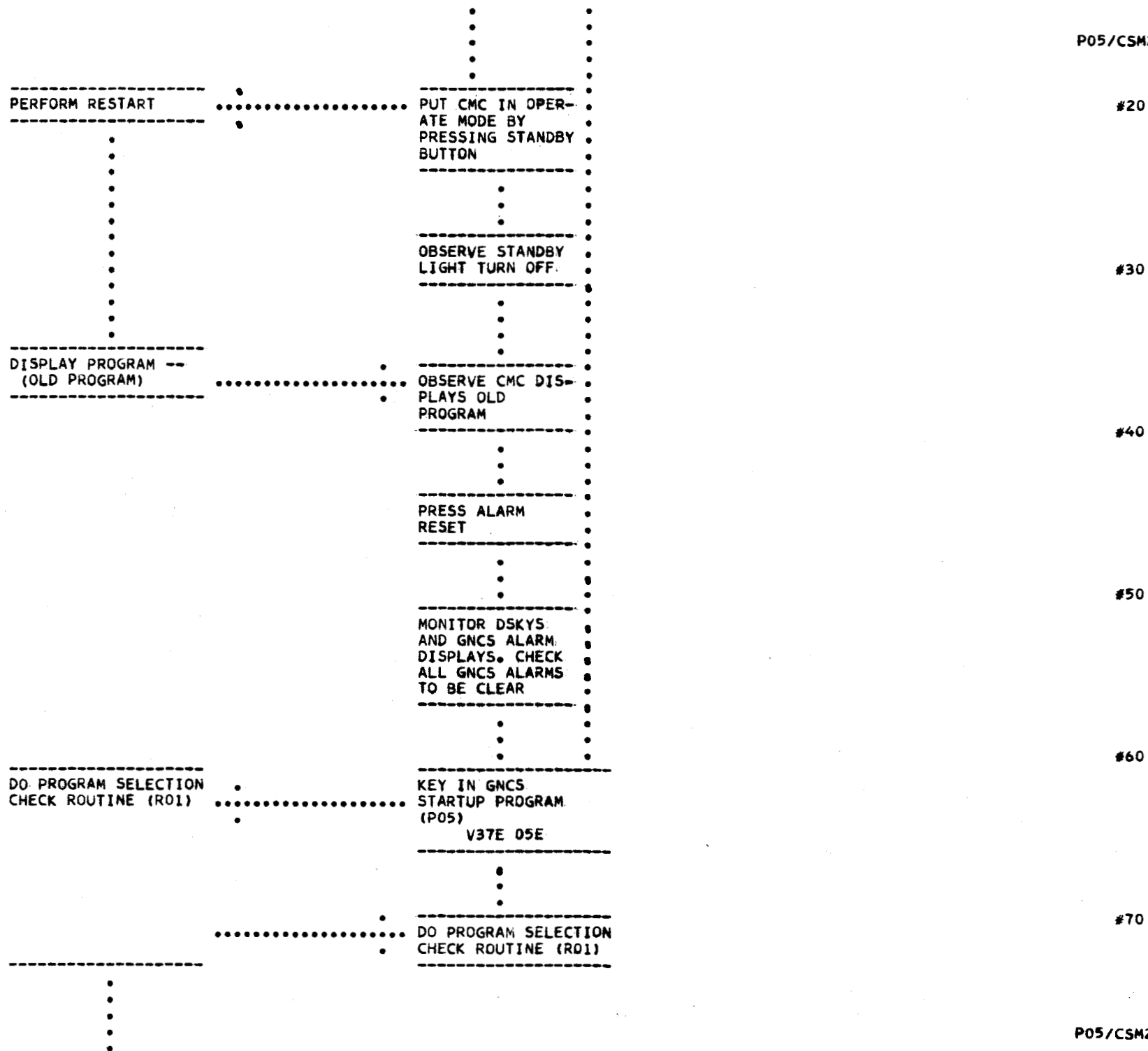
#50

- 4. NEW PROGRAM MAY BE SELECTED BY V37EXXE

#60

#70

END OF RUN



4 5023

```

-----
START GNCS
STARTUP PROGRAM (P05).....
DISPLAY PROGRAM 05
-----

```

```

-----
MONITOR DSKY:
OBSERVE DISPLAY OF
PROGRAM 05
-----

```

#80

```

-----
IS STANDBY FLG SET?
-----

```

```

.N      .Y
.
.
.

```

#90

```

-----
RESET STANDBY
FLAG
-----

```

```

-----
UPDATE CMC CLOCKS
-----

```

#100

```

-----
WAIT 3 SECONDS
-----

```

```

-----
FLASH VERB-NOUN TO
REQUEST PLEASE
PERFORM ISS TURN ON:
V50 N25
R1-00060
R2-BLANK
R3-BLANK
-----

```

HOLD

```

-----
MONITOR DSKY:
OBSERVE FLASHING
VERB-NOUN TO REQUEST
ISS TURN ON
-----

```

#110

```

-----
DO I WANT TO TURN ON
IMU?
-----

```

#120

```

-----
WAIT FOR KEYBOARD
ENTRY
-----

```

```

-----
KEY IN
PROCEED
V33E
-----

```

#130

 CMC RECEI-
 VES IMU OP-
 ERATE AND
 TURN ON RE-
 QUEST BITS

 SET CONTROL
 SWITCHES PER
 CHECKLIST IN-
 CLUDING IMU MODE
 SWITCH TO
 OPERATE.

#140

 SET COARSE
 ALIGN ENABLE
 BIT. (CAUSES
 ALL GIMBALS
 TO DRIVE TO
 ZERO)

 OBSERVE NO ATT
 LIGHT COME ON.
 WAIT 90 SEC FOR
 COMPLETION OF
 TURN ON SEQUENCE
 AND LIGHT TURN
 OFF

#150

 SET ZERO CDU
 BIT. (ZEROS
 ICDU GIMBAL
 ANGLE
 COUNTERS)

#160

 WAIT 90 SEC

#170

 SET BIT
 CAUSING RE-
 MOVAL OF
 TURN ON RE-
 QUEST BIT.

#180

RESET COARSE
ALIGN ENABLE
AND ZERO CDU
BITS. (IMU
GOES
INERTIAL)

..... KEY IN ENTER

#190

TERMINATE FLASH UPON
RECEIPT OF ENTER OR
NEW PROGRAM

.....
E P
N R
T O
E C
R E
D
.....

#200

RESET IMU ORIEN-
TATION KNOWN FLAG
(REFSMFLG)

#210

SET ISS ZERO FLAG
(ISS ZERO INDICA-
TES IMU OPERATE
BIT IS PRESENT
AND IMU TURN-OFF
REQUEST BIT
REMOVED)

#220

TERMINATE P05 AND
GO TO CMC IDLING
PROGRAM (P00)

..... MONITOR DSKY:
OBSERVE TERMINATION
OF P05 AND DISPLAY
OF P00

#230

P05/CSM2/278

•
•
•
•
•
•
•
•

EXIT P05

•
•
•
•
•
•
•
•

EXIT P05

START GNCS
 POWER DOWN
 PROGRAM (P06)
 DISPLAY PROGRAM 06

MONITOR DSKY:
 OBSERVE DISPLAY
 OF PROGRAM 06

#30

CHECK DISCRETES.
 IS IMU OPERATE BIT
 PRESENT?

#40

N. Y
 FLASH VERB-NOUN
 TO REQUEST
 PLEASE PERFORM
 IMU POWER DOWN:
 V50 N25
 R1-00061
 R2-BLANK
 R3-BLANK

MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 PLEASE PERFORM IMU
 POWER DOWN

#50

DO I WISH TO
 POWER DOWN
 THE IMU?

#60

WAIT FOR KEY-
 BOARD ENTRY

TURN IMU
 MODE SWITCH
 TO STANDBY.

#70

KEY IN ENTER

POSS
 HOLD

20

TERMINATE FLASH
UPON RECEIPT OF
PROCEED OR ENTER

KEY IN
PROCEED

#80

.P
.R
.O
.C
.E
.E
.D

.E
.N
.T
.E
.R

RESET IMU
ORIENTA-
TION
KNOWN
FLAG (REF
SMFLAG)

#90

RESET ISS
ZERO FLAG

#100

FLASH VERB-NOUN TO
REQUEST PLEASE PER-
FORM CMC POWER DOWN:
V50 N25
R1-00062
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE VERB-NOJN
FLASHING TO REQUEST
PLEASE PERFORM CMC
POWER DOWN

#110

DO I WISH TO POWER
DOWN THE CMC?

#120

.Y .N

HOLD

WAIT FOR KEYBOARD
ENTRY

KEY IN ENTER
(NOTE: THIS
IS THE ONLY
CASE WHERE AN
ENTER MUST BE
MADE PRIOR TO
CREW CONCUR-
RENCE WITH
AN CMC RE-
QUEST FOR PER-
FORMANCE.)

#130

PRESS STANDBY
BUTTON. OB-
SERVE STAND
BY LIGHT COME
ON

#140

EXIT P06

#150

KEY IN
PROCEED
V33E

TERMINATE FLASH UPON
RECEIPT OF PROCEED

#160

ENTER PROCEED

RESET IMU
ORIENTA-
TION
KNOWN
FLAG (RE-
FSMFLG)

#170

END OF RUN

24

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

EARTH ORBIT INSERTION MONITOR PROGRAM (P11)

REV 6 10/31/66

- PURPOSE:
- (1) TO INDICATE TO THE ASTRONAUT THAT THE CMC HAS RECEIVED THE LIFTOFF DISCRETE.
 - (2) TO GENERATE AN ATTITUDE ERROR INDICATION ON THE FDAI EQUAL TO THE DIFFERENCE BETWEEN THE CURRENT VEHICLE ATTITUDE AND THE CMC COMPUTATION OF THE NOMINAL VEHICLE ATTITUDE PROGRAM BASED UPON A STORED POLYNOMIAL. IF THE SATURN CONTROL SWITCH IS MOVED TO THE SPACECRAFT CONTROL POSITION THESE ERROR SIGNALS WILL BE SENT TO THE SATURN AUTO-PILOT, THESE ERROR SIGNALS MAY ALSO BE REPLACED BY ROTATION HAND CONTROLLER SIGNALS AS DESCRIBED IN SECTION 3 OF R547 VOL I.
 - (3) TO DISPLAY CMC COMPUTED TRAJECTORY PARAMETERS.
- ASSUMPTIONS:
- (1) THE PROGRAM IS NORMALLY AUTOMATICALLY SELECTED BY THE GYRO COMPASSING PROGRAM (P02) WHEN THE CMC RECEIVES THE LIFTOFF DISCRETE FROM THE SIVB. IN THE BACKUP CASE IT WOULD HAVE BEEN SELECTED BY KEYING IN V75 ENTER AS NOTED EARLIER IN P02.

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
	CMC PROG SELECTION					#10
	----- DO PROGRAM SELECTION CHECK ROUTINE (R01) -----	.....	DO PROGRAM SELECTION CHECK ROUTINE (R01) -----			#20
	. . .		MONITOR DSKY: OBSERVE DISPLAY OF PROGRAM 11 -----			#30
	----- START EO1 MONITOR PROGRAM (P11) DISPLAY PROGRAM 11 -----	.....			
	. . .					
	----- ZERO CMC CLOCK -----					
					

SEND EFFECTIVE TIME
OF LIFTOFF ON
DOWNLINK

VERIFY AUTOMATIC
START OF DIGITAL
EVENT TIMER

#40

TERMINATE GYRO-
COMPASSING

#50

CALL AVERAGE
G INTEGRATION
WITH DELTA V
INTEGRATION

#60

SET ISS ZERO
FLAG

COMPUTE REFSMMAT

#70

SET IMU ORIEN-
TATION KNOWN FLAG
(REFSMFLG)

#80

CALL ROUTINE TO
LOAD ICDU DACS WITH
PITCH, ROLL, AND YAW
ATTITUDE ERRORS DE-
RIVED FROM PRESENT
ATTITUDE AND STORED
BOOST POLYNOMIAL.

MONITOR:
(A) FDAI:
ATT ERRORS LESS
THAN -- DEG
ATT RATES LESS
THAN --DEG/SEC

BALL INDICATES

#90

INITIAL VEHI-
CLE ROLLOUT
AND THEN GRAD-
UAL PITCHOVER.

DISPLAY ON DSKY:

V06 N40
R1 - V1
R2 - H DOT
R3 - H

(B) DSKY:

R1-VI INCREASING
R2-H DOT FOLLOWS
NOMINAL HISTORY
R3-H INCREASING

#100

VI-INERTIAL VELO-
CITY MAGNITUDE. IN
FPS TO NEAREST FPS

H DOT - RATE OF
CHANGE OF VEHICLE
ALTITUDE ABOVE
LAUNCH PAD RADIUS.
IN FPS TO
NEAREST FPS

H-VEHICLE ALTITUDE
ABOVE THE LAUNCH
PAD RADIUS. IN NAUTI-
CAL MILES TO
NEAREST .1 NM

VERIFY SATURN
SHUT DOWN

#110

#120

TERMINATE P11
AND GO TO P00

KEY IN REQUEST
FOR CMC IDLING
PROGRAM (P00)
V37E00E

#130

.....
EXIT P11

.....
EXIT P11

END OF RUN

4 116

28

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

RENDEZVOUS NAVIGATION PROGRAM (P20)

REV 7

10/31/66

PURPOSE: (1) TO CONTROL THE CSM ATTITUDE AND OPTICS TO ACQUIRE THE LM IN THE SXT FIELD AND TO POINT THE CSM TRANSPONDER AT THE LM.
(2) TO UPDATE EITHER THE LM OR CSM STATE VECTOR (AS SPECIFIED BY THE ASTRONAUT BY DSKY ENTRY) ON THE BASIS OF OPTICAL TRACKING DATA.

ASSUMPTIONS: (1) THE ISS MAY BE IN STANDBY OR OPERATE. THE GNCS START UP PROGRAM (P05) AND THE IMU ORIENTATION DETERMINATION PROGRAM (P51) WOULD NORMALLY BE COMPLETED BEFORE THE SELECTION OF THIS PROGRAM. NO PREFERRED ORIENTATION IS SPECIFIED OR REQUIRED FOR THIS PROGRAM AS THE ATTITUDE MANEUVER ROUTINE (R60) CAN ALWAYS CALCULATE A VEHICLE ORIENTATION ABOUT A SPECIFIED TRACK AXIS (I) (REFER TO PREFERRED TRACKING ATTITUDE ROUTINE (R61)) THAT CAN AVOID GIMBAL LOCK FOR ANY INERTIAL IMU ORIENTATION.
THE ISS THUS MAY BE:

(A) OFF (STANDBY).

(B) ON, AND NOT ALIGNED SINCE TURN ON.

(C) ON AND AT AN INERTIAL ORIENTATION KNOWN ONLY INACCURATELY BY THE CMC, I.E. HAVING BEEN ALIGNED AT LEAST ONCE SINCE TURN ON BUT NOT WITHIN THE LAST --HRS.

(D) ON AND AT AN INERTIAL ORIENTATION KNOWN ACCURATELY BY THE CMC, I.E. HAVING BEEN ALIGNED WITHIN THE LAST --HRS.

IF (A) IS TRUE PROGRAM 05 SELECTION WILL BE REQUESTED BY THIS PROGRAM.

IF (B) IS TRUE PROGRAM 51 SELECTION WILL BE REQUESTED BY THIS PROGRAM.

IF (C) IS TRUE THE CMC MAY OR MAY NOT HAVE A SATISFACTORY INERTIAL REFERENCE TO ACCURATELY COMPLETE THE PROGRAM.

IF (D) IS TRUE THE CMC HAS A SATISFACTORY INERTIAL REFERENCE TO ACCURATELY COMPLETE THE PROGRAM.

(2) THE GNCS IS IN CONTROL OF THE VEHICLE IN THE AUTO MODE IN THE NOMINAL CASE.

(3) THIS PROGRAM IS DESIGNED FOR ONE MAN OPERATION.

(4) AN OPTION IS PROVIDED THE CREW AT THE BEGINNING OF THE PROGRAM TO DEFINE THE STATE VECTOR TO BE UPDATED BY THE TRACKING PROCESS. THIS OPTION MAY BE CHANGED AT ANY TIME LATER BY ONE OF THE FOLLOWING ENTRIES:

V--E UPDATE LM STATE VECTOR

V--E UPDATE CSM STATE VECTOR

(5) THE OPERATION OF THE PROGRAM INCLUDES THE FOLLOWING FLAGS:

RENDEZVOUS FLAG- CONTROLS THE PERMANENT TERMINATION OF THE TOTAL RENDEZVOUS NAVIGATION PROCESS. THIS PROGRAM WILL ONLY RUN OR RESUME RUNNING WHEN THIS FLAG IS SET. SET BY P20 SELECTION. RESET BY SELECTION OF CMC IDLING PROGRAM(P00) OR BY V--E.

TRACK FLAG- CONTROLS THE TEMPORARY TERMINATION OF THE TOTAL RENDEZVOUS NAVIGATION PROCESS. RESET OF THIS FLAG INTERRUPTS THE AUTOMATIC ATTITUDE MANEUVER/OPTICS POINTING PROCESS, AS WELL AS THE STATE VECTOR UPDATE PROCESS. THE SET OF THIS FLAG ENABLES ALL THESE PROCESSES. SET BY P20, 34, 35, 36, 74, AND 75 SELECTION. RESET AT THE START OF AND SET AT THE END OF P40, 41, 47, 52, AND 53, RESET ALSO BY P20 TERMINATION.

UPDATE FLAG- CONTROLS THE TEMPORARY TERMINATION OF THE STATE VECTOR UPDATE PROCESS ONLY. SET BY P20, P34, 35, 74, AND 75 SELECTION. RESET AT END OF P34, 35, 74, AND 75. ALSO RESET BY P36 SELECTION, AND BY P20 TERMINATION. ALSO RESET AND SET AT THE BEGINNING AND END RESPECTIVELY OF P47, 52, 53 AND THE TARGET DELTA V ROUTINE (R32). SET AT END OF P40, 41, RESET IN 40, 41.

STATE VECTOR FLAGS (LM AND CSM) - DEFINES THE STATE VECTOR TO BE UPDATED BY THIS PROGRAM. SEE ASSUMPTION(4).

OPTICS ENABLE FLAG - CONTROLS AUTOMATIC OPTICS POSITIONING BY THE AUTO OPTICS POSITIONING ROUTINE (R52). WHEN THE TRACK FLAG IS RESET DURING THRUSTING OPERATIONS IT IS REQUIRED TO INHIBIT AUTO OPTICS POINTING UNTIL THE CSM HAS BEEN RETURNED TO THE PREFERRED TRACKING ATTITUDE TO PRECLUDE AN ALARM DUE TO EXCESSIVE SXT TRUNNION ANGLES.

(8) STATE VECTOR UPDATES BY P27 ARE DISALLOWED DURING THIS PROGRAM.

(9) THIS PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY. IT MAY BE TERMINATED ONLY BY THE SELECTION OF THE CMC IDLING PROGRAM (P00) OR BY V--E. P00 SELECTION WILL TERMINATE P20 AND ANY OTHER PROGRAM IN PROCESS AND ESTABLISH P00. ALL OTHER PROGRAMS SELECTED WILL CHANGE THE PROGRAM NUMBER DISPLAYED ON THE DSKY BUT WILL NOT TERMINATE P20. THIS PROGRAM IS THEREFORE DESIGNED TO OPERATE AUTOMATICALLY AND SIMULTANEOUSLY WITH ANOTHER PROGRAM WITHOUT REQUIRING USE OF THE DSKY UNLESS NON-NOMINAL CIRCUMSTANCES REQUIRE CMC COMMUNICATION WITH THE ASTRONAUT.

(10) RENDEZVOUS DATA PROCESSING ROUTINE CAN BE INITIATED BY V--E.

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
			•CREW •PROGRAM •SELECTION • • •			#10
----- DO PROGRAM SELECTION CHECK ROUTINE (R01) -----	• •••••••••••••••••••• •		KEY IN RENDEZVOUS NAVIGATION PROGRAM (P20) V37E20E -----			#20
----- • • -----		• •••••••••••••••••••• •	DO PROGRAM SELECTION CHECK ROUTINE (R01) -----			#30
----- START RENDEZVOUS NAVIGATION PROGRAM (P20). DISPLAY P20 -----	• • • • • • • • • •	• •••••••••••••••••••• •	MONITOR DSKY: OBSERVE DISPLAY OF P20 -----			

DO IMU STATUS CHECK
ROUTINE (R02)

DO IMU STATUS CHECK
CHECK ROUTINE (R02)

#40

SET RENDEZVOUS FLAG

SET TRACK FLAG

#50

SET UPDATE FLAG

#60

BLOCK UPLINK ACCEPT-
ANCE OF STATE
VECTOR UPDATES

#70

ZERO RENDEZVOUS
TRACKING MARK
COUNTER

#80

HOLD

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY OPTION CODE
FOR ASSUMED STATE
VECTOR TO BE UPDATED
BY NAVIGATION PRO-
CESS:

V06 N--
R1-000--

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OPTION CODE FOR
ASSUMED STATE VECTOR
TO BE UPDATED BY
NAVIGATION PROCESS.

#90

R2=0000X
R3=BLANK

R1 IS THE OPTION
CODE FOR ASSUMED
STATE VECTOR TO BE
UPDATED.

R2 IS THE CMC
ASSUMED OPTION:
00001 - LM
00002 - CSM

IS THE STATE-VECTOR-
TO-BE-IMPROVED
ASSUMPTION CORRECT?

.Y .N

KEY IN PROCEED
V33E

WAIT FOR KEYBOARD
ENTRY

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW DATA

.P .NEW
.R .CODE
.O .
.C .
.E .
.E .
.D STORE CODE

KEY IN
V22
AND LOAD
THE
DESIRED
STATE
VECTOR
CODE IN
R2.

SET LM OR CSM STATE
VECTOR FLAG BASED ON
CODE.

DO PREFERRED TRACK-
ING ATTITUDE ROUTINE
(R61)

#100

#110

#120

#130

#140

SET TARGET FLAG TO
LM FOR USE BY AUTO
OPTICS POSITIONING
ROUTINE (R52)

#150

SET OPTICS ENABLE
FLAG FOR USE BY AUTO
OPTICS POSITIONING
ROUTINE (R52)

#160

CALL AUTO OPTICS
POSITIONING ROUTINE
(R52)

MONITOR DSKY:
THE AUTOMATIC
ATTITUDE MANEUVER/
OPTICS POINTING
PROCESS IS NOW AUTO-
MATIC. THE CMC WILL
ONLY COMMUNICATE
WITH THE ASTRONAUT
IF THE OPTICS IS NOT
INITIALLY IN CMC
MODE OR IF THE RE-
QUIRED SXT TRUNNION
ANGLE EXCEEDS THE
OPTICS LIMITS. THE
LATER ALARM SHOULD
NEVER OCCUR AS R61
SHOULD KEEP THE SXT
LOS POINTED AT THE
LM WITHIN THE
TRUNNION LIMITS.

#170

IS RENDEZVOUS FLAG
SET?

.N .Y

EXIT P20

#180

IS TRACK FLAG SET?

.Y .N

#190

#200

4 5113

RESET OPTICS
ENABLE FLAG

WAIT -- SEC

WAIT 15 SEC.
(NOTE: THIS
TIME DELAY
IS CHOSEN TO
MINIMIZE
COMPUTATION
ITERATIONS
BUT ALSO
SCHEDULE A
NEW MANEU-
VER BEFORE
THE VEHICLE
EXCEEDS THE
DEADBAND
LIMITS. THE
ATTITUDE
CHANGES ARE
THUS MADE
CONTINUALLY
WITHIN THE
DEADBAND RE-
QUIRING
MINIMUM
MANEUVERING
FUEL EX-
PENSE.)

DO PREFERRED
TRACKING AT-
TITUDE ROU-
TINE (R61)

#210

#220

#230

#240

#250

SET OPTICS
ENABLE FLAG
FOR USE BY
AUTO OPTICS
POSITIONING
ROUTINE
(R52)

#260

#270

DO I DESIRE TO
TERMINATE P20?

.Y .N

#280

IS ANOTHER PROGRAM
BESIDES P20 IN
PROCESS?

.N .Y

#290

P20 MAY BE
TERMINATED IN
TWO WAYS.

WAIT FOR KEYBOARD
ENTRY.

SELECT CMC
IDLING PROGRAM
(P00).
KEY IN
V37E00E

#300

KEY IN
V--E

#310

4 3912

RESPONSE TO V--E
OR V37E00E
IMMEDIATELY.

.V .V
.- .3
.- .7
.E .E

IS ANOTHER
PROGRAM BESIDES
P20 IN PROCESS?

.Y .N
.
.

GO TO CMC
IDLING PROGRAM
(P00).
DISPLAY P00.
(NOTE: P00
WILL TERMINATE
THE RENDEZVOUS
TRACK, AND UP-
DATE FLAGS AND
ALSO THE AUTO
OPTICS POSI-
TIONING ROU-
TINE (R52)).

TERMINATE
THE REN-
DEZVOUS,
TRACK,
AND, UP-
DATE
FLAGS AND
THE AUTO
OPTICS
POSITION-
ING ROU-
TINE
(R52)

EXIT P20

EXIT P20

KEY IN
V--E

EXIT P20

OBSERVE
DISPLAY OF P00.

EXIT P20

#320

#330

#340

#350

#360

#370

END OF RUN

GROUND TRACK DETERMINATION PROGRAM (P21)

REV 8

10/27/66

- PURPOSE: (1) TO PROVIDE THE ASTRONAUT DETAILS OF HIS GROUND TRACK WITHOUT THE NEED FOR GROUND COMMUNICATION.
- ASSUMPTIONS: (1) THE PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY.
 (2) THIS PROGRAM CAN ONLY BE ENTERED FROM PROGRAM 00.

4 5911

PRG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
			.CREW .PROGRAM .SELECTION			#10
	DO PROGRAM SELECTION CHECK ROUTINE (R01)	.....	KEY IN GROUND TRACK DETERMINATION. PROGRAM (P21) V37E21E			
			. . .			#20
		.....	DO PROGRAM SELECTION CHECK ROUTINE (R01)			
		.....	MONITOR DSKY; OBSERVE DISPLAY OF PROGRAM 21			#30
	START GROUND TRACK DETERMINATION PROGRAM (P21). DISPLAY PROGRAM 21	.....			
					

FLASH VERB-NOUN TO
REQUEST LOAD OF T
LAT LONG:
V25 N34
R1-BLANK
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
LOAD OF T LAT LONG

#40

WAIT FOR KEYBOARD
ENTRY
TERMINATE FLASH UPON
RECEIPT OF DATA

LOAD DESIRED. T LAT
LONG:
R1-T LAT LONG-HRS
R2-T LAT LONG-MINS
R3-T LAT LONG-SECS

#50

T LAT LONG - TIME
(GET) AT WHICH LAT
AND LONG OF VEHICLE
POSITION IS DESIRED.
IN HRS, MINS, SECS
TO NEAREST .01 SEC.

#60

INCRE-
MENT T
LAT LONG
BY 10
MIN.

#70

CALCULATE LATITUDE,
LONGITUDE AND ALTI-
TUDE OF VEHICLE AT
T LAT LONG

#80

4 3010

HOLD

FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY LATITUDE,
 LONGITUDE AND
 ALTITUDE:
 V06 N44
 R1-LAT
 R2-LONG
 R3-ALT

MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF LATITUDE, LONGI-
 TUDE AND ALTITUDE

#90

LAT-LATITUDE OF
 VEHICLE. + IS NORTH.
 IN DEGREES TO NEAR-
 EST .01 DEGREE.

#100

LONG-LONGITUDE OF
 VEHICLE. + IS EAST.
 IN DEGREES TO NEAR-
 EST .01 DEGREE.

ALT-ALTITUDE OF
 VEHICLE ABOVE THE
 PAD RADIUS
 IN NAUTICAL MILES TO
 NEAREST .1 NM.

#110

DO I WISH TO OBTAIN
 NEW PARAMETERS FOR
 A TIME 10 MIN.
 LATER THAN THAT
 WHICH APPLIES TO
 PRESENT DISPLAY?

#120

.N .Y

WAIT FOR KEYBOARD
 ENTRY

WHEN FINISHED
 WITH DISPLAY
 KEY IN
 TERMINATE
 V34E

#130

TERMINATE FLASH UPON
RECEIPT OF RECYCLE
OR TERMINATE

R T
E E
C R
Y M
C I
L N
E A
T
E
.....
.....
.....

GO TO CMC IDLING
PROGRAM (P00)

.....
.....
.....
EXIT P21

WHEN FINISHED
WITH DISPLAY KEY
IN RECYCLE
V32E

WAIT 10 SEC

MONITOR DSKY:
OBSERVE DISPLAY OF
P00

.....
.....
.....
EXIT P21

#140

#150

#160

42 END OF RUN

4 8909

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

ORBITAL NAVIGATION PROGRAM (P22)

REV 7

10/31/66

PURPOSE

- (1) TO LOCATE AND TRACK A LANDMARK SUITABLE FOR NAVIGATION PURPOSES. THIS MAY BE DONE BY THE CMC WITH THE OPTICS AUTOMATICALLY POINTED AT A "KNOWN" (SEE ASSUMPTIONS BELOW) LANDMARK WHOSE LATITUDE, LONGITUDE, AND ALTITUDE HAVE BEEN KEYED INTO THE DSKY BY THE ASTRONAUT. IT MAY ALSO BE DONE BY THE ASTRONAUT WITH THE OPTICS MANUALLY POINTED AT A "KNOWN" LANDMARK PREDETERMINED BY THE ASTRONAUT OR A "KNOWN" OR "UNKNOWN" (SEE ASSUMPTIONS BELOW) LANDMARK SELECTED AT WILL DURING SEARCH FOR TARGETS OF OPPORTUNITY.
- (2) TO OBTAIN SIGHTING MARKS ON THE CHOSEN LANDMARK.
- (3) TO CALCULATE THE ORBITAL PARAMETER CHANGES GENERATED BY THE LANDMARK SIGHTING.
- (4) TO DISPLAY THE ORBITAL PARAMETER CHANGES GENERATED, FOR DECISION AS TO THEIR VALIDITY BY THE ASTRONAUT/GROUND BEFORE THEIR INCORPORATION INTO THE CMC CALCULATION OF SC POSITION AND VELOCITY.
- (5) TO PROVIDE UPDATED COORDINATES OF THE KNOWN LANDMARKS.
- (6) TO PROVIDE COORDINATES OF UNKNOWN LANDMARKS (LANDMARK DESIGNATION ROUTINE).

ASSUMPTIONS:

- (1) THERE ARE TWO TYPES OF LANDMARK TRACKING METHODS:
 - (A) "KNOWN" LANDMARK TRACKING-THE TRACKING OF A LANDMARK IDENTIFIED TO THE CMC BY LATITUDE, LONGITUDE, AND ALTITUDE AFTER THE MARKS ARE COMPLETE.
 - (B) "UNKNOWN" LANDMARK TRACKING- THE TRACKING AND MARKING OF A LANDMARK OR SURFACE FEATURE IDENTIFIED TO THE CMC ONLY AS AN UNKNOWN LANDMARK.
- (2) DURING THIS PROGRAM THE GNCS HAS THE CAPABILITY FOR ATTITUDE CONTROL OF THE VEHICLE. POSSIBLE ATTITUDE CONTROL METHODS MIGHT BE AS FOLLOWS (IN ALL CASES CARE MUST BE TAKEN TO MONITOR POSSIBLE IMPENDING IMU GIMBAL LOCK).
 - (A) MANUAL CONTROL BY THE PILOT OR NAVIGATOR WITH THE ROTATION CONTROL ANY MODE.
 - (B) MANUAL RATE CONTROL BY THE NAVIGATOR WITH THE MINIMUM IMPULSE CONTROL IN THE GNC FREE MODE.
- (3) THE PROGRAM MAY BE PERFORMED WITH SIVB ATTACHED IF THE SATURN CONTROL SWITCH IS PLACED IN THE SPACECRAFT POSITION THEREBY PERMITTING SIVB ATTITUDE CONTROL WITH THE ROTATIONAL CONTROLLER. GNC A/P CONTROL IS REQUIRED IN THIS CASE
- (4) THE GNCS STARTUP AND CHECKOUT PROGRAM (P05) AND THE INFLIGHT ALIGNMENT-IMU ORIENTATION DETERMINATION PROGRAM (P51) MUST BE COMPLETED BEFORE THE COMPLETION OF THIS PROGRAM.
THE ISS MAY BE:
 - (A) OFF (STANDBY)
 - (B) ON, AND NOT ALIGNED SINCE TURN ON.
 - (C) ON AND AT AN INERTIAL ORIENTATION KNOWN ONLY INACCURATELY BY THE CMC, I.E. HAVING BEEN ALIGNED AT LEAST ONCE SINCE TURN ON BUT NOT WITHIN THE LAST 3 HOURS.
 - (D) ON AND AT AN INERTIAL ORIENTATION KNOWN ACCURATELY BY THE CMC, I.E. HAVING BEEN ALIGNED WITHIN THE LAST 3 HOURS.

IF (A) IS TRUE AND P22 IS SELECTED, THE CMC WILL REQUEST SELECTION OF P05.
 IF (B) IS TRUE AND P22 IS SELECTED, THE CMC WILL REQUEST SELECTION OF P51.
 IF (C) IS TRUE THE CMC MAY OR MAY NOT HAVE A SATISFACTORY INERTIAL REFERENCE TO COMPLETE THE PROGRAM.
 IF (D) IS TRUE THE CMC HAS A SATISFACTORY INERTIAL REFERENCE.

(5) THE GROUND TRACK DETERMINATION PROGRAM P 21 IS AVAILABLE TO AID THE CREW IN THE SELECTION OF APPROPRIATE LANDMARKS PRIOR TO THE SELECTION OF P22 AND TO PROVIDE UPDATED GROUND TRACK INFORMATION AFTER THE COMPLETION OF P22.

(6) THE PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY.

4 5908

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
			• CREW PROG. • SELECTION •••			
	----- DO PROGRAM SELECTION CHECK ROUTINE (R01)	• •••••••••••••••••••• •	• • •	----- KEY IN ORBITAL NAVIGATION PROGRAM (P22) V 37 E 22 E -----		#10
			• • •			
		••••••••••••••••••••	•	----- DO PROGRAM SELECTION CHECK ROUTINE (R01) -----		#20
	• •					
	----- START ORBITAL NAVIGATION PROGRAM (P22) DISPLAY PROGRAM 22 -----	• ••••••••••••••••••••	• •	----- MONITOR DSKY: OBSERVE DISPLAY OF PROGRAM 22 -----		#30
	• • • • • • • • • • • • • •					

4 3907

ADVISE CREW
ON ANTICIPATED G+N
ERRORS AND
SUBSEQUENT
PROCEDURES

.....
SHALL I BYPASS
IMU ALIGNMENT?

.N .Y
:
:
.....

#100

SELECT CSM/IMU
REALIGN PROGRAM
(P53 OR P52).
WHEN COMPLETE,
KEY IN V37E22E.

#110

.
.
.
EXIT P22
.
.
.

TERMINATE FLASH UPON
RECEIPT OF PROCEED
NEW PROGRAM

KEY IN PROCEED
V33E

#120

.P .NEW
.R .PROG
.O .
.C .
.E .
.E .
.D .EXIT
P22

CONTROL ATTITUDE
FOR LANDMARK
ACQUISITION

#130

FLASH VERB-NOUN TO
REQUEST PLEASE
PERFORM AUTO OPTICS
POSITIONING:
V50 N25
R1-00011
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM AUTO
OPTICS POSITIONING

#140

#150

DO I WISH TO POSITION OPTICS AUTOMATICALLY?

.Y .N

KEY IN ENTER

TERMINATE FLASH UPON RECEIPT OF ENTER OR PROCEED

P R O C E E D

KEY IN PROCEED V33E

USE SCT TO ACQUIRE A LANDMARK

SET SIGHTING FLAG TO LANDMARK FOR USE BY SIGHTING MARK AND AUTO OPTICS POSITIONING ROUTINES

IS LANDMARK SUFFICIENTLY IDENTIFIABLE TO TAKE MARKS?

.N .Y

DO I WISH TO CONTINUE EFFORT TO TRACK A LANDMARK?

.Y .N

#160

#170

#180

#190

#200

 SET MARK INDEX
 TO 5 FOR USE BY
 SIGHTING MARK
 ROUTINE (R53)

 DO AUTO OPTICS
 POSITIONING
 ROUTINE (R52).
 INCLUDES SIGHT-
 ING MARK ROUTINE
 (R53).

 SET MARK INDEX
 TO 5 FOR USE BY
 SIGHTING MARK ROU-
 TINE (R53)

 DO SIGHTING MARK
 ROUTINE (R53)

 SELECT NEW
 PROGRAM

EXIT
 P22

 DO AUTO OPTICS
 POSITIONING
 ROUTINE (R52).
 INCLUDES SIGHT-
 ING MARK ROU-
 TINE (R53).

 DO SIGHTING MARK
 ROUTINE (R53)

#210

#220

#230

#240

#250

FLASH VERB-NOUN
 TO REQUEST LOAD
 LMK IDENTIFICATION
 V21 N37
 R1-BLANK
 R2-BLANK
 R3-BLANK

MONITOR DSKY:
 OBSERVE FLASHING
 VERB-NOUN REQUEST-
 ING LOAD OF LMK
 IDENTIFICATION

#260

WAIT FOR KEYBOARD
 ENTRY:

LOAD LANDMARK
 IDENTIFICATION.

#270

TERMINATE FLASH UPON
 RECEIPT OF ENTER

R1: 000X
 R2: 000X
 R1= 1, IF KNOWN
 LANDMARK
 R1= 0, IF LMK
 UNKNOWN

IS R1= 0 AND
 R2= 1?

R2= 1, IF LMK CO-
 ORDINATES
 HAVE BEEN
 STORED IN
 CMC

#280

TURN ON
 OPERATOR
 ERROR
 ALARM

R2= 0, IF LMK CO-
 ORDINATES
 HAVE NOT
 BEEN STORED
 IN CMC.

#290

IS R1= 1?
 (KNOWN LMK?)

WAS SIGHTING ON A
 KNOWN LMK?

#300

WAS ONLY ONE
 MARK RECEIVED?

Y N

Y N

#310

#320

#330

#340

#350

#360

TURN ON
PROGRAM
ALARM
AND
DISPLAY
FLASHING
V05 N31
R1-
R2-
R3-

DOES
PROGRAM ALARM
INDICATE CMC
RECEIVED
INSUFFICIENT
MARKS?

.Y

GO TO
"A"
BELOW

GO TO
"A"
BELOW

COMPUTE LMK
LOCATION FROM
FIRST MARK DATA

IS R2=1?
(LMK COORDINATES
STORED?)

.N .Y

HAVE THE COORDINATES
OF THIS LMK BEEN
STORED IN THE CMC?

.Y .N

POSS
HOLD

FLASH VERB -
NOUN REQUEST-
ING LOAD LMK
ID NO. N
V21 N--
R1-BLANK
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE FLASH-
ING VERB NOUN
REQUESTING LOAD
LMK. ID NO. N

50

4 9005

FLASH VERB-NOUN
TO REQUEST LOAD
LMK DATA:

POSS V21 N63
..... R1: LAT
HOLD R2: LONG/2
R3: ALT

WAIT FOR KEYBOARD
ENTRY

TERMINATE FLASH
UPON RECEIPT OF
ENTER

MONITOR DSKY:
OBSERVE FLASH
REQUESTING LOAD
LMK PARAMETERS

LOAD LANDMARK PA-
RAMETERS:
R1: LAT
R2: LONG/2
R3: ALT

LAT-LATITUDE OF
LANDMARK IN
DEGREES TO
NEAREST
.001 DEG.
+ IS NORTH

LONG/2-LONGITUDE
OF LANDMARK
DIVIDED BY
TWO, IN DE-
GREES TO
NEAREST
.001 DEG.
+ IS EAST

ALT-ALTITUDE OF
LANDMARK
ABOVE FI-
SCHER EL-
LIPSOID IN
NAUTICAL
MILES TO
.01 N.M.

LOAD LANDMARK
ID NUMBER

#370

#380

#390

#400

#410

52

4 3304

SELECT FIRST
SIGHTING MARK
DATA

#420

COMPUTE ORBITAL
PARAMETER AND
LANDMARK COOR-
DINATE CHANGES
AS A RESULT OF
THIS SIGHTING
MARK

#430

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY ORBITAL
PARAMETER CHANGES:

HOLD.

V06 N75
R1 - DELTA R
R2 - DELTA V
R3 - MULT MARK
CTR

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST RE-
SPONSE AND DISPLAY
OF ORBITAL PARAMETER
CHANGES

#440

DELTA R - MAGNITUDE
OF THE DIFFERENCE
BETWEEN THE POSI-
TION VECTOR
BEFORE AND AFTER
INCORPORATION OF
THE LANDMARK
SIGHTING DATA.
IN N.M. TO NEAREST
0.1 N.M.

#450

#460

DELTA V - MAGNITUDE
OF THE DIFFERENCE
BETWEEN THE VELO-
CITY VECTOR
BEFORE AND AFTER
INCORPORATION OF
THE LANDMARK
SIGHTING DATA.
IN FPS TO NEAREST
FPS

#470

MULT MARK CTR -
FIRST AND SECOND
CHARACTERS -
ZERO: THIRD CHAR-
ACTER DESIGNATES
IF THIS IS
1ST OR 2ND
DATA DISPLAY FOR
MARK BEING PRO-
CESSED:
FOURTH CHARACTER-
DESIGNATES THE
NUMBER OF THE
MARK NOW BEING
PROCESSED:
FIFTH CHARACTER-
DESIGNATES HOW
MANY MARKS WERE
MADE IN THIS
SEQUENCE

#480

#490

ARE ORBITAL
PARAMETER CHANGES
ACCEPTABLE FOR IN-
SERTION INTO CMC
CALCULATION OF
POSITION AND
VELOCITY

#500

.Y N.
:
:
:

#510

WAIT FOR DSKY ENTRY

KEY IN PROCEED
V 33 E

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR TERMINATE

KEY IN TERMINATE
V34 E

#520

.P T.
.R E.
.O R.
.C M.
.E
.E
.D

UPDATE CMC STATE
VECTOR AND COM-
PUTE REVISED LAND-
MARK COORDINATES

#530

HAVE THE ORBITAL
PARAMETER
CHANGES BEEN
COMPUTED TWICE
FOR THIS MARK

#540

.N .Y

HAVE ALL
THE MARKS
BEEN PRO-
CESSED

#550

.N .Y

SELECT THE
DATA FROM THE
NEXT SIGHTING
MARK

#560

HOLD

 FLASH VERB-NOUN
 TO REQUEST PROCEED
 AND DISPLAY LANDMARK
 ID NO.
 V06 N--
 R1-000XX
 R2-BLANK
 R3-BLANK

 MONITOR DSKY:
 OBSERVE DISPLAY OF
 LMK ID NO.

#570

 DO I DESIRE DISPLAY
 OF UPDATED (OR UN-
 KNOWN) LANDMARK
 COORDINATES

#580

.N .Y
 .
 .

 WAIT FOR KEYBOARD
 ENTRY:

 KEY IN
 TERMINATE
 V34E

#590

 TERMINATE FLASH UPON
 RECEIPT OF PROCEED
 OR TERMINATE

 KEY IN PROCEED
 V33E

T. .PROCEED
 E. .
 R. .
 M. .

#600

 I. FLASH VERB-NOUN
 N. TO REQUEST PRO-
 A. CEED AND DISPLAY
 T. UPDATED LMK
 E. COORDINATES

 MONITOR DSKY:
 OBSERVE DISPLAY
 OF UPDATED LMK
 COORDINATES

HOLD

V06 N63
 R1-LAT
 R2-LONG/2
 R3-ALT

 RECORD DATA

#610

 SHALL THESE DATA BE
 SAVED IN CMC MEMORY?

.N .Y
 .
 .

#620

4 5002

WAIT FOR KEY-
BOARD ENTRY

KEY IN
TERMINATE
V34E

TERMINATE FLASH
UPON RECEIPT OF
PROCEED OR
TERMINATE

KEY IN PROCEED
V33E

#630

T P
E O
R O
M C
I E
N E
A D
T
E

#640

STORE THESE
COORDINATES
AS UPDATED
LMK PARAME-
TERS

#650

FROM
"A"
ABOVE

FROM
"A"
ABOVE

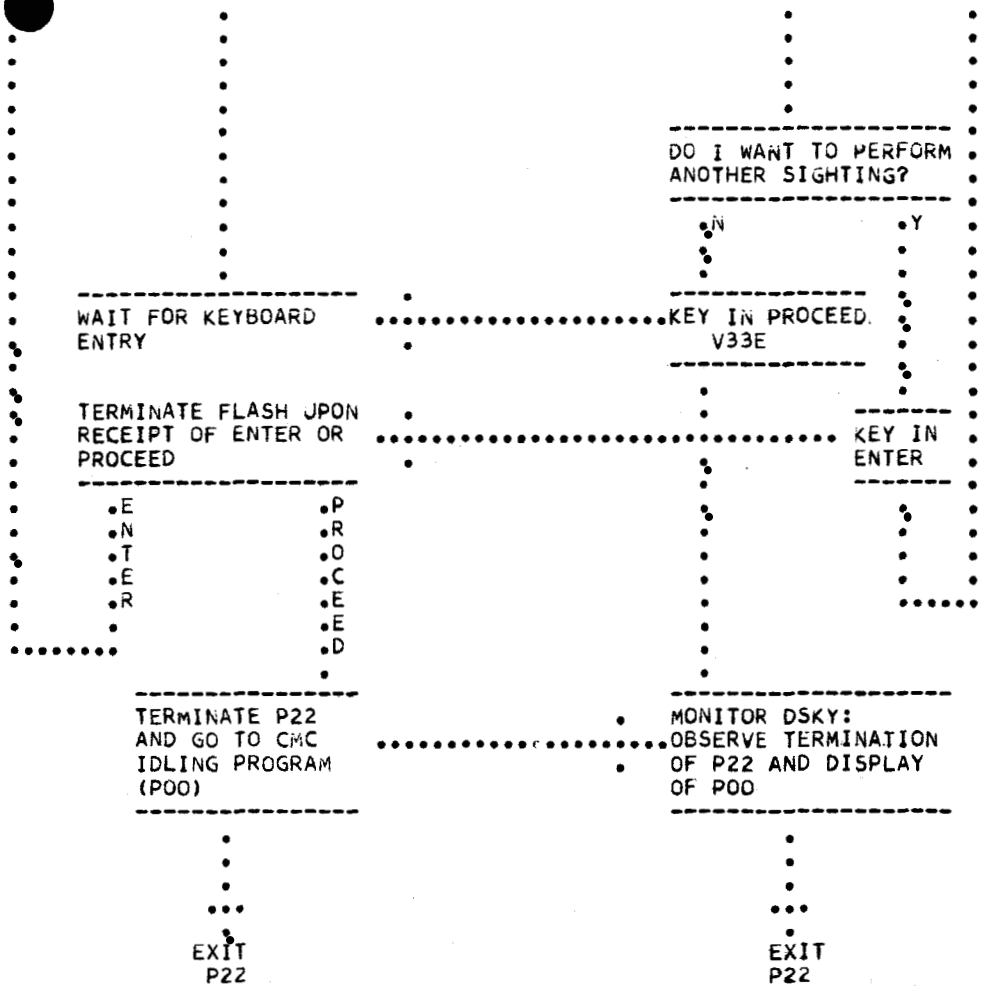
#660

HOLD

FLASH VERB-NOUN TO
REQUEST PLEASE PER-
FORM ADDITIONAL SIGHTING:
V50 N25
R1-XXXXX
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM
ADDITIONAL SIGHTING

#670



#680

#690

#700

#710

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

CISLUNAR MIDCOURSE NAVIGATION PROGRAM (P23)

REV 6

10/31/66

PURPOSE: (1) TO OBTAIN THE ANGLE BETWEEN A NAVIGATION STAR AND AN EARTH/LUNAR LANDMARK OR THE EARTH/LUNAR HORIZON FOR NAVIGATION PURPOSES. FOR MISSION 278 THIS PROGRAM WILL BE AN ABBREVIATED SEQUENCE FOR EXPERIMENTAL ANALYSIS ONLY. IT WILL BE DONE ONLY FOR THE STAR/LUNAR HORIZON CASE OR THE STAR/LUNAR LANDMARK CASE. FOR MISSION 503 IT WILL ALSO BE DONE FOR THE STAR/EARTH HORIZON AND THE STAR/EARTH LANDMARK CASE.

- ASSUMPTIONS: (1) THIS PROGRAM DOES NOT REQUIRE THAT THE ISS BE ON.
- (2) THE VEHICLE POSITION, TIME OF MARKS, AND THE OPTICS ANGLES WILL BE ON THE CMC DOWNLINK. IF THE PROGRAM IS NOT CONDUCTED OVER A GROUND STATION THE NAV MUST RECORD THE OPTICS ANGLES AND TIME FOR EACH MARK.
- (3) THE PROGRAM MAKES NO PROVISION FOR VEHICLE ATTITUDE CONTROL AND IS INDEPENDENT OF THE METHOD USED.
- (4) THE PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY.

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
			.CREW PROG. .SELECTION . . .			#10
	DO PROGRAM SELECTION CHECK ROUTINE (R01)	.....	KEY IN CISLUNAR MID- COURSE NAVIGATION PROGRAM (P23) V37E 23E			
		.....	DO PROGRAM SELECTION CHECK ROUTINE (R01)			#20
	START CISLUNAR MID- COURSE NAVIGATION PROGRAM (P23)	.....	MONITOR DSKY: OBSERVE DISPLAY OF PROGRAM 23			#30

0000 A

HOLD

FLASH PLEASE MARK
 V51 N BLANK
 R1- BLANK
 R2- BLANK
 R3- BLANK

MONITOR DSKY:
 OBSERVE FLASH OF
 PLEASE MARK V51

#40

PERFORM STAR/LAND-
 MARK OR HORIZON
 ACQUISITION PRO-
 CEDURE PER CHECKLIST

#50

WAIT FOR MARK

PERFORM SIGHTING
 MARK

#60

HOLD

FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY OPTICS ANGLES
 V06 N57
 R1-SHAFT ANGLE
 R2-TRUNNION ANGLE
 R3-BLANK

MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF OPTICS ANGLES

#70

OPTICS ANGLES IN
 DEGREES TO NEAREST
 .01 DEG FOR SHAFT,
 .001 DEG FOR TRUNNION

COORDINATE RECEIPT
 OF THIS DATA AND
 STAR/LANDMARK OR
 HORIZON IDENT-
 IFICATION BY THE
 GROUND. IS DATA
 ACKNOWLEDGED?

#80

N. Y.

#90

RECORD DISPLAY
AND IDENTI-
FICATION
DATA IN FLIGHT
DATA BOOK

#100

WAIT FOR KEYBOARD
ENTRY
TERMINATE FLASH UPON
RECEIPT OF PROCEED

KEY IN PROCEED
V 33 E

#110

FLASH VERB-NOUN TO
REQUEST PROCEED AND
DISPLAY TIME OF MARK
V06 N34
R1-T MARK-HRS
R2-T MARK-MIN
R3-T MARK-SEC

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PROCEED AND DISPLAY
OF TIME OF MARK

#120

T MARK-TIME OF MARK
(GET). IN HRS, MIN
AND SEC TO NEAREST
.01 SEC.

COORDINATE RECEIPT
OF THIS DATA BY THE
GROUND
IS DATA ACKNOW-
LEDGED?

N. Y.

#130

RECORD DISPLAY
DATA IN FLIGHT
DATA BOOK

#140

WAIT FOR KEYBOARD
ENTRY
TERMINATE FLASH
UPON RECEIPT OF
PROCEED

KEY IN PROCEED
V 33 E

HOLD

62

HOLD

```

-----
FLASH VERB=NOUN TO
REQUEST PLEASE PER-
FORM ADDITIONAL
SIGHTING
V50 N25
R1=000XX
R2=BLANK
R3=BLANK
-----

```

```

-----
MONITOR DSKY
OBSERVE VERB=NOUN
FLASH TO REQUEST
PLEASE PERFORM
ADDITIONAL SIGHTING
-----

```

#150

```

-----
DO I WANT TO PERFORM
ANOTHER SIGHTINGS?
-----

```

#160

```

      .N      .Y
      .
      .

```

```

-----
WAIT FOR KEYBOARD
ENTRY
-----

```

```

-----
KEY IN PROCEED
V33E
-----

```

#170

```

-----
TERMINATE FLASH UPON
RECEIPT OF ENTER OR
PROCEED
-----

```

```

-----
KEY IN ENTER
-----

```

#180

```

.E   .P
.N   .R
.T   .O
.E   .C
.R   .E
     .E
     .D

```

```

-----
TERMINATE P23 AND GO
TO CMC IDLING (P00)
-----

```

```

-----
MONITOR DSKY:
OBSERVE TERMINATION
OF P23 AND DISPLAY
OF P00
-----

```

#190

EXIT P23

EXIT P23

END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

LGC INITIALIZATION PROGRAM. (P26)

REV 1

10/14/66

- PURPOSE:
- (1) TO DISPLAY CMC CLOCK TIME IF REQUIRED FOR DETERMINATION OF DIFFERENCE BETWEEN CMC AND LGC CLOCKS.
 - (2) TO DISPLAY THE CSM/LM STATE VECTOR FOR SUBSEQUENT LOADING INTO THE LGC. SINCE THE CSM AND LM ARE ATTACHED DURING EXECUTION OF THIS PROGRAM THE CSM AND LM STATE VECTORS ARE IDENTICAL.
 - (3) TO DISPLAY TEPHEM FOR SUBSEQUENT LOADING INTO THE LGC. TEPHEM IS THE TIME OF CMC CLOCK ZERO FROM JULY 1 OF THE REFERENCE BESSELIAN YEAR.

ASSUMPTIONS: (1) THE CSM AND LM ARE ATTACHED.

(2) THIS PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY AND IS COORDINATED WITH THE LGC INITIALIZATION PROGRAM (P01) IN THE LGC BY CREW PROCEDURES.

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
--------------	-----	--------	------	-----------	------	---------------

			DO I HAVE A PRECISE VALUE FOR THE DIF- FERENCE BETWEEN THE CMC AND LGC CLOCKS SUPPLIED FROM THE GROUND AND OBTAINED BY COMPARING CLOCK READINGS ON THE CMC AND LGC DOWNLINKS?			#10

				.N .Y		
				:		
				:		

				KEY IN V06N65		#20

				:		
				:		
				:		
				:		
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				:		

#30

.....
 . . .
 . . .
 . . .
 . . .

 . PERFORM COUNT-
 . DOWN WITH CREW
 . MEMBER IN LM TO
 . ENSURE SIMULTA-
 . NEOUS DEPRESSION
 . OF ENTER KEYS ON
 . BOTH DSKYS.

#40

.....
 .
 .
 .

 RECORD CONTENTS OF
 CMC CLOCK AT TIME OF
 ENTER.

.....
 . KEY IN ENTER

.
 .
 .

#50

 DISPLAY V06N65
 DISPLAY READING OF
 CMC CLOCK AT ENTER
 IN R1, R2 AND R3.
 R1-HRS
 R2-MIN
 R3-SEC

.....
 . RECORD CMC TIME
 . OF ENTER. DIS-
 . PLAYED IN R1, R2
 . AND R3.

R3 GIVES SECONDS TO
 THE NEAREST .01
 SECOND

.....
 . OBTAIN VALUE VIA
 . VOICE LINK OF
 . LGC TIME AT
 . ENTER

#60

.....
 .
 .
 .

.....
 . COMPUTE TIME
 . DIFFERENCE: (CMC
 . TIME)-(LGC TIME)
 . AND RECORD

#70

.....
 .
 .
 .

.....
 . DO I WISH TO
 . TAKE MORE DATA
 . POINTS?

#80

.....
 . Y . N
 . .
 . .
 . .
 . .
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.....
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.....
.....

TAKE AVERAGE OF
TIME DIFFERENCES
TO INCREASE
ACCURACY

#90

DO PROGRAM SELECTION
CHECK ROUTINE (R01)

.....
.....

KEY IN LGC INITIALI-
ZATION PROGRAM (P26)
V37E26E

#100

.....

DO PROGRAM SELECTION
CHECK ROUTINE (R01)

#110

.....
.....

START LGC INITIALI-
ZATION PROGRAM (P26)
DISPLAY P26

.....

MONITOR DSKY:
OBSERVE DISPLAY OF
P26

#120

.....

INITIALIZE COMPONENT
COUNTER

#130

.....

FLASH VERB=NOUN TO
REQUEST RESPONSE
V04 N01
R1-XXXXX
R2-XXXXX
R3-AAAA

.....

MONITOR DSKY:
OBSERVE VERB=NOUN
FLASH TO REQUEST
RESPONSE

• R1 CONTAINS OCTAL
• DIGITS OF MOST SIG-
• NIFICANT PART OF
• COMPONENT CORRES-
• PONDING TO COMPONENT
• COUNTER AND R2 CON-
• TAINS LEAST SIG.
• PART OF SAME COMPO-
• NENT. R3 CONTAINS
• OCTAL ADDRESS OF
• THIS COMPONENT.

• RECORD AND/OR VOICE
• TO LM CREW DATA IN
• R1 AND R2 FOR LOAD
• IN SAME ADDRESS IN
• LGC DURING LGC
• INITIALIZATION
• PROGRAM (P01).

#140

• :
• :
• :

• WAIT FOR KEYBOARD
• ENTRY

• KEY IN PROCEED
• V33E

#150

• TERMINATE FLASH UPON
• RECEIPT OF PROCEED

#160

• P
• R
• O
• C
• E
• E
• D
• :
• :

#170

• CHECK COMPONENT
• COUNTER: WAS THIS
• THE LAST COMPONENT?

• N Y

#180

• INCREASE COMPONENT
• COUNTER

#190

.....
 HOLD

 FLASH VERB-NOUN TO
 REQUEST PLEASE PER-
 FORM SELECTION OF
 IDLING PROGRAM (P00)
 V50 N07
 R1-00000
 R2-BLANK
 R3-BLANK

.....

 WAIT FOR KEYBOARD
 ENTRY

.....

 TERMINATE FLASH UPON
 RECEIPT OF REQUEST
 FOR NEW PROGRAM

.....

 GO TO PROGRAM
 SELECTED

.....

 EXIT P26

.....

 MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 SELECTION OF P00

.....

 KEY IN PROGRAM
 DESIRED
 V37E--E

.....

 GO TO PROGRAM
 SELECTED

.....

 EXIT P26

#200

#210

#220

END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

CMC UPDATE PROGRAM (P27)

REV 4

10/11/66

- PURPOSE: (1) TO INSERT INFORMATION INTO THE CMC VIA THE DIGITAL UPLINK BY TRANSMISSION FROM THE GROUND OR VIA THE DSKY KEYBOARD BY CREW MANUAL INPUT.
- ASSUMPTIONS: (1) THE CMC MUST BE IN THE OPERATE CONDITION. THE IMU MAY BE IN STANDBY OR OPERATE CONDITION.
- (2) CMC UPDATES ARE OF FOUR CATEGORIES:
- (A) AIM PARAMETERS FOR AN EXTERNAL DELTA V MANEUVER (V72).
 - (B) LM POSITION, VELOCITY AND TIME (RVT) (V70).
 - (C) CSM POSITION, VELOCITY AND TIME (RVT) (V76).
 - (D) TIME UPDATE (V77).
- (3) A COMPLETE DESCRIPTION OF THE CMC UPLINK FORMAT IS INCLUDED IN SECTION 3 OF R-547 VOL I.
- (4) THE PROGRAM IS NORMALLY MANUALLY SELECTED BY THE ASTRONAUT BY DSKY ENTRY OR BY THE GROUND BY UPLINK TRANSMISSION. THE ABILITY OF THE CMC TO RECEIVE UPLINK TRANSMISSIONS HOWEVER IS CONTINGENT UPON THE CREW PLACING THE UPTEL SWITCH IN THE 'ACCEPT' POSITION. THE PROGRAM CAN ONLY BE ENTERED FROM P00 AND, WHEN TERMINATED, AUTOMATICALLY RETURNS TO P00.

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
			<ul style="list-style-type: none"> • CREW • PROG • SELECTION • ••• • 			#10
		<p>-----</p> <p>CONFIRM UPDATE PARAMETERS AND MISSION TIME PREPARE PARA- METERS AT NECES- SARY GROUND STATION.</p> <p>-----</p> <ul style="list-style-type: none"> • • • • • • • • • • 	<p>-----</p> <p>REQUEST CMC UPDATE. SPECIFY PARAMETERS AND COORDINATE TIME OF MISSION. ENSURE CMC WILL BE ABLE TO ACCEPT.</p> <p>-----</p> <ul style="list-style-type: none"> • • • • • • • • • • 			#20

72

4 3894

```

-----
SELECT THE DESIRED
TYPE OF UPDATE:
1. EXT DELTA V V72
2. LM RVT V70
3. CSM RVT V76
4. TIME V77
-----

```

```

1. 2. 3. 4.

```

```

-----
DO PROGRAM          . TRANS-
SELECTION CHECK     . . . . MIT
ROUTINE (R01)       .   V72E
-----

```

```

-----
. . . . . TRANS-
. . . . . MIT
. . . . . V70E
-----

```

```

-----
. . . . . TRANS-
. . . . . MIT
. . . . . V76E
-----

```

```

-----
. . . . . TRANS-
. . . . . MIT
. . . . . V77E
-----

```

```

-----
. . . . . KEY IN
. . . . . V72E
-----

```

```

-----
. . . . . KEY IN
. . . . . V70E
-----

```

```

-----
SELECT THE DESIRED
TYPE OF UPDATE:
1. EXT DELTA V V72
2. LM RVT V70
3. CSM RVT V76
4. TIME V77
-----

```

```

1. 2. 3. 4.

```

#80

#90

#100

#110

#120

#130

4 5693

HOLD.

FLASH VERB-NOUN
 TO REQUEST LOAD
 OF DATA IN
 MACHINE ADDRESS
 SPECIFIED IN R3
 AND DISPLAY:
 V21 N01
 R1-BLANK
 R2-UNCHANGED
 R3-UPADR

MONITOR DOWNLINK:
 OBSERVE VERB-NOUN
 FLASH AND DISPLAY
 OF UPADR

MONITOR DSKY:
 OBSERVE VERB-NOJN
 FLASH TO REQUEST
 LOAD OF DATA AND
 DISPLAY OF UPADR

#190

UPADR-THE ADDRESS
 OF AN ERASABLE
 MEMORY LOCATION
 TO BE USED FOR
 TEMPORARY
 STORAGE OF THE
 DATA WORD NEXT
 LOADED.

DO I WISH TO
 TERMINATE

Y. N.

DO I WISH TO
 TERMINATE

Y. N.

#200

#210

WAIT FOR KEY-
 BOARD ENTRY.
 DISPLAY DATA
 IN R1 AS IT IS
 LOADED.

TRANSMIT TERMINATE

V 34 E

TRANSMIT UPDATE

KEY IN TERMINATE
 V 34 E

#220

TERMINATE FLASH
 UPON RECEIPT OF
 TERMINATE OR DATA

DATA

KEY IN DATA FOR
 UPDATE:
 XXXXXE
 OBSERVE DATA LOADED
 TO BE DISPLAYED IN
 R1.

#230

TERMINATE

IS DOWNLINK
COUNTER = X

WHERE:

V72, X = 8
V70, X = 14
V76, X = 14
V77, X = 1

N. Y.

INCREMENT
UPADR AND
DOWNLINK
COUNTER

SELECT NEW LOCATION
FOR UPADR FOR
POSSIBLE IDENTIFIER
OF UPDATED INFORM-
ATION TO BE CORRECT-
ED

#240

#250

#260

#270

#280

#290

#300

#310

#320

#330

FLASH VERB-NOUN
TO REQUEST LOAD
OF OCTAL IDENTIFIER
IN MACHINE ADDRESS
SPECIFIED IN R3.....
AND DISPLAY:
V21 N02
R1 - BLANK
R2-- UNCHANGED
R3 - UPADR

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
LOAD OF OCTAL
IDENTIFIER
.Y .N
.....

MONITOR DOWNLINK:
OBSERVE FLASH TO
REQUEST LOAD OF
OCTAL IDENTIFIER
.....

WAIT FOR KEYBOARD
ENTRY. DISPLAY OCTAL
IDENTIFIER IN R1 AS
IT IS LOADED.
Y. N.

DO I WISH TO
TERMINATE
Y. N.

TRANSMIT
TERMINATE
V 34 E

DO I WISH TO
CHANGE DATA
LOADED?
N. Y

KEY IN TERMINATE
V 34 E

DO I WISH TO CHANGE
DATA LOADED
N. Y

TRANSMIT
FINAL
PROCEED
V 33 E

#340

#350

#360

#370

#380

#390

KEY IN FINAL
PROCEED
V 33 E

TRANSMIT OCTAL
IDENTIFIER OF
REGISTER TO BE
CHANGED
X X E

TERMINATE FLASH
UPON RECEIPT
OF TERMINATE
PROCEED, OR XXE

T . P
E . R
R . O
M . C
I . E
N . E
A . D
T .
E .

SHIFT UPDATE
PARAMETERS
INTO WORKING
REGISTERS

SET UPDATE FLAG

WAIT 8 SECONDS

KEY IN OCTAL IDENTIFIER OF REGISTER TO BE CHANGED

XXE
OBSERVE IDENTIFIER TO BE DISPLAYED IN RI.

78

ICM 4

IS OCTAL IDENTIFIER
POSITIVE

N. .Y

#400

IS OCTAL IDENTIFIER
GREATER THAN 0 AND
LESS THAN OR EQUAL
TO X

WHERE:

V72, X = 8
V70, X = 14
V76, X = 14
V77, X = 1

#410

N. .Y

PUT ADDRESS OF
COMPONENT TO BE
CORRECTED INTO UPADR

#420

(SEE ABOVE)

TURN OFF UPTL
ACTIVITY LIGHT

MONITOR DSKY:
OBSERVE UPTL ACTIV-
ITY LIGHT OUT

#430

MONITOR DOWNLINK:
OBSERVE UPTL ACTIV-
ITY LIGHT OUT

CHANGE DOWNLINK
LIST TO ORIGINAL

#440

.....

TERMINATE
P27 AND
GO TO P00

.....

MONITOR DSKY:
OBSERVE TERMINATION
OF P27 AND DISPLAY
OF PROGRAM 00

#450

.....

MONITOR DOWNLINK:
OBSERVE TERMINATION
OF P27, THE RETURN
TO P00, AND REVERSION
TO ORIGINAL DOWN-
LINK FORMAT.

#460

.....

SET UPTTEL SWITCH TO
BLOCK

#470

.....

EXIT P27

.....

EXIT P27

END OF RUN

4 3890

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

EXTERNAL DELTA V PROGRAM (P30)

REV 8

10/31/66

PURPOSE:

(1) TO ACCEPT TARGETING PARAMETERS OBTAINED FROM A SOURCE(S) EXTERNAL TO THE CMC AND COMPUTE THEREFROM THE REQUIRED VELOCITY AND OTHER INITIAL CONDITIONS REQUIRED BY THE CMC FOR EXECUTION OF THE DESIRED MANEUVER. THE TARGETING PARAMETERS INSERTED INTO THE CMC ARE THE IMPULSIVE DELTA V ALONG CSM LOCAL VERTICAL AXES AT TIG, AND THE TIME OF IGNITION(TIG).

(2) TO DISPLAY TO THE ASTRONAUT AND THE GROUND CERTAIN SPECIFIC DEPENDENT VARIABLES ASSOCIATED WITH THE DESIRED MANEUVER FOR APPROVAL BY THE ASTRONAUT/GROUND.

(3) THIS PROGRAM IS DESIGNED FOR ONE-MAN OPERATION.

ASSUMPTIONS:

(1) THE TARGET PARAMETERS (DELTA V(LV) AND TIGN) MAY HAVE BEEN LOADED FROM THE GROUND DURING A PRIOR EXECUTION OF P27.

(2) THE ISS MAY BE IN STANDBY OR OPERATE. THE GNC5 START UP PROGRAM (P05) AND THE IMU ORIENTATION DETERMINATION PROGRAM (P51) SHOULD BE COMPLETED BEFORE THE SELECTION OF THIS PROGRAM UNLESS THIS PROGRAM IS SELECTED ONLY FOR DATA LOADING AND THRUSTING PARAMETER COMPUTATION. TIME AND RCS FUEL MAY BE SAVED AND SUBSEQUENT IMU ALIGNMENT DECISIONS GREATLY SIMPLIFIED IF P51 IS PERFORMED IN SUCH A WAY AS TO LEAVE THE IMU INERTIALLY STABILIZED AT AN ORIENTATION CLOSE TO THE PREFERRED ORIENTATION. THIS PROGRAM GENERATES THE MANEUVER INITIAL CONDITIONS FROM WHICH THE PREFERRED IMU ORIENTATION CAN BE DETERMINED IN PROGRAM 40 OR 41.

THE ISS THUS MAY BE:

(A) OFF (STANDBY).

(B) ON, AND NOT ALIGNED SINCE TURN ON

(C) ON AND AT AN INERTIAL ORIENTATION KNOWN ONLY INACCURATELY BY THE CMC, I.E. HAVING BEEN ALIGNED AT LEAST ONCE SINCE TURN ON BUT NOT WITHIN THE LAST --HRS

(D) ON AND AT AN INERTIAL ORIENTATION KNOWN ACCURATELY BY THE CMC, I.E. HAVING BEEN ALIGNED WITHIN THE LAST --HRS

IF (A) IS TRUE PROGRAM 05 SELECTION WILL BE REQUESTED BY THIS PROGRAM.

IF (B) IS TRUE PROGRAM 51 SELECTION WILL BE REQUESTED BY THIS PROGRAM.

IF (C) IS TRUE THE CMC MAY OR MAY NOT HAVE A SATISFACTORY INERTIAL REFERENCE TO ACCURATELY COMPLETE THE PROGRAM.

IF (D) IS TRUE THE CMC HAS A SATISFACTORY INERTIAL REFERENCE TO ACCURATELY COMPLETE THE PROGRAM. CASES (B), (C) AND (D) HOWEVER ARE FURTHER SUBJECT TO THE CONSTRAINT OF LARGE MIDDLE GIMBAL ANGLE, I.E. THE EXISTING INERTIAL ORIENTATION MAY CAUSE A MIDDLE GIMBAL ANGLE GREATER THAN 45 DEGREES AT THE THRUSTING ORIENTATION OF THE CSM, WHICH IS UNSATISFACTORY.

(3) IT IS NORMALLY REQUIRED THAT THE ISS BE ON FOR --PRIOR TO A THRUSTING MANEUVER.

(4) THIS PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY AT LEAST --BEFORE THE TIME OF IGNITION.

60005

PROG
CONT

CMC

GROUND

CREW

CHECKLIST

TIME

TOTAL
TIME

.CREW PROG.
.SELECTION

.
.
.
.

#10

DO PROGRAM SELECTION
CHECK ROUTINE (R01)

.....
.....

EXTERNAL DELTA V
PROGRAM (P30)
V37E 30E

#20

DO PROGRAM SELECTION
CHECK ROUTINE (R01)

.....
.....

START EXTERNAL DELTA
V PROGRAM (P30)
DISPLAY PROGRAM 30

.....
.....

MONITOR DSKY:
OBSERVE DISPLAY OF
PROGRAM 30

#30

SET TRACK FLAG (SEE
P20)

.
.

#40

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY STORED TIG:

V06 N34
R1-TIG-HRS
R2-TIG-MIN
R3-TIG-SEC

.....
.....

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF STORED TIG.

#50

.....
HOLD

TIG-TIME OF
IGNITION (GET)
IN HRS, MIN, SEC
TO NEAREST .01 SEC.

AM I SATISFIED WITH
THIS VALUE?

Y. N

RECORD THIS
VALUE

WAIT FOR KEYBOARD
ENTRY

KEY IN PROCEED
V 33 E

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW DATA

KEY IN V25 AND
LOAD THE DESIRED
TIG.

P. NEW
R. DATA
O.
C.-----
E. STORE DATA
E.-----
D.

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY THREE STORED
COMPONENTS OF DELTA
(LV):
V06N--
R1:DELTA VX (LV)
R2:DELTA VY (LV)
R3:DELTA VZ (LV)

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF THREE STORED
COMPONENTS OF
IMPULSIVE DELTA V
ALONG CSM LOCAL
VERTICAL AXES AT
TIG.

.....
HOLD

#60

#70

#80

#90

#100

DELTA VX (LV):
 COMPONENT OF
 IMPULSIVE DELTA V AT
 TIG ALONG (RXV)XR. IN
 FPS TO NEAREST .1
 FPS.

 :
 :
 :

 AM I SATISFIED WITH
 THESE VALUES?

#110

DELTA VY (LV):
 COMPONENT OF
 IMPULSIVE DELTA V AT
 TIG ALONG VXR. IN FPS
 TO NEAREST .1 FPS.

.Y

#120

DELTA VZ (LV):
 COMPONENT OF
 IMPULSIVE DELTA V AT
 TIG ALONG -R. IN FPS
 TO NEAREST .1 FPS

WHERE R IS GEOCEN-
 TRIC RADIUS VECTOR
 AND V IS CSM INER-
 TIAL VELOCITY VECTOR
 VECTOR AT TIG.

#130

 :
 :
 :

 WAIT FOR KEYBOARD
 ENTRY

 KEY IN PROCEED
 V33E

#140

 TERMINATE FLASH UPON
 RECEIPT OF PROCEED
 OR NEW DATA

 KEY IN V25 AND
 LOAD THE DESIRED
 COMPONENTS OF
 DELTA V

#150

.P .NEW
 .R .DATA
 .O .
 .C .
 .E -----
 .E STORE DATA
 .D -----

#160

4 5088

.....

BASED ON THE STORED
TARGET PARAMETERS
COMPUTE NECESSARY
DEPENDENT VARIABLES
FOR EVALUATION OF THE
THRUSTING MANEUVER
INCLUDING PERIGEE
ALTITUDE, APOGEE
ALTITUDE AND DELTA V
REQUIRED (DEFINED
BELOW).

#170

.....

PUT MANEUVER DATA
ON CMC DOWNLINK TO
REMAIN THERE UNTIL
TERMINATION OF THE
PROGRAM.

#180

.....
.....
.....

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY CALCULATED
THRUSTING PARAMETERS:
V06 N45
R1-APOGEE ALT
R2-PERIGEE ALT
R3-DELTA V

.....

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF CALCULATED
THRUSTING PARAMETERS

#190

APOGEE ALT - ALTITUDE
OF APOGEE ABOVE
LAUNCH PAD RADIUS.
IN NAUTICAL
MILES TO
NEAREST .1 NM.

#200

PERIGEE ALT - ALTITUDE
OF PERIGEE ABOVE
LAUNCH PAD RADIUS.
IN NAUTICAL
MILES TO
NEAREST .1 NM.

#210

DELTA V - MAGNITUDE
OF IMPULSIVE DELTA V
VECTOR AT TIG, IN FPS
TO NEAREST .1 FPS

.....
.....

IS A GROUND STATION
AVAILABLE FOR CON:
FIRMATION OF THESE
PARAMETERS?

85

86

4 3887

MONITOR CMC
 DOWNLINK TELE-
 METRY OF APOGEE
 ALT, PERIGEE ALT,
 AND DELTA V RE-
 QUIRED. COORDI-
 NATE EVALUATION
 OF CMC COMPUTED
 PARAMETERS WITH
 ASTRONAUT

Y. N

COORDINATE
 EVALUATION OF
 THE CMC COMPU-
 TED PARAMETERS
 WITH THE
 GROUND

#220

#230

SELECT ONE OF THE
 FOLLOWING FIVE
 ALTERNATIVES:

#240

(1) IF THE CALCULATED DATA IS SATISFACTORY, PERFORM THE THRUSTING MANEUVER USING THE CMC CALCULATED PARAMETERS WITHOUT GROUND CONFIRMATION.

#250

(2) IF THE CALCULATED DATA IS NOT SATISFACTORY ADJUST THE CALCULATED PARAMETERS BY RESELECTING P 30 AS NECESSARY AND CHANGING THE LOADED AIM PARAMETERS UNTIL CMC COMPUTED PARAMETERS ARE SATISFACTORY. THEN PERFORM THE THRUSTING MANEUVER.

#260

(3) REMAIN AT THIS POINT IN THE CMC PROGRAM UNTIL GROUND CO-ORDINATION IS AVAILABLE
 (4) SELECT A NEW PROGRAM AS DESIRED UNTIL

#270

GROUND CO-ORDINATION IS AVAILABLE
 THEN RESELECT
 P 30, LEAVE AIM
 PARAMETERS
 UNCHANGED ETC.
 (5) SELECT A NEW
 PROGRAM AS DESIRED AND PERFORM
 THRUSTING MANEUVER USING BACKUP
 PROCEDURE.

#280

3 2.1
 4
 5

#290

ARE THESE
 PARAMETERS
 SATISFACTORY
 FOR USE BY THE
 CMC FOR THE
 THRUSTING
 MANEUVER?

#300

N. Y.

SELECT ONE OF
 THE FOLLOWING
 FOUR ALTERNATIVES:

#310

(1) ADJUST THE
 CALCULATED PARAMETERS BY RESELECTING P 30 AS
 NECESSARY AND
 CHANGING THE
 LOADED AIM PARAMETERS UNTIL CMC

#320

4 5086

COMPUTED PARAMETERS ARE SATISFACTORY.
 (2) OBTAIN NEW AIM PARAMETERS FROM THE GROUND BY VOICE LINK, RESELECT P 30, KEY IN NEW DATA, ETC.
 (3) SELECT THE CMC UPDATE PROGRAM (P27), LOAD NEW AIM PARAMETERS FROM THE GROUND VIA THE CMC UPLINK, OR BY CREW DSKY INPUT. OBSERVE NEW AIM PARAMETERS, ETC.
 (4) TERMINATE P 30 BY SELECTING A NEW PROGRAM AS DESIRED AND PERFORM THRUSTING MANEUVER USING BACKUP PROCEDURES.

#330

#340

#350

- 1.
- 2.
- 3.
- 4.

 WAIT FOR KEYBOARD ENTRY.

 KEY IN PROGRAM SELECTION AS DESIRED
 V37E--E

#360

.....
 EXIT P30

#370

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW PROGRAM.

KEY IN PROCEED
V 33 E

P.
R.
O.
C.
E.
E.
D.
NEW
PROGRAM
GO TO PROGRAM
SELECTED.

EXIT P 30

#380

#390

HOLD
FLASH VERB-NOUN
TO REQUEST RESPONSE
AND DISPLAY TTI:
V06 N35
R1-TTI - HRS
R2-TTI - MIN
R3-TTI - SEC

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF TTI.

#400

TTI - TIME TO GO TO
TIG. IN HRS. MIN.
SEC TO NEAREST
.01 SEC.

SET LEB CLOCK (AND
MDC CLOCK IF DE-
SIRED) TO TTI.

#410

DO I WISH TO CONTI-
NUE THIS PROGRAM AT
THIS TIME IN PREPAR-
ATION FOR MANEUVER

.Y .N
:
:
:

#420

WAIT FOR KEYBOARD
ENTRY

KEY IN PROCEED
V33E

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW PROGRAM

SELECT DESIRED
PROGRAM
KEY IN

#430

P NEW
R PROG
D
C
E
E GO TO PROGRAM
D SELECTED

V37E --E

#440

GO TO PROGRAM
SELECTED

#450

EXIT P30

EXIT P30

DO IMU STATUS CHECK
ROUTINE (R02)

DO IMU STATUS CHECK
ROUTINE (R02)

#460

COMPUTE IMU GIMBAL
ANGLES AT IGNITION
FOR THRUST ALONG
CSM +X AXIS

#470

.....
HOLD . FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY MANEUVER
DATA:

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF MANEUVER DATA

#480

V06 N--
R1-BLANK
R2-TTI
R3-MGA

NOTE: R1 WOULD NORMALLY CONTAIN N (THE NUMBER OF MARKS SINCE THE LAST THRUSTING MANEUVER). HOWEVER IT IS ASSUMED RENDEZVOUS TRACKING DATA IS NOT BEING TAKEN IN THIS PROGRAM.

TTI- TIME TO GO TO TIG. IN MIN AND SEC TO NEAREST SEC. MAXIMUM READING IS 59 59

MGA: MIDDLE GIMBAL ANGLE AT TIG IF +X CSM AXIS IS ALIGNED WITH INITIAL THRUST DIRECTION. IN DEGREES TO NEAREST .01 DEGREE

 .
 .
 .

 WAIT FOR KEYBOARD ENTRY

 .
 .
 .

 KEY IN PROCEED
 V33E

 .
 .
 .

 TERMINATE FLASH UPON RECEIPT OF PROCEED

 .
 .
 .

 SET EXTERNAL DELTA V STEERING FLAG FOR USE BY THRUSTING PROGRAM

#490

#500

#510

#520

A 0884

HOLD

FLASH VERB-NOUN TO
 REQUEST PLEASE PER-
 FORM SELECTION OF
 NEW PROGRAM:
 V50N07
 R1-BLANK
 R2-BLANK
 R3-BLANK

MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 PLEASE PERFORM SEL-
 ECTION OF NEW
 PROGRAM.

#530

IF TIME AND
 LOCATION
 PERMIT
 ASSIST
 ASTRONAUT IN
 SELECTION OF
 PROPULSION
 SYSTEM. AT
 THIS TIME,
 OR EARLIER
 IF POSSIBLE
 THE ASTRONAUT
 MUST LEARN
 OF THE
 SYSTEM USED
 IN MCC COM-
 PUTATIONS
 OF DATA LOAD

CONSIDERING VALUE OF
 DELTA V, FUEL
 AVAILABLE, STATUS OF
 PROPULSION HARDWARE,
 AND TIME AVAILABLE
 TO RE-ALIGN THE IMU
 TO AVOID GIMBAL LOCK
 SELECT A PROPULSION
 SYSTEM TO PERFORM
 THE MANEUVER. CO-
 ORDINATE WITH GROUND
 IF REQUIRED.

#540

.SPS .RCS

#550

#560

WAIT FOR KEYBOARD
 ENTRY

KEY IN
 REQUEST
 FOR SPS
 THRUSTING
 PROGRAM
 (P40)
 V37E40E

#570

GO TO
 PROGRAM
 SELECTED

#580

EXIT P30

TERMINATE FLASH UPON
RECEIPT OF REQUEST
FOR NEW PROGRAM.

KEY IN REQUEST
FOR RCS THRUST:
ING PROGRAM
(P41)
V37E41E

GO TO PROGRAM
SELECTED

GO TO PROGRAM
SELECTED

EXIT P30

EXIT P30

#590

#600

#610

94
END OF RUN

4 8883

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

TRANSFER PHASE INITIATION (TPI) PROGRAM (P34)

REV 12

10/31/66

PURPOSE:

(1) TO CALCULATE THE REQUIRED DELTA V AND OTHER INITIAL CONDITIONS REQUIRED BY THE CMC FOR CSM EXECUTION OF THE TRANSFER PHASE INITIATION MANEUVER. GIVEN:

(A) TIME OF IGNITION TIG (TPI) OR THE ELEVATION ANGLE (E) OF THE CSM/LM LOS AT TIG(TPI)

(B) TRANSFER DURATION (DELTA T TRANS) FROM TIG(TPI) TO INTERCEPT TIME.

(2) TO CALCULATE TIG (TPI) GIVEN E OR E GIVEN TIG (TPI).

(3) TO CALCULATE THESE PARAMETERS BASED UPON MANEUVER DATA APPROVED AND KEYED INTO THE CMC BY THE ASTRONAUT.

(4) TO DISPLAY TO THE ASTRONAUT AND THE GROUND CERTAIN DEPENDENT VARIABLES ASSOCIATED WITH THE MANEUVER FOR APPROVAL BY THE ASTRONAUT/GROUND.

(5) TO STORE THE TPI TARGET PARAMETERS FOR USE BY THE DESIRED THRUSTING PROGRAM.

(6) TO GOVERN THE USE OF THE SXT TO OBTAIN RENDEZVOUS NAVIGATION DATA DURING THIS PROGRAM.

(7) THIS PROGRAM IS DESIGNED FOR ONE-MAN OPERATION.

ASSUMPTIONS:

(1) STATE VECTOR UPDATES BY P27 ARE DISALLOWED DURING STATE VECTOR UPDATING INITIATED BY P20 (SEE ASSUMPTION (4)).

(2) THE PROGRAM MUST BE DONE OVER A TRACKING STATION FOR REAL TIME GROUND PARTICIPATION IN CMC DATA INPUT AND OUTPUT. CMC COMPUTED VARIABLES MAY BE STORED FOR LATER VERIFICATION BY THE GROUND. THESE STORAGE CAPABILITIES ARE LIMITED ONLY TO THE PARAMETERS FOR ONE THRUSTING MANEUVER AT A TIME EXCEPT FOR CONCENTRIC FLIGHT PLAN MANUEVER SEQUENCES.

(3) THIS PROGRAM MAY BE PERFORMED CONCURRENTLY WITH THE RENDEZVOUS NAVIGATION PROGRAM (P20) TO UPDATE THE LM OR CSM STATE VECTORS WITH OPTICAL TRACKING OF THE LM. THIS PROGRAM MAY ALSO BE PERFORMED INDEPENDENTLY OF P20. IF OPTICAL TRACKING IS DESIRED THE OPTICS SHOULD BE LOCKED ON THE LM BY PREVIOUS SELECTION OF P20. THE RENDEZVOUS TRACKING MARK COUNTER IS ZEROED BY THE SELECTION OF P20 AND AFTER EACH THRUSTING MANEUVER.

IF P20 IS IN EFFECT, OPTICAL TRACKING MARKS MAY BE MADE BY SELECTION OF THE RENDEZVOUS TRACKING DATA PROCESSING ROUTINE (R22). R22 IS SELECTED BY V--E WHICH MAY BE ENTERED WHENEVER THE CMC IS HOLDING FOR A V/N FLASHING DATA DISPLAY (NOTE: FOR SIMPLICITY IT IS ONLY SHOWN BELOW AT THE V06N--DISPLAY.) R22 RETURNS TO THIS PROGRAM AT THE INTERRUPTED DISPLAY.

(4) THE ISS MAY BE IN STANDBY OR OPERATE. THE GNCS START UP PROGRAM (P05) AND THE IMU ORIENTATION DETERMINATION PROGRAM (P51) WOULD NORMALLY BE COMPLETED BEFORE THE SELECTION OF THIS PROGRAM UNLESS THIS PROGRAM IS SELECTED ONLY FOR DATA LOADING AND THRUSTING PARAMETER COMPUTATION. TIME AND RCS FUEL MAY BE SAVED AND SUBSEQUENT IMU ALIGNMENT DECISIONS GREATLY SIMPLIFIED IF P51 IS PERFORMED IN SUCH A WAY AS TO LEAVE THE IMU INERTIALLY STABILIZED AT AN ORIENTATION CLOSE TO THE PREFERRED ORIENTATION. THIS PROGRAM GENERATES THE MANEUVER INITIAL CONDITIONS FROM WHICH THE PREFERRED IMU ORIENTATION CAN BE DETERMINED IN PROGRAM 40, OR 41.
THE ISS THUS MAY BE:

(A) OFF (STANDBY).

(B) ON, AND NOT ALIGNED SINCE TURN ON

(C) ON AND AT AN INERTIAL ORIENTATION KNOWN ONLY INACCURATELY BY THE CMC. I.E. HAVING BEEN ALIGNED AT LEAST ONCE SINCE TURN ON BUT NOT WITHIN THE LAST --HRS

(D) ON AND AT AN INERTIAL ORIENTATION KNOWN ACCURATELY BY THE CMC, I.E. HAVE BEEN ALIGNED WITHIN THE LAST --HRS

IF (A) IS TRUE PROGRAM 05 SELECTION WILL BE REQUESTED BY THIS PROGRAM.
 IF (B) IS TRUE PROGRAM 51 SELECTION WILL BE REQUESTED BY THIS PROGRAM.
 IF (C) IS TRUE THE CMC MAY OR MAY NOT HAVE A SATISFACTORY REFERENCE TO ACCURATELY COMPLETE THE PROGRAM.
 IF (D) IS TRUE THE CMC HAS A SATISFACTORY INERTIAL REFERENCE TO ACCURATELY COMPLETE THE PROGRAM. CASES (B), (C) AND (D) HOWEVER ARE FURTHER SUBJECT TO THE CONSTRAINT OF LARGE MIDDLE GIMBAL ANGLE, I.E. THE EXISTING INERTIAL ORIENTATION MAY CAUSE A MIDDLE GIMBAL ANGLE GREATER THAN 45 DEGREES AT THE THRUSTING ORIENTATION OF THE CSM, WHICH IS UNSATISFACTORY.

(5) THE OPERATION OF THE PROGRAM UTILIZES THE FOLLOWING FLAGS:

ACTIVE VEHICLE FLAG - DESIGNATES THE VEHICLE WHICH IS DOING RENDEZVOUS THRUSTING MANEUVERS TO THE PROGRAM WHICH CALCULATES THE MANEUVER PARAMETERS. SET AT THE START OF EACH RENDEZVOUS PRE-THRUSTING PROGRAM.

FINAL COMPUTATION FLAG - SELECTS FINAL PROGRAM DISPLAYS AFTER CREW HAS SELECTED THE FINAL MANEUVER COMPUTATION CYCLE.

RENDEZVOUS INTERCEPT STEERING FLAG - DESIGNATES THE TYPE OF STEERING REQUIRED FOR EXECUTION OF THIS MANEUVER BY THE THRUSTING PROGRAM SELECTED AFTER COMPLETION OF THIS PROGRAM.

(6) IN THE CREW LOGIC BELOW ASSOCIATED WITH THE FINAL ACCEPTANCE OF THE CMC COMPUTED PARAMETERS, THE FOLLOWING PERFORMANCE TIMES ARE ASSUMED:

(A) PARTIAL DATA LOAD - 1 MIN

(B) CSM MANEUVER COMPUTATION - SIGNIFICANTLY LESS THAN 1 MIN; DISREGARD

(C) MANEUVER PARAMETER DISPLAY AND CREW EVALUATION - 1 MIN

(D) PROPULSION SYSTEM AND THRUSTING PROGRAM IDENTIFICATION - 1 MIN

(E) THRUSTING PROGRAM SELECTION AND COUNT DOWN TO TIG(TPI) - 5 MIN (ASSUMES IMU ALIGNMENT IS SATISFACTORY)

(7) IT IS NORMALLY REQUIRED THAT THE ISS BE ON FOR 1 HOUR PRIOR TO A THRUSTING MANEUVER.

(8) THIS PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY AT LEAST -- MIN BEFORE THE ESTIMATED TIME OF THE IGNITION.

PROG
CONT

CMC

GROUND

CREW

CHECKLIST

TIME

TOTAL
TIME

• CREW PROG.
• SELECTION

•
•
•••
•
•
•
•
•
•

#10

DO PROGRAM SELECTION
CHECK ROUTINE (R01)

.....

KEY IN TRANSFER
PHASE INITIATION
PROGRAM (P34)
V37E 34E

#20

.....

DO PROGRAM SELECTION
CHECK ROUTINE (R01)

START TRANSFER PHASE
INITIATION PROGRAM
(P34)
DISPLAY PROGRAM 34

.....

MONITOR DSKY:
OBSERVE DISPLAY OF
PROGRAM 34

#30

SET ACTIVE VEHICLE
FLAG TO CSM

#40

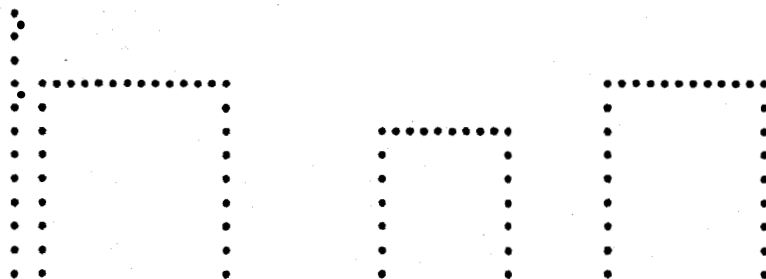
RESET FINAL COMPUTA-
TION FLAG

#50

SET TRACK FLAG
(SEE P20)

SET UPDATE FLAG
(SEE P20)

#60



#70

#80

#90

#100

#110

#120

```

.....
HOLD .
.....
FLASH VERB=NOUN TO
REQUEST RESPONSE AND
DISPLAY OPTION CODE
FOR ASSUMED TPI DATA
LOAD OPTION:
V06 N---
R1-000--
R2-0000X
R3-BLANK

R1 IS THE OPTION
CODE FOR ASSUMED TPI
DATA LOAD OPTION.

R2 IS THE CMC
ASSUMED OPTION:
00001-LOAD TIG (TPI)
CMC COMPUTES E.
00002-LOAD E: CMC
COMPUTES TIG (TPI).

-----
OPTION CORRECT?
. Y . N
. . . .

KEY IN PROCEED
V33E

-----
WAIT FOR KEYBOARD
ENTRY

TERMINATE FLASH
UPON RECEIPT OF
PROCEED OR NEW
CODE
P NEW
R CODE
O
C
E STORE CODE
E
D

-----
MONITOR DSKY-
OBSERVE VERB=NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF OPTION CODE FOR
TPI DATA LOAD OPTION

-----
KEY IN V22
AND LOAD
DESIRED
OPTION CODE
IN R2

-----

```

98

CHECK DATA LOAD
OPTION CODE

.00001 .00002
.TIG(TPI) .E
.....

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY STORED TIG
(TPI) CALCULATED
FROM PREVIOUS
PROGRAMS:
V06 N34
R1-TIG (TPI)-HRS
R2-TIG (TPI)-MIN
R3-TIG (TPI)-SEC

TIG(TPI)-TIME OF TPI
IGNITION (GET).
IN HRS, MIN, SEC
TO NEAREST .01 SEC.

WAIT FOR KEYBOARD
ENTRY

DID I SPECIFY TIG
(TPI) OR E TO THE
CMC?

.TIG(TPI) .E
.....

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF STORED TIG (TPI)
CALCULATED FROM
PREVIOUS PROGRAMS

AM I SATISFIED WITH
THESE VALUES?

Y. .N
.....

RECORD THIS
VALUE

KEY IN PROCEED
V 33 E

#130

#140

#150

#160

97

#170

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW DATA

KEY IN V25 AND
LOAD THE DESIRED TIG

P.
R.
O.
C.
E.
E.
D.

NEW
DATA

STORE DATA

#180

#190

POSS .
.....
HOLD .

FLASH VERB-NOUN
TO REQUEST RES-
PONSE AND DISPLAY
STORED E.
V06 N--
R1-BLANK
R2-E
R3-BLANK

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF STORED E.

#200

E-ELEVATION ANGLE.
THE ANGLE BE-
TWEEN THE CSM/LM
LOS AND THE LOCAL
CSM HORIZONTAL
AT TIG(TPI) MEA-
SURED FROM THE
DIRECTION OF
FLIGHT. IN DE-
GREES TO NEAREST
.01 DEGREE.

#210

#220

ADD

4 0380

AM I SATISFIED WITH THIS VALUE?

.Y .N

RECORD THIS VALUE

WAIT FOR KEY-BOARD ENTRY

KEY IN PROCEED

TERMINATE FLASH UPON RECEIPT OF PROCEED OR NEW DATA

KEY IN V22 AND LOAD THE DESIRED E IN R2

.P .NEW
.R .DATA
.O
.C
.E
.E STORE DATA
.D

DOES A TIG EXIST FOR THE ELEVATION ANGLE (E)?

.Y .N

#230

#240

#250

#260

#270

4 3879

POSS .
.....
HOLD .

FLASH VERB-
NOUN TO RE-
QUEST RESPONSE
AND DISPLAY
ALARM CODE:
V05N31
R1-
R2-
R3-

MONITOR DSKY:
IS THERE AN ALARM
CODE DISPLAY
INDICATING COMPUTA-
TIONAL DIFFICULTY

.Y .N

#280

WAIT FOR KEY-
BOARD ENTRY.

RETURN TO DIS-
PLAY OF STORED
E AND ADJUST
INPUT PARAMET-
ER. KEY IN
RECYCLE
V32E

#290

TERMINATE
FLASH UPON RE-
CEIPT OF RE-
CYCLE.

.R
.E
.C
.Y
.E
.L
.E
.....

#300

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY STORED
DELTA T TRANS;
V06 N--
R1- DELTA T TRANS-
HRS
R2-DELTA T TRANS-
MINS
R3-DELTA T TRANS-
SECS

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF STORED DELTA T
TRANS

#310

.....
HOLD .

DELTA T TRANS - TIME
REQUIRED FOR

AM I SATISFIED WITH
THIS VALUE?

#320

TRANSFER FROM
TIG(TPI) TO TIME OF
INTERCEPT. IN HRS,
MINS, SEC TO NEAREST
.01 SEC.

.Y .N

RECORD THIS
VALUE

#330

WAIT FOR KEYBOARD
ENTRY

KEY IN PROCEED
V33E

#340

TERMINATE FLASH
UPON RECEIPT OF
PROCEED OR NEW DATA

KEY IN V25
AND LOAD THE
DESIRED DELTA T
TRANS.

#350

.P .NEW
.R .DATA
.O
.C
.E
.E STORE DATA
.D

#360

BASED ON THE STORED
TARGET PARAMETERS
COMPUTE THE TRANSFER
TRAJECTORY, INITIAL
CONDITIONS AND THE
NECESSARY DEPENDENT
VARIABLES FOR EVAL-
UATION OF THE
TRANSFER PHASE
INITIATION MANEUVER
AS DESCRIBED IN
SECTION 5.3 OF
R547 VOL I.
ESTABLISH ALARM IF:

#370

#380

(A) A TIG DOES NOT EXIST FOR THE REQUIRED ELEVATION ANGLE IN THE 00002 OPTION CASE

(B) FOR THE SPECIFIED ORBITAL PARAMETERS AT TIG(TPI) THE SPECIFIED DELTA T TRANS RESULTS IN HYPERBOLIC CSM VELOCITY.

NO ALARM ALARM

POSS
.....
HOLD

FLASH VERB-
NOUN TO RE-
QUEST RESPONSE
AND DISPLAY
ALARM CODE:
V05N31
R1-
R2-
R3-

MONITOR DSKY:
IS THERE AN ALARM
CODE DISPLAY
INDICATING COMPUTA-
TIONAL DIFFICULTY

Y N

WAIT FOR KEY-
BOARD ENTRY.

RETURN TO START
OF PROGRAM
AND ADJUST IN-
PUT PARAMETERS.
KEY IN RECYCLE
V32E

TERMINATE
FLASH UPON RE-
CEIPT OF RE-
CYCLE.

R
E
C
Y
C
L
E

#390

#400

#410

#420

#430

#440

 PUT TARGET PARA-
 METERS ON DOWNLINK
 TO REMAIN THERE
 UNTIL TERMINATION OF
 PROGRAM

 CHECK THE DATA
 LOAD OPTION

 .00001 .00002
 .TIG(TPI) .E

 DID I SPECIFY TIG
 (TPI) OR E TO THE
 CMC

 .TIG(TPI) .E

#450

#460

POSS

 HOLD

 FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY CALCULATED E:

 V06 N--
 R1-BLANK
 R2-E
 R3-BLANK

 MONITOR DSKY:
 OBSERVE VERB-NOJN
 FLASH TO REQUEST
 RESPONSE AND
 DISPLAY OF
 CALCULATED E.

#470

 E - ELEVATION ANGLE.
 THE ANGLE BETWEEN
 CSM/LM LOS AND THE
 CSM LOCAL HORIZONTAL
 AT TIG(TPI) MEASURED
 FROM THE DIRECTION
 OF FLIGHT. IN
 DEGREES TO NEAREST
 .01 DEG.

 RECORD THIS VALUE

#480

 WAIT FOR KEYBOARD
 ENTRY

 KEY IN PROCEED
 V33E

#490

 TERMINATE FLASH UPON
 RECEIPT OF PROCEED

106

4 5877

#500

FLASH VERB-NOUN
 TO REQUEST RES-
 PONSE AND DISPLAY.
 CALCULATED TIG(TPI):

MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF CALCULATED TIG
 (TPI)

POSS
 HOLD

V06 N34
 R1-TIG(TPI) -
 HRS
 R2-TIG(TPI) -
 MIN
 R3-TIG(TPI)-
 SEC

RECORD THIS VALUE

#510

TIG(TPI) - TIME
 OF TPI IGNITION
 (GET), IN HRS,
 MIN, SEC TO
 NEAREST .01 SEC

#520

WAIT FOR KEY-
 BOARD ENTRY
 TERMINATE FLASH
 UPON RECEIPT OF
 PROCEED

KEY IN PROCEED
 V33E

#530

HOLD

FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY CALCULATED
 TERMINAL PHASE PARA-
 METERS.

MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF CALCULATED
 TERMINAL PHASE PARA-
 METERS.

#540

V06 N--
 R1-DELTA V (TPI)
 R2-PERIGEE ALT(TPI)
 R3-DELTA V(TPF)

DELTA V (TPI) -
 REQUIRED IMPULSIVE
 DELTA V TO ACCOMPLISH
 TPI MANEUVER AT
 TIG(TPI). IN FPS TO
 NEAREST .1 FPS

PERIGEE ALT (TPI) -
 POST TPI ALTITUDE OF
 PERIGEE ABOVE
 LAUNCH PAD RADIUS.
 IN NAUTICAL MILES TO
 NEAREST .1NM.

#550

DELTA V (TPF)-
 REQUIRED IMPULSIVE
 DELTA V TO ACCOMPLISH
 INTERCEPT (TPF)
 MANEUVER AT CALCUL-
 ATED TIME OF INTER-
 CEPT. IN FPS TO
 NEAREST .1 FPS.

#560

 RECORD THESE VALUES

#570

 WAIT FOR KEYBOARD
 ENTRY
 TERMINATE FLASH UPON
 RECEIPT OF PROCEED

 KEY IN PROCEED
 V33E

#580

 FLASH VERB-NOUN
 TO REQUEST RESPONSE
 AND DISPLAY TTI:
 V06 N35
 R1-TTI - HRS
 R2-TTI - MINS
 R3-TTI - SECS

 MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF TTI.

#590

TTI - TIME TO GO
 TO TIG(TPI). IN
 HRS,MINS,SECS, TO
 NEAREST .01 SEC.

 SET LEB CLOCK (AND
 MDC CLOCK IF
 DESIRED) TO TTI

#600

#610

KEY IN PROCEED
V 33 E

#620

HAS THE FINAL
COMPUTATION
CYCLE BEEN SELECTED?

#630

#640

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF TOTAL MARKS AND
TIME TO TIG(TPI)

#650

IS TTI LESS THAN
7 MIN?

#660

IS A GROUND STA-
TION AVAILABLE

68

4 5576

(NOTE: R3 WILL BE
BLANK UNTIL
THE THRUSTING
DECISION IS MADE.
THEREAFTER MGA WILL
APPEAR IN R3)

FOR CONFIRMATION
OF ALL THE PARA-
METERS WHICH ARE
ON DOWN LINK?

.Y .N

MONITOR CMC
DOWNLINK
TELEMETRY OF
MANEUVER DATA
COORDINATE
EVALUATION OF
CMC COMPUTED
PARAMETERS
WITH ASTRO-
NAUT

COORDINATE
EVALUATION
OF THE CMC
COMPUTATION
PARAMETERS
WITH THE
GROUND

#670

AM I SATISFIED
WITH THE DISPLAYED
MANEUVER PARA-
METERS (I.E. HAVE
I COMPLETED MAN-
IPULATION OF THE
INPUT PARAMETERS?)

.N .Y

#690

IS TTI LESS
THAN 9 MIN?

.Y N

#700

WAIT FOR KEYBOARD
ENTRY

TIG(TPI) MUST
BE SLIPPED.
RESELECT P34
AND ADJUST IN-
PUT PARAMETERS
KEY IN
V37E34E

EXIT P34

#710

#720

RESELECT P34
AND READJUST
INPUT PARAMETERS
KEY IN
V37E34E

EXIT P34

#730

IS ITI LESS THAN
8 MIN?

.N
.Y

#740

IS THE RENDEZVOUS
NAVIGATION PROGRAM
(P20) IN PROCESS?

.Y
.N

#750

SHALL I
ATTEMPT TO
MAKE ADDIT-
IONAL OPTICS
MARKS AT THIS
TIME?

.Y
.N

#760

KEY IN V--E

DO I WISH
TO INCORPO-
RATE THE
PRESENT
STATE VEC-
TORS INTO

#770

//b

THE MANEU-
VER COMPU-
TATION AND
TERMINATE
FURTHER UP-
DATES?
I.E. SELECT
THE FINAL
COMPUTATION
AND DISPLAY
CYCLE?

.N Y.

#780

KEY IN
RECYCLE
V32E

#790

TERMINATE FLASH UPON
RECEIPT OF NEW PRO-
GRAM, RECYCLE, PRO-
CEED OR V--E

SELECT THE
FINAL COMPU-
TATION AND DIS-
PLAY CYCLE.
KEY IN PROCEED
V33E

#800

.R .P .V .N
.E .R .- .E
.C .O .- .W
.Y .C .E
.C .E .P
.L .E .R
.E .D .O
. .G

.GO TO
.PRO-
.GRAM
.SELEC-
.TED

#810

EXIT
P34

#820

SET FINAL
COMPUTA-
TION FLAG

#830

112
43474
RESET UP-
DATE FLAG
(SEE P20)

DO RENDEZVOUS
TRACKING
DATA PROCESS-
ING ROUTINE
(R22)

DO RENDEZVOUS
TRACKING DATA
PROCESSING
ROUTINE (R22)
(NOTE: PERFORM
MARKS PREFER-
ABLY FOR NOT
LONGER THAN 2
MINUTES BUT IN
NO CASE LATER
THAN TTI EQUAL
TO 8 MIN.)

#840

#850

#860

DO IMU STATUS CHECK
ROUTINE (R02)

DO IMU STATUS CHECK
ROUTINE (R02)

#870

HOLD
FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY TOTAL NUMBER
OF MARKS, TTI, AND
V06 N--
R1-N
R2-TTI
R3-MGA

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
TOTAL NUMBER OF
MARKS, TTI, AND MGA.

#880

N-NUMBER OF MARKS
MADE SINCE LAST
THRUSTING MANEUVER
OR INITIATION OF P20

TTI-TIME TO GO TO
TIG(TPI). IN MIN AND
SEC TO NEAREST SEC.
MAX READING IS
59 59

MGA-MIDDLE GIMBAL
ANGLE AT TIG(TPI)
IF +X CSM AXIS IS
ALIGNED WITH
IMPULSIVE THRUST
DIRECTION. IN
DEGREES TO NEAREST
.01 DEGREE.

RECORD N
AND MGA

#890

WAIT FOR KEYBOARD
ENTRY

KEY IN
PROCEED

#900

TERMINATE FLASH UPON
RECEIPT OF PROCEED

#910

SET RENDEZVOUS IN-
TERCEPT FLAG FOR USE
BY THRUSTING PROGRAM

#920

FLASH VERB-NOUN TO
REQUEST PLEASE PER-
FORM SELECTION OF
NEW PROGRAM:
V50N07
R1-BLANK
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM SELE-
CTION OF NEW PROGRAM

#930

·
·
·
·

GO TO PROGRAM
SELECTED

·
·
·
·
·
·
·
·
·
·
EXIT P34

·
·
·
·
·

GO TO PROGRAM
SELECTED

·
·
·
·
·
·
·
·
·
·
EXIT P34

#990

116 END OF RUN

4 3872

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

TRANSFER PHASE (MIDCOURSE) PROGRAM (P35)

REV 13

10/31/66

PURPOSE:

- (1) TO CALCULATE THE REQUIRED DELTA V AND OTHER INITIAL CONDITIONS REQUIRED BY THE CMC FOR CSM EXECUTION OF THE NEXT POSSIBLE MIDCOURSE CORRECTION OF THE TRANSFER PHASE OF AN ACTIVE CSM RENDEZVOUS.
- (2) TO COMPUTE AND DISPLAY SUITABLE INFORMATION TO ENABLE THE CREW TO ENTER THE FINAL RENDEZVOUS PHASE (P36) AT THE CORRECT TIME TO COMPLETE THE REQUIRED THRUSTING MANEUVER AT THE FIRST RANGE GATE.
- (3) TO GOVERN THE USE OF THE SXT TO OBTAIN RENDEZVOUS NAVIGATION DATA DURING THIS PROGRAM.
- (4) THIS PROGRAM IS DESIGNED FOR ONE-MAN OPERATION.

ASSUMPTIONS:

- (1) THE ISS IS ON AND PRECISELY ALIGNED.
- (2) STATE VECTOR UPDATES BY P27 ARE DISALLOWED DURING STATE VECTOR UPDATING INITIATED BY P20 (SEE ASSUMPTION (3)).
- (3) THIS PROGRAM MAY BE PERFORMED CONCURRENTLY WITH THE RENDEZVOUS NAVIGATION PROGRAM (P20) TO UPDATE THE LM OR CSM STATE VECTORS WITH OPTICAL TRACKING OF THE LM. THIS PROGRAM MAY ALSO BE PERFORMED INDEPENDENTLY OF P20. IF OPTICAL TRACKING IS DESIRED THE OPTICS SHOULD BE LOCKED ON THE LM BY PREVIOUS SELECTION OF P20. THE RENDEZVOUS TRACKING MARK COUNTER IS ZEROED BY THE SELECTION OF P20 AND AFTER EACH THRUSTING MANEUVER.
IF P20 IS IN EFFECT, OPTICAL TRACKING MARKS MAY BE MADE BY SELECTION OF THE RENDEZVOUS TRACKING DATA PROCESSING ROUTINE (R22). R22 IS SELECTED BY V--E WHICH MAY BE ENTERED WHENEVER THE CMC IS HOLDING FOR A V/N FLASHING DATA DISPLAY (NOTE: FOR SIMPLICITY IT IS ONLY SHOWN BELOW AT THE VO6N-- DISPLAY.). R22 RETURNS TO THIS PROGRAM AT THE INTERRUPTED DISPLAY.
- (4) THE OPERATION OF THIS PROGRAM UTILIZES THE FOLLOWING FLAGS?
ACTIVE VEHICLE FLAG - DESIGNATES THE VEHICLE WHICH IS DOING RENDEZVOUS THRUSTING MANEUVERS TO THE PROGRAM WHICH CALCULATES THE MANEUVER PARAMETERS. SET AT THE START OF EACH RENDEZVOUS PRE-THRUSTING PROGRAM.
RENDEZVOUS INTERCEPT STEERING FLAG - DESIGNATES THE TYPE OF STEERING REQUIRED FOR EXECUTION OF THIS MANEUVER BY THE THRUSTING PROGRAM SELECTED AFTER COMPLETION OF THIS PROGRAM.
- (5) IN THE LOGIC BELOW ASSOCIATED WITH THE FINAL ACCEPTANCE OF THE CMC COMPUTED PARAMETERS, THE FOLLOWING PERFORMANCE TIMES ARE ASSUMED:
 - (A) MANEUVER PARAMETER DISPLAY AND CREW EVALUATION - 1 MIN
 - (B) PROPULSION SYSTEM AND THRUSTING PROGRAM IDENTIFICATION - 1 MIN
 - (C) THRUSTING PROGRAM SELECTION AND COUNT DOWN TO TIG(MID) - 5 MIN (ASSUMES IMU ALIGNMENT IS SATISFACTORY)
 - (D) NO MIDCOURSE MANEUVERS WILL BE PERFORMED WITHIN 20 MINUTES OF THE CALCULATED TIME OF INTERCEPT.
- (6) THE PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY PRIOR TO ANY ANTICIPATED RENDEZVOUS MIDCOURSE CORRECTION.

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
			.CREW .PROG .SELECTION . . .			#10
			----- KEY IN TRANSFER PHASE (MIDCOURSE) PROGRAM (P35) V37E 35E -----			#20
			----- DO PROGRAM SELECTION CHECK ROUTINE (R01) -----			
			----- DO PROGRAM SELECTION CHECK ROUTINE (R01) -----			
			----- MONITOR DSKY: OBSERVE DISPLAY OF PROGRAM 35 -----			#30
			----- START TRANSFER PHASE (MIDCOURSE) PROGRAM (P35). DISPLAY PROGRAM 35. -----			
			----- SET ACTIVE VEHICLE FLAG TO CSM -----			#40
			----- SET TRACK FLAG (SEE P20) -----			
			----- SET UPDATE FLAG (SEE P20) -----			#50

#60

```

-----
DEFINE THE TIME OF
ARRIVAL AT INTERCEPT
AS TIG(TPI) PLUS
DELTA T TRANS
-----

```

#70

```

-----
FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY TT INT:
V06 N35
R1-TT INT - HRS
R2-TT INT - MINS
R3-TT INT - SECS
-----

```

```

-----
MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF TT INT.
-----

```

#80

```

-----
TT INT - TIME TO GO
TO INTERCEPT. IN
HRS, MINS, SECS, TO
NEAREST .01 SEC.
-----

```

```

-----
SET LEB CLOCK (AND
MDC CLOCK IF
DESIRED) TO TT INT
-----

```

#90

```

-----
WAIT FOR KEYBOARD
ENTRY
TERMINATE FLASH UPON
RECEIPT OF PROCEED
-----

```

```

-----
KEY IN PROCEED
V33E
-----

```

#100

120

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
HOLD DISPLAY TOTAL MARKS
SINCE THE LAST BURN
AND THE TT INT:

V06 N--
R1 - N
R2 - TT INT
R3 - BLANK

N=NUMBER OF MARKS
MADE SINCE LAST
THRUSTING MANEUVER
OR INITIATION OF P20

TT INT-TIME TO GO TO
INTERCEPT. IN
MIN AND SEC TO
NEAREST SECOND. MAX
READING IS 59 59.

(NOTE: R3 WILL BE
BLANK UNTIL
TRACKING IS
TERMINATED AND THE
LAMBERT PROBLEM IS
SOLVED. AT THAT TIME
MGA WILL APPEAR IN
(R3))

WAIT FOR KEYBOARD
ENTRY

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF TOTAL MARKS AND
TIME TO GO TO
INTERCEPT

IS TT INT GREATER
THAN 10 MIN.

.N .Y

KEY IN
REQUEST
FOR
TRANSFER
PHASE,
FINAL
(TPF)
PROGRAM
(P36)
V37E 36E

GO TO
PROGRAM
SELECTED

#110

#120

#130

#140

#150

#160

EXIT P35

IS THE RENDEZVOUS
NAVIGATION PROGRAM
(P20) IN PROCESS?

#170

.Y .N

SHALL I ATTEMPT
TO MAKE
ADDITIONAL OPTICS
MARKS AT THIS
TIME?

#180

.Y .N

KEY IN
V--E

#190

TERMINATE FLASH UPON
RECEIPT OF NEW
PROGRAM. PROCEED
OR V--E

KEY IN PROCEED
V33E

#200

.P .N .V
.R .E .-
.O .W .-
.C . .E
.E .P
.E .R DO RENDEZ-
.D .O VOUS TRACK-
.G ING DATA
. . PROCESSING
. . ROUTINE (R22)

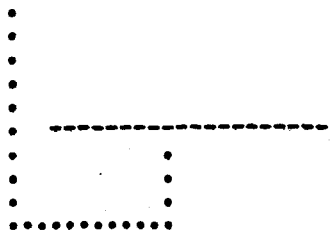
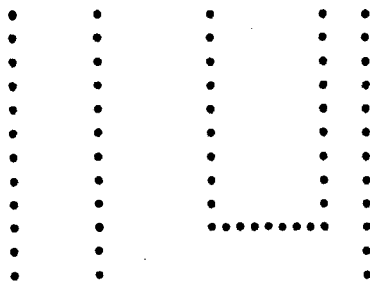
DO RENDEZVOUS
TRACKING DATA
PROCESSING ROUTINE
(R22)

#210

(NOTE: PERFORM MARKS
PREFERABLY FOR NOT
LONGER THAN 2 MIN-
UTES BUT IN NO CASE
LATER THAN TT INT TO
EQUAL TO 17 MIN. IF
A MIDCOURSE CORREC-
TION BURN IS CONTEM-
PLATED)

122

4 0069



 GO TO PROGRAM
 SELECTED

·
 ·
 ···
 ·
 EXIT P35

 TERMINATE UPDATE
 FLAG (SEE P20)

·
 ·

 SET TIG(MID) =
 T + 7 MIN

·
 ·

 EXTRAPOLATE CSM AND
 LM ORBITS TO
 TIG(MID)

·
 ·

 DO LAMBERT ROUTINE
 TO CALCULATE RE-
 QUIRED VELOCITY FOR
 MIDCOURSE CORRECTION

·
 ·

 CALCULATE THRUST
 INITIAL CONDITION
 PARAMETERS

#220

#230

#240

#250

#260

#270

124

4-3000

HOLD

FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY CALCULATED
 TERMINAL PHASE
 PARAMETERS:
 V06 N--
 R1-DELTA V (MID)
 R2-TTI
 R3-DELTA V (TPF)

DELTA V (MID) -
 REQUIRED IMPULSIVE
 DELTA V TO ACCOMP-
 LISH NEXT MIDCOURSE
 MANEUVER AT TIG(MID).
 IN FPS TO NEAREST
 .1 FPS.

TTI - TIME TO GO TO
 TIG(MID). IN MIN AND
 SEC TO NEAREST
 SEC. MAX READING IS
 59 59.

DELTA V (TPF) -
 REQUIRED IMPULSIVE
 DELTA V TO ACCOMPLISH
 INTERCEPT (TPF)
 MANEUVER AT CALCUL-
 ATED TIME OF INTER-
 CEPT. IN FPS TO
 NEAREST .1 FPS.

WAIT FOR KEYBOARD
 ENTRY

MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF CALCULATED
 TERMINAL PHASE
 PARAMETERS

RECORD THESE VALUES

IS A MIDCOURSE COR-
 RECTION BURN REQUIR-
 ED? (MAIN CONSIDERA-
 TION IS MAGNITUDE OF
 DELTA V(MID))

.N .Y

KEY IN
 RECYCLE
 V32E

#330

#340

#350

#360

#370

#380

KEY IN PROCEED
V33E

#390

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR RECYCLE

P R
R E
O C
C Y
E C
E L
D E

#400

SET RENDEZVOUS
INTERCEPT FLAG FOR
USE BY THRUSTING
PROGRAM.

#410

.....
HOLD . FLASH VERB-NOUN TO
REQUEST PLEASE PER-
FORM SELECTION OF
NEW PROGRAM:
V50N07
R1-BLANK
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM SELE-
CTION OF NEW PROGRAM

#420

```

-----
IF TIME AND
LOCATION PER-
MIT ASSIST
ASTRONAUT IN
SELECTION OF
PROPULSION
SYSTEM
-----

```

```

-----
CONSIDERING VALUE
OF DELTA V, FUEL
AVAILABLE, THE
STATUS OF THE
PROPULSION HARD-
WARE, AND THE
POSSIBILITY OF
GIMBAL LOCK
SELECT A PROPUL-
SION SYSTEM TO
PERFORM THE MAN-
EUVER COORDINATE
WITH GROUND IF
REQUIRED
-----

```

#430

#440

```

    .SPS  .RCS
      .
      .
      .

```

```

-----
KEY IN
REQUEST
FOR SPS
THRUSTING
PROGRAM
(P40)
V37E40E
-----

```

#450

```

-----
GO TO
PROGRAM
SELECTED
-----

```

#460

EXIT P35.

#470

```

-----
TERMINATE FLASH UPON
RECEIPT OF REQUEST
FOR NEW PROGRAM
-----

```

```

-----
KEY IN REQUEST
FOR RCS THRUST-
ING PROGRAM
(P41)
V37E41E
-----

```

#480

•
•
•
•
•

GO TO PROGRAM
SELECTED

•
•
•

EXIT P35

•
•
•
•

GO TO PROGRAM
SELECTED

•
•
•

EXIT P35

128 END OF RUN

4 5966

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

TRANSFER PHASE, FINAL (TPF) PROGRAM (P36)

REV 12

10/31/66

PURPOSE:

- (1) TO DISPLAY FINAL RENDEZVOUS PHASE PARAMETERS TO THE CREW.
- (2) TO MEASURE ANY DELTA V APPLIED TO THE CSM DURING FINAL PHASE MANEUVERS.
- (3) THIS PROGRAM IS DESIGNED FOR ONE-MAN OPERATION.

ASSUMPTIONS:

- (1) THE ISS IS ON AND IS PRECISELY ALIGNED.
- (2) STATE VECTOR UPDATES BY P27 ARE DISALLOWED DURING THIS PROGRAM (AVERAGE G IS IN PROCESS).
- (3) THIS PROGRAM MAY BE PERFORMED CONCURRENTLY WITH THE RENDEZVOUS NAVIGATION PROGRAM (P20) OR INDEPENDENTLY OF P20. HOWEVER IF P20 OPERATION IS DESIRED STATE VECTOR UPDATING IS INHIBITED AS AVERAGE G IS IN PROCESS. IF OPTICAL TRACKING IS DESIRED THE OPTICS SHOULD BE LOCKED ON THE LM BY PREVIOUS SELECTION OF P20. THE RENDEZVOUS TRACKING MARK COUNTER IS ZEROED BY THE SELECTION OF P20 AND AFTER EACH THRUSTING MANEUVER.
- (4) ALL THRUSTING MANEUVERS DURING THIS PHASE WILL BE MANUALLY ORIGINATED AND CONTROLLED BY THE CREW. IF THE CREW DESIRED TO DO ANY FINAL PHASE THRUSTING MANEUVERS AUTOMATICALLY UNDER GNCS CONTROL THEY MUST BE ACCOMPLISHED VIA SELECTION OF TRANSFER PHASE INITIATION (TPI) PROGRAM (P34) AND THEN THE DESIRED THRUSTING PROGRAM (40 OR 41).
- (5) THE PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY AFTER THE LAST MIDCOURSE CORRECTION.

PROG
CONT

CMC

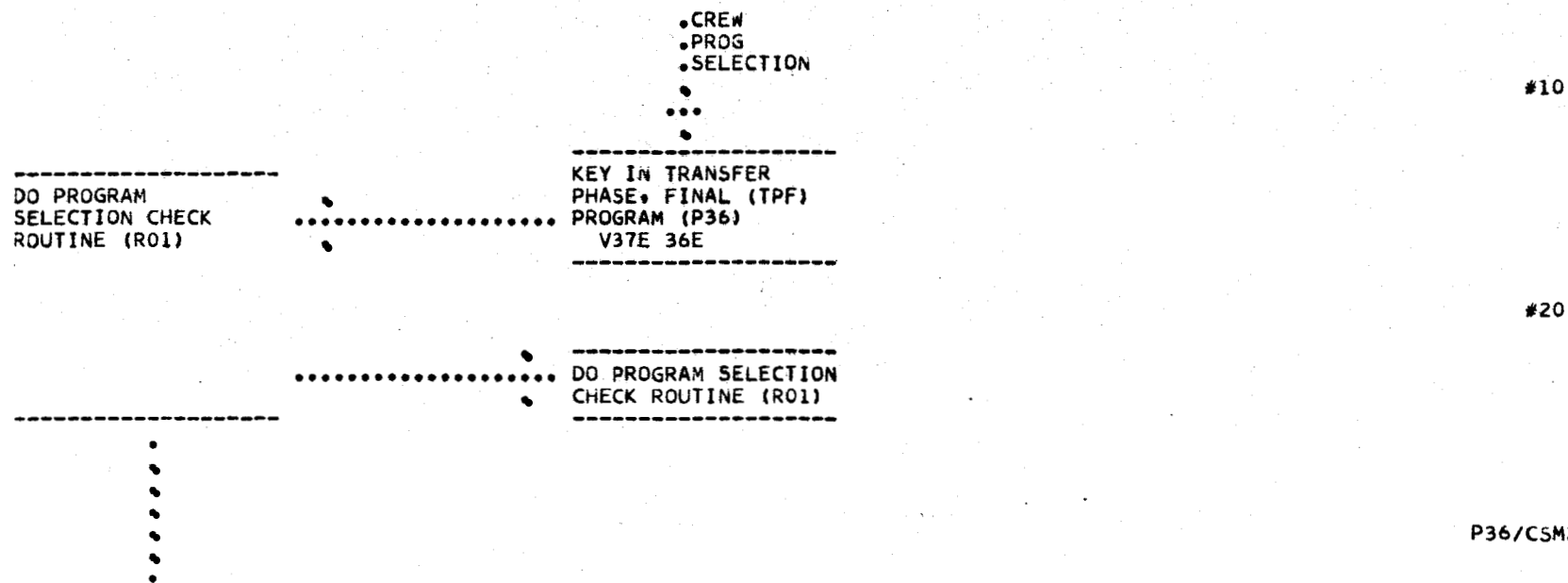
GROUND

CREW

CHECKLIST

TIME

TOTAL
TIME



START TRANSFER PHASE,
 FINAL (TPF) PROGRAM
 (P36).
 DISPLAY PROGRAM 36.

MONITOR DSKY:
 OBSERVE DISPLAY OF
 PROGRAM 36

#30

SET TRACK FLAG (SEE
 P20)

#40

RESET UPDATE FLAG
 (SEE P20)

#50

CALL AVERAGE G
 COMPUTATION

#60

HOLD.
 FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY RENDEZVOUS
 PARAMETERS:
 V06 N--
 R1-RANGE
 R2-RANGE RATE
 R3-THETA

MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF RENDEZVOUS
 PARAMETERS

#70

RANGE-CALCULATED
 RANGE TO LM. IN
 NAUTICAL MILES TO
 NEAREST .01 NM.

RANGE RATE-
CALCULATED RANGE
RATE BETWEEN CSM AND
LM. NEGATIVE SIGN
INDICATES CLOSING.
IN FPS TO NEAREST
.1 FPS

#80

THETA-ANGLE BETWEEN
CSM +X AXIS AND THE
LOCAL HORIZONTAL
PLANE AT THE PRESENT
TIME. PLUS SIGN
INDICATES +X AXIS
ABOVE PLANE. IN
DEGREES TO NEAREST
.01 DEGREE

#90

USING FINAL PHASE
RENDEZVOUS CHARTS
COMPLETE THE FINAL
PHASE THRUSTING
MANEUVERS MANUALLY.

#100

IF P20 IS IN EFFECT
AND THE AUTO MODE IS
RETAINED THE CMC
WILL CONTINUE TO
KEEP THE OPTICS
POINTED AT THE LM.
AS A RESULT OF THIS
AUTOMATIC PROCESS
THE CSM TRACKING
AXIS (15 DEG FROM Z
TOWARD X IN XZ
PLANE) WILL
ALWAYS REMAIN WITHIN
+/- -- DEGREES OF
THE LOS TO THE LM.

#110

NORMALLY THRUSTING
MANEUVERS WILL BE
MADE WITH THE +X
AXIS POINTED AT THE
LM. THESE MANUEVERS
CAN BE MADE IN
ANY MODE. IF P20
CONTROL OF THE
OPTICS LOS TO THE

#120

WAIT FOR KEYBOARD
ENTRY

LM IS DESIRED THE
AUTO MODE SHOULD
BE RESTORED
IMMEDIATELY UPON
COMPLETION OF
THE MANEUVER.

#130

DO I WISH THE DISPL-
AY UPDATE FOR A
LATER TIME?

#140

.Y .N

KEY IN RECYCLE
V32E

#150

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR RECYCLE

WHEN ALL RENDEZ-
VOUS AND DOCKING
(OR STATION-KEEP-
ING) THRUSTING MA-
NEUVERS ARE COMP-
LETE KEY IN
PROCEED
V33E

#160

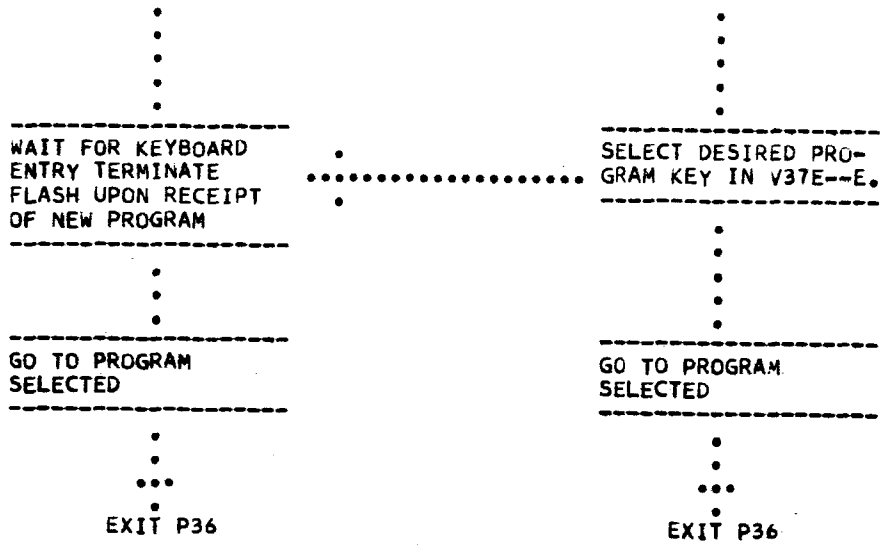
.R . P
.E . R
.C . O
.Y . C
.C . E
.L . E
.....E . D

.....
HOLD
FLASH VERB-NOUN
TO REQUEST PLEASE
PERFORM SELECTION OF
CMC IDLING PROGRAM
(POO):
V50N07
R1-00000
R2-BLANK
R3-BLANK

.....
MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM SELE-
CTION OF CMC IDLING
PROGRAM (POO)

#170

#180



#190

END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

SPS PROGRAM (P40)

REV 15

10/31/66

PURPOSE:

- (1) TO COMPUTE A PREFERRED IMU ORIENTATION AND A PREFERRED VEHICLE ATTITUDE FOR A SPS THRUSTING MANEUVER.
- (2) TO CALCULATE AND DISPLAY THE GIMBAL ANGLES WHICH WOULD RESULT FROM THE PRESENT IMU ORIENTATION IF THE VEHICLE IS MANEUVERED TO THE PREFERRED VEHICLE ATTITUDE FOR A SPS THRUSTING MANEUVER. THE CREW IS THEREBY GIVEN AN OPPORTUNITY TO PERFORM THE MANEUVER WITH:
 - (A) THE PRESENT IMU ORIENTATION, IF THE MIDDLE GIMBAL ANGLE IS NOT GREATER THAN 45 DEGREES, AND THE IMU HAS BEEN ALIGNED WITHIN THE LAST --HRS.
 - (B) THE NOMINAL IMU ORIENTATION (BY SELECTION OF P53 OR P52.)
 - (C) THE PREFERRED IMU ORIENTATION (BY SELECTION OF P53 OR P52.)
- (3) TO DO THE VEHICLE MANEUVER TO THE THRUSTING ATTITUDE. (THE VEHICLE MANEUVER IS DONE CONCURRENTLY WITH IMU REALIGNMENT IF P53 IS USED.)
- (4) TO CONTROL THE GNCS DURING COUNTDOWN, IGNITION, THRUSTING, AND THRUST TERMINATION OF A GNCS CONTROLLED SPS MANEUVER.

ASSUMPTIONS:

- (1) THE TARGET PARAMETERS HAVE BEEN CALCULATED AND STORED IN THE CMC BY PRIOR EXECUTION OF A PRE-THRUSTING PROGRAM.
- (2) THE REQUIRED STEERING EQUATIONS ARE IDENTIFIED BY THE PRIOR PRE-THRUST PROGRAM, WHICH SET EITHER THE LAMBERT OR EXTERNAL DELTA V STEERING FLAG.
- (3) IT IS NORMALLY REQUIRED THAT THE ISS BE ON FOR ONE HOUR PRIOR TO A THRUSTING MANEUVER.
- (4) THE TTE CLOCK IS SET TO COUNT TO ZERO AT TIG.
- (5) THE GNCS START-UP PROGRAM (P05) AND THE IMU ORIENTATION DETERMINATION PROGRAM (P51) HAVE BEEN COMPLETED BEFORE SELECTION OF THIS PROGRAM.
- (6) ENGINE IGNITION MAY BE SLIPPED BEYOND THE ESTABLISHED TIG IF DESIRED BY THE CREW.
- (7) IN EVENT CONTROL IS TAKEN AWAY FROM THE GNCS, THE CMC WILL ONLY BE RESPONSIBLE FOR COMPUTATION OF POSITION AND VELOCITY.
- (8) THIS PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY AT LEAST 5 MIN. BEFORE THE ESTIMATED TIME OF IGNITION.
- (9) THE DOCKED CONFIGURATION OF THE VEHICLE(S) HAS BEEN MADE KNOWN TO THE CMC BY THE APPLICABLE DISCRETE:
 - (A) CM ALONE -- BY CM/SM SEP DISCRETE
 - (B) CSM -- BY NO CM/SM SEP DISCRETE OR LM DOCKED DISCRETE (BACKED UP BY V--)
 - (C) LM/CSM -- BY LM DOCKED DISCRETE. (BACKED UP BY V--)

10004

PROG
CONT

CMC

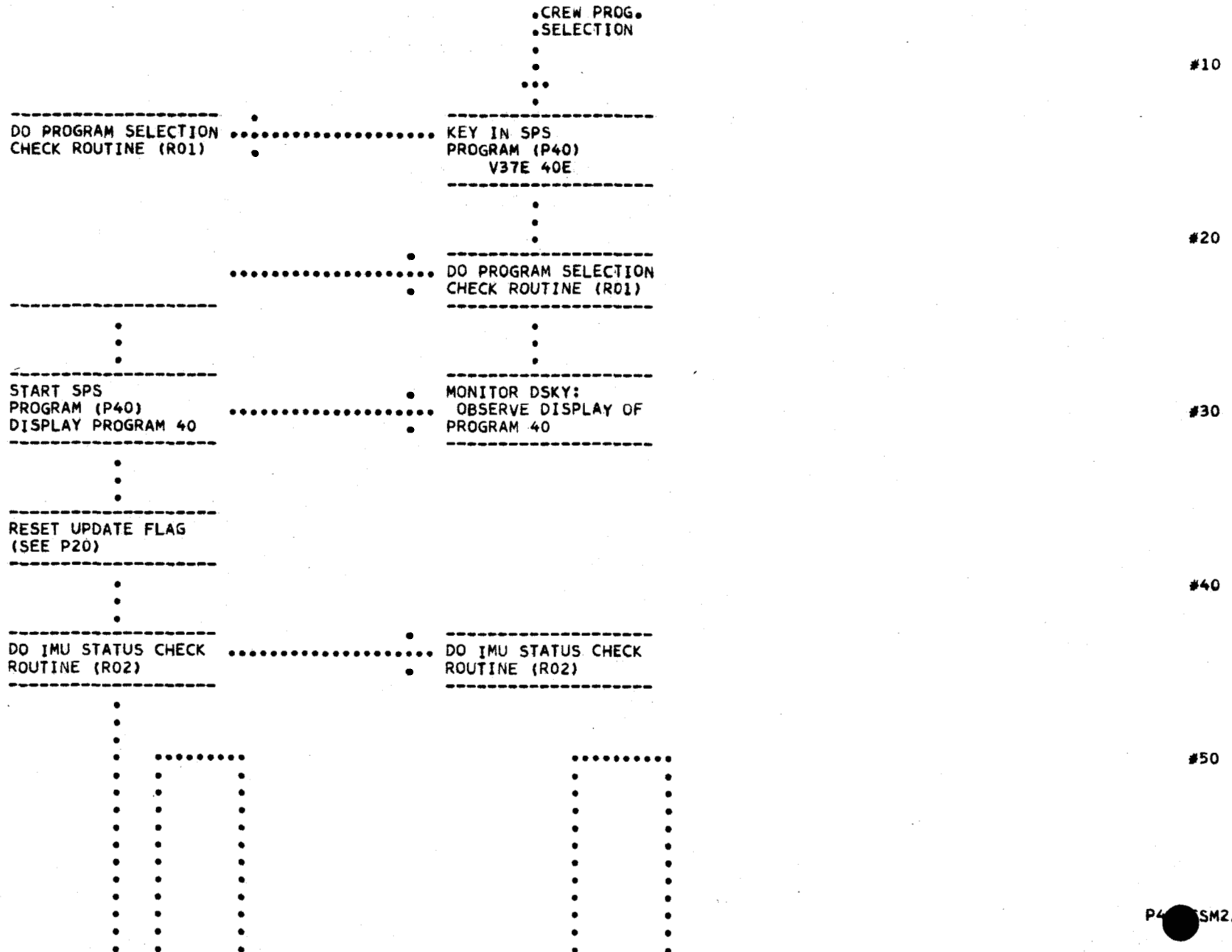
GROUND

CREW

CHECKLIST

TIME

TOTAL
TIME



HOLD

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY STORED
MASS PARAMETERS:
V06 N--
R1-IX
R2-IY/IZ
R3-W

IX - MOMENT OF
INERTIA ABOUT CSM X
AXIS. IN SLUG-FT.SQ.
TO NEAREST 100
SLUG-FT.SQ.

IY/IZ - AVERAGE OF
MOMENTS OF INERTIA
ABOUT CSM Y AND Z
AXES. IN SLUG-FT.SQ.
TO NEAREST 100 SLUG-
FT.SQ.

W - TOTAL WEIGHT.
IN LBS. TO NEAREST
LB.

WAIT FOR KEYBOARD
ENTRY

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW DATA

.P .NEW
.R .DATA
.O .
.C .
.E .
.E .
.D .
STORE DATA

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF STORED PARAMETERS

AM I SATISFIED WITH
THESE VALUES?

.Y .N

KEY IN PROCEED
V33E

KEY IN V25 AND LOAD
THE DESIRED PARA-
METERS

#60

#70

#80

#90

#100

IS RENDEZVOUS
INTERCEPT STEERING
FLAG SET?

#110

Y N

SET C=1 IN
STEER LAW

#120

SET C=0 IN
STEER LAW

#130

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY STORED
MASS/PROPULSION
PARAMETERS:

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF STORED PARAMETERS

#140

V06 N70
R1-PITCH TRIM
R2-YAW TRIM
R3-TLX

PITCH TRIM AND YAW
TRIM-SPS ENGINE BELL
TRIM ANGLES AT
IGNITION FROM DATA
TAKEN FROM FUEL
LOADING CHARTS AND
VEHICLE FUEL GAUGES.
IN DEGREES TO
NEAREST .01 DEGREE.

AM I SATISFIED WITH
THESE VALUES?

#150

Y N

TLX-SPS THRUST TIMES
CG TO HINGE POINT
DISTANCE AT TIG IN
FT. LBS. TO NEAREST
100 FT. LBS.

#160

1000 4 3001

HOLD

 WAIT FOR KEYBOARD
 ENTRY

 KEY IN PROCEED
 V 33 E

 TERMINATE FLASH UPON
 RECEIPT OF PROCEED
 OR NEW DATA

 KEY IN V25 AND
 LOAD THE DESIRED
 PARAMETERS

 P. NEW DATA
 R. DATA
 O.
 C.
 E. STORE DATA
 E.
 D.

 COMPUTE INITIAL
 THRUST DIRECTION AND
 INITIAL VALUE OF VG
 VECTOR

 FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY INITIAL VG
 VECTOR COMPONENTS:
 V06 N--
 R1-VGX(LV)
 R2-VGY(LV)
 R3-VGZ(LV)

 MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF VG COMPONENTS

VGX(LV)-COMPONENT OF
 VG AT TIG ALONG
 (RXV)XR. IN FPS TO
 NEAREST .1 FPS.

VGY(LV)-COMPONENT OF
 VG AT TIG ALONG VXR.
 IN FPS TO NEAREST

.1 FPS.
 VGZ(LV)-COMPONENT OF
 VG AT TIG ALONG -R.
 IN FPS TO NEAREST
 .1 FPS.

 RECORD FOR POSSIBLE
 FUTURE TRANSMISSION
 TO LM OR GROUND

#170

#180

#190

#200

#210

.....
 HOLD

140

4 0650

WHERE R IS GEOCENTRIC RADIUS VECTOR AND V IS VEHICLE INERTIAL VELOCITY VECTOR AT TIG.

#220

WAIT FOR KEYBOARD ENTRY

KEY IN PROCEED V33E

#230

TERMINATE FLASH UPON RECEIPT OF PROCEED

FROM INITIAL THRUST DIRECTION AND ENGINE BELL TRIM ANGLES COMPUTE PREFERRED IMU ORIENTATION:

#240

X = UNIT (X)
-SM -CSM

Y = UNIT (X X R)
-SM -CSM -

#250

Z =UNIT (X X Y)
-SM -SM -SM

WHERE:
X = THE CSM X AXIS
-CSM AT IGNITION
(AT THE PREFERRED VEHICLE ATTITUDE)

#260

R = THE GEOCENTRIC RADIUS VECTOR AT TIG.

STORE FOR USE BY SUBSEQUENT COMPUTATIONS.

#270

.....

 COMPUTE GIMBAL
 ANGLES AT THE
 PREFERRED VEHICLE
 ATTITUDE IF THE
 PRESENT IMU
 ORIENTATION IS HELD.
 THE PREFERRED VEHI-
 CLE ATTITUDE IS DE-
 FINED AS FOLLOWS:

#280

ENGINE THRUST AXIS
 IN DIRECTION OF
 INITIAL THRUST
 VECTOR

Y = UNIT (X X R)
 -CSM -CSM -

#290

THIS IS A WINGS
 LEVEL, HEADS UP
 ATTITUDE AS SEEN
 FROM THE COUCH
 LOOKING OUT ALONG
 THE +X AXIS

#300

.....

 SET PREFERRED
 ORIENTATION FLAG

#310

.....

 FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY THE GIMBAL
 ANGLES THAT WILL
 EXIST AT THE PRE-
 FERRED VEHICLE
 ATTITUDE IF THE PRE-
 SENT IMU ORIENTATION
 IS HELD:

HOLD

V06 N17
 R1-OG ROLL
 R2-IG PITCH
 R3-MG YAW

.....

 MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF GIMBAL ANGLES AT
 THE PREFERRED
 VEHICLE ATTITUDE

#320

.....

ADVISE CREW
WITHIN
GROUND
CAPABILITY

.....
DO I WISH TO MAKE
THE THRUSTING
MANEUVER WITH THE
PRESENT IMU ORIENTA-
TION?
CONSIDER:

#380

(A) THE TIME SINCE
THE LAST FINE
ALIGNMENT OF THE
IMU.

(B) IS TIME
CRITICAL?

#390

(C) IS RCS FUEL
CRITICAL?

(D) DOES THE
GROUND CONCUR WITH
THE THRUSTING
MANEUVER AT THIS
ORIENTATION?

#400

N Y

.....
SELECT CSM/IMU
REALIGN PROGRAM
(P53) OR IMU REA-
LIGN PROGRAM
(P52). KEY IN
V37E 53E
(OR 52E)
WHEN P53 OR P52
IS COMPLETE
RESELECT P40

#410

.....
EXIT P40

#420

144

KEY IN PROCEED
V 33 E

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW PROGRAM

P. •NEW
R. •PROGRAM
O. -----
C. GO TO PROGRAM
E. SELECTED
E. -----
D. •
 •
 •••
 •
 EXIT P40
•
•
•
•
•
•
•
•

#430

#440

EXTRAPOLATE STATE
VECTOR TO TIG - 30
SEC

#450

STORE DESIRED ATTITUDE SPECIFICATION (TRIMMED ENGINE BELL CENTER LINE IN DIRECTION OF INITIAL THRUST) FOR USE BY ATTITUDE MANEUVER ROUTINE (R60). THE FINAL ATTITUDE WILL BE COMPUTED DURING R60, AND WILL POINT THE TRIMMED ENGINE BELL IN THE INITIAL THRUST DIRECTION. HOWEVER, IN ORDER TO CONSERVE RCS FUEL AND NOT CONSTRAIN THE NON- CRITICAL ROLL ATTITUDE, WINGS MAY NOT BE LEVEL IN THE COMPUTED FINAL ATTITUDE.

#460

#470

```

.....
-----
RESET TRACK FLAG
(SEE P20).
IF AN ATTITUDE
MANEUVER TO THE
PREFERRED RENDEZVOUS
TRACKING ATTITUDE IS
IN PROCESS, IT WILL
BE TERMINATED AT
THIS POINT.
-----

```

#480

```

.....
-----
SET .5 DEGREE
DEADBAND IN RCS DAP.
-----

```

#490

```

.....
-----
DO ATTITUDE MANEUVER
ROUTINE (R60)
-----

```

```

.....
-----
DO ATTITUDE MANEUVER
ROUTINE (R60)
-----

```

#500

```

.....
-----
HAS GNCS A/P AND
AUTO MODE BEEN SE-
LECTED?
-----

```

#510

```

.Y      .N
.....

```

```

POSS .....
HOLD  ..

```

```

-----
FLASH VERB-NOUN
TO REQUEST
PLEASE PERFORM
GNC A/P AND AUTO
MODE SELECTION:
V50 N25
R1-000--
R2-BLANK
R3-BLANK
-----

```

```

-----
MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM
GNCS A/P AND AUTO
MODE SELECTION
-----

```

#520

```

-----
HAVE REQUESTED MODES
BEEN SELECTED?
-----

```

#530

```

.N      .Y
.....

```

146

4-057

SET A/P CONTROL
SWITCH TO GNC
AND MODE SWITCH
TO AUTO

#540

WAIT FOR KEY-
BOARD ENTRY

KEY IN ENTER

#550

TERMINATE FLASH
UPON RECEIPT OF
PROCEED OR ENTER

KEY IN PROCEED
V33E

.P .ENTER
.R .
.O .
.C
.E
.E
.D

#560

.....
HOLD . FLASH VERB-NOUN TO
REQUEST PLEASE PER-
FORM ENGINE GIMBAL
DRIVE TEST ENABLE
V50 N25
R1-XXXXX
R2-BLANK
R3-BLANK

MONITOR DSKY
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM
ENGINE GIMBAL DRIVE
TEST ENABLE

#570

SHALL I ENABLE
GIMBAL DRIVE TEST?

#580

.N .Y

WAIT FOR KEYBOARD
ENTRY

KEY IN PROCEED
V33E

#590

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR ENTER

KEY IN ENTER

.P .ENTER
.R .
.O .
.C -----
.E PERFORM
.E GIMBAL DRIVE
.D TEST

MONITOR GIMBAL DRIVE
BY REFERENCE TO
ANALOG DIALS

#600

IS TIME TO GO TO
ENGINE IGNITION LESS
THAN 45 SECONDS?

.N .Y

#610

POSS
.....
HOLD

FLASH VERB-NOUN
TO REQUEST RES-
PONSE AND DIS-
PLAY ALARM CODE
TO INDICATE THAT
IGNITION TIME IS
LESS THAN 45
SECONDS AWAY:
V05 N31
R1-
R2-
R3-

MONITOR DSKY:
DOES VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF ALARM CODE INDI-
CATE THAT CHECKLIST
HAS NOT BEEN COM-
PLETED ON TIME?

#620

.Y .N

#630

REFER TO TTE
CLOCK AND
MANEUVER RULES.
SHALL I SLIP
ENGINE IGNITION
TO 45 SECONDS
FROM TIME I DE-
PRESS ENTER KEY
AT THE COMPLE-
TION OF A PRO-
CEED INSTRUC-
TION?

#640

.N .Y

148

A 3856

WAIT FOR KEY-
BOARD ENTRY

KEY IN
PROCEED
V33E

#650

TERMINATE FLASH
UPON RECEIPT OF
ENTER OR
TERMINATE

KEY IN TERMIN-
ATE
V34E

#660

.P .TERMINATE
.R .
.O .
.C .
.E .
.E .
.D .

#670

POSS
HOLD

FLASH VERB-
NOUN TO RE-
QUEST PLEASE
PERFORM SELEC-
TION OF CMC
IDLING PROGRAM
POO

MONITOR DSKY:
OBSERVE VERB-
NOUN FLASH TO
REQUEST PLEASE
PERFORM SELEC-
TION OF POO

#680

V50 N07
R1-00000
R2-BLANK
R3-BLANK

WAIT FOR KEY-
BOARD ENTRY

#690

TERMINATE
FLASH UPON
RECEIPT OF
REQUEST FOR
NEW PROGRAM

KEY IN REQUEST
FOR NEW PROGRAM
V37E --E

#700

GO TO PROGRAM
SELECTED

TERMINATE P40
AND GO TO
PROGRAM SELE-
CTED

.....
EXIT P40

.....
EXIT P40

#710

ESTABLISH NEW
TIG EQUAL TO
PRESENT TIME
PLUS 45 SECONDS

#720

EXTRAPOLATE
STATE VECTOR
TO TIG - 30 SEC

#730

DISPLAY ON DSKY:
V06 N51
R1 - TTI
R2 - VG
R3 - DELTA VM

MONITOR DSKY&
OBSERVE DISPLAY OF
TTI AND VG.

TTI - TIME TO GO TO
SPS IGNITION. IN
MIN, SEC TO NEAR-
EST SEC. MAX
READING IS 59 59.
SIGN IS + BEFORE
NOMINAL TIG, -
THEREAFTER

.....

UPDATE TTE CLOCK
IF DESIRED. CLOCK
WILL NOT AGREE WITH
DSKY R1 IF IGNITION
HAS BEEN SLIPPED

#740

VG - MAGNITUDE OF THE
VELOCITY TO BE
GAINED BY THRUSTING
MANEUVER. IN FPS
TO NEAREST .1 FPS

#750

4 855

DELTA VM-MEASURED
DELTA V MAGNITUDE
IN FPS TO NEAREST
.1 FPS. THIS DIS-
PLAY WILL BE 00000
UNTIL ULLAGE IS
STARTED.

#760

CALL AVERAGE G
INTEGRATION ON AT
TIG - 30 SEC

LOAD VG INTO
SCS DELTA V
REMAINING COUNTER

#770

CHECK STATUS OF C/W
LAMPS

#780

MONITOR DSKY:
AT TTI=30 SEC
OBSERVE DISPLAY OF
DELTA VM IN R3

#790

IN THE PERIOD FROM
TTI = 30 SEC UNTIL
TTI = 25 SEC
DOES DELTA VM BECOME
GREATER THAN .2 FPS
INDICATING EXCESSIVE
PIPA BIAS ERROR.

#800

.N .Y
GO TO BACKUP
PROCEDURES

UPON RECEIPT OF SPS
READY DISCRETE COM-
MAND 2 JET +X TRANS-
LATION

SPS READY
DISCRETE

AT TTI = -- SEC MOVE
MAIN PANEL NORMAL
/OFF/ DIRECT ON
SWITCH TO NORMAL
WHICH SIGNALS SPS
READY AND MONITOR
START OF +X TRANS-
LATION.

#810

MONITOR DSKY:
WAIT UNTIL DELTA VM
DISPLAYED IS GREATER
THAN OR EQUAL TO--
FPS INDICATING
SUFFICIENT ULLAGE.
REQUIRED ULLAGE
DELTA V IS A
FUNCTION OF VEHICLE
WEIGHT.

#820

AT TTI = 10 SEC
DRIVE SPS ENGINE
BELL TO TRIM PO-
SITION

OBSERVE DIAL INDICA-
TION OF ENGINE BELL
DRIVING TO TRIM
POSITION

#840

TEMP .
.....
HOLD .
AT TTI = 5 SEC
CHANGE VERB-NOUN BUT
RETAIN PRESENT DIS-
PLAYS IN R1, R2, R3,
FLASH VERB-NOUN TO
REQUEST PLEASE
PERFORM ENGINE ON
ENABLE:

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM
ENGINE ON ENABLE

#850

V50 N11
R1 - TTI
R2 - VG
R3 - DELTA VM

#860

15 2

4 3454

WAIT FOR KEYBOARD
ENTRY

SHALL I PERMIT
IGNITION?

.N .Y
.
.

#870

.....KEY IN ENTER

RESUME STATIC V06 N51
DISPLAY UPON RECEIPT
OF ENTER

KEY IN
TERMINATE
V34E

#880

.E .TERMINATE
.N .
.T .
.E .
.R .
.
.
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.
.

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.
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.
.
.

POSS .
.....
HOLD .

FLASH VERB-NOUN
TO REQUEST
PLEASE PERFORM
SELECTION OF CMC
IDLING PROGRAM
(P00):
V50 N07
R1-00000
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE VERB-
NOUN FLASH TO
REQUEST PLEASE
PERFORM SELEC-
TION OF P00

#890

.....

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.
.
.
.

#900

WAIT FOR KEY-
BOARD ENTRY

KEY IN REQUEST
FOR NEW
PROGRAM
V37E--E

#910

TERMINATE FLASH
UPON RECEIPT OF
REQUEST FOR NEW
PROGRAM

GO TO PROGRAM
SELECTED

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GO TO PROGRAM
SELECTED

EXIT P40

IS TTI GREATER THAN
ZERO

.Y .N

WAIT UNTIL
TTI=0

COMMAND SPS ON

SWITCH FROM RCS DAP
TO TVC DAP

WAIT UNTIL DELTA V
MONITOR DETECTS
SPS ON

EXIT P40

MONITOR DSKY:
IS R1 DISPLAY OF TTI
POSITIVE AND GREATER
THAN ZERO?

.Y .N

STANDBY FOR
THRUST ON
WHEN TTI = 0

STANDBY FOR
THRUST ON
IMMEDIATELY

HAS ENGINE IGNITED?

.Y .N

GO TO BACKUP
PROCEDURES

#920

#930

#940

#950

#960

#970

154

4 3853

.....

COMMAND +X ULLAGE
TRANSLATION OFF

.....

.....

MONITOR TERMINATION
OF +X TRANSLATION
AFTER ENGINE
IGNITION

#980

.....

CHANGE TTI DISPLAY
TO TG IN R1
V06 N51
R1 - TG
R2 - VG
R3 - DELTA VM

.....

.....

MONITOR DSKY:
OBSERVE CHANGE OF
TTI DISPLAY TO TG IN
R1

#990

TG - TIME TO GO TO
ENGINE CUTOFF.
IN MIN AND SEC TO
NEAREST SEC.

.....

#1000

.....

MONITOR SPS
THRUSTING:

1. DSKY:
R1-TG
SHOULD BE
DECREASING

#1010

R2-VG SHOULD BE
DECREASING

R3-DELTA VM
SHOULD INCREASE

2. FDAI-ATT. ERROR
SHOULD BE LESS THAN
OR EQUAL TO --DEGREE
ATT RATES SHOULD BE
LESS THAN OR EQUAL
TO -- DEGREE/SEC.

.....

#1020

3. SPS CHAMBER
PRESSURE (PC)
SHOULD BE NORMAL

#1030

N. .Y

MONITOR DSKY:
AS TG AND VG GO TO
ZERO THRUST SHOULD
CUTOFF

#1040

N. .Y

GO TO BACKUP
PROCEDURES

#1050

CMC COMMANDS ENGINE
OFF WHEN INDICATED
BY CUTOFF EQUATION

SWITCH FROM TVC DAP
TO RCS DAP

#1060

ZERO RENDEZVOUS
COUNTER

MOVE MAIN PANEL NOR-
MAL/OFF/DIRECT ON
SWITCH TO OFF.

#1070

4 3852

MAINTAIN VG
COMPUTATIONS AFTER
CUTOFF FOR POSSIBLE
NULLING BY RCS
TRIMMING MANEUVER

#1080

SET MAX DEADBAND
LIMITS IN DAP

#1090

HOLD

FLASH VERB-NOUN TO
REQUEST PROCEED.
HOLD DISPLAY OF TG
AT ITS VALUE AT
ENGINE CUTOFF.

V06 N51
R1 - TG
R2 - VG
R3 - DELTA VM

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PROCEED AND DISPLAY
OF TG, VG AND DELTA
VM.

#1100

WAIT FOR KEYBOARD
ENTRY

CONSIDERING MAGNI-
TUDE OF VG DO I WISH
TO MAKE A FINAL
TRIMMING THRUSTING
MANEUVER WITH THE
RCS?

#1110

KEY IN PROCEED
V33E

#1120

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW PROGRAM

P. .
R. .NEW
O. .PROGRAM
C. .
E. .
E. .
D. GO TO PRO-
GRAM SELECTED

. .
. .
. .
. .
EXIT P40

.....
KEY IN RE-
QUEST FOR
THRUSTING-RCS
PROGRAM (P41)
V37E 41E

. .
. .
EXIT P40

#1130

#1140

#1150

RESET STEER
LAW FLAG

TRANSMIT ORBITAL
DATA TO CREW

.....
RECEIVE ORBITAL DATA
FROM GROUND

#1160

DO ORBITAL PARAMETER
DISPLAY ROUTINE
(R30)

.....
DO ORBITAL PARAMETER
DISPLAY ROUTINE
(R30)

#1170

IS RENDEZVOUS FLAG
SET?

.N .Y
. .
. .
. .

IS RENDEZVOUS
NAVIGATION PROGRAM
(P20) IN PROCESS?

.Y .N
. .
. .
. .

SET TRACK FLAG
(SEE P20)

#1180

SET UPDATE FLAG
(SEE P20)

DISPLAY P20

EXIT P40

FLASH VERB-NOUN TO
REQUEST PLEASE
PERFORM SELECTION OF
CMC IDLING PROGRAM
(P00)
V50 N07
R1-00000
R2-BLANK
R3-BLANK

WAIT FOR KEYBOARD
ENTRY

TERMINATE FLASH UPON
RECEIPT OF REQUEST
FOR NEW PROGRAM

MONITOR DSKY:
OBSERVE DISPLAY
OF P20 UPON
COMPLETION OF
RENDEZVOUS BURN

EXIT P40

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM
SELECTION OF P00

KEY IN REQUEST FOR
NEW PROGRAM

GO TO PROGRAM
SELECTED.

EXIT P40

#1190

#1200

#1210

#1220

#1230

4 5851

•
•
•
•
•

GO TO PROGRAM
SELECTED

•
•
•••
•

EXIT P40

160
END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

RCS PROGRAM (P41)

REV 12

10/31/66

PURPOSE:

- (1) TO COMPUTE A PREFERRED IMU ORIENTATION AND A PREFERRED VEHICLE ATTITUDE FOR AN RCS THRUSTING MANEUVER.
- (2) TO CALCULATE AND DISPLAY THE GIMBAL ANGLES WHICH WOULD RESULT FROM THE PRESENT IMU ORIENTATION IF THE VEHICLE IS MANEUVERED TO THE PREFERRED VEHICLE ATTITUDE FOR AN RCS THRUSTING MANEUVER. THE CREW IS THEREBY GIVEN AN OPPORTUNITY TO PERFORM THE MANEUVER WITH:
 - (A) THE PRESENT IMU ORIENTATION (NOT RECOMMENDED IF MIDDLE GIMBAL ANGLE IS GREATER THAN 45 DEGREES). IF THE IMU HAS NOT BEEN ALIGNED WITHIN THE LAST --HRS, REALIGNMENT IS DESIRABLE.
 - (B) THE NOMINAL IMU ORIENTATION (BY SELECTION OF P53 OR P52)
 - (C) THE PREFERRED IMU ORIENTATION (BY SELECTION OF P53 OR P52)
- (3) TO DO THE VEHICLE MANEUVER TO THE THRUSTING ATTITUDE. (THE VEHICLE ATTITUDE MANEUVER IS DONE CONCURRENTLY WITH IMU REALIGNMENT IF P53 IS USED.)
- (4) TO CONTROL THE GNCS DURING COUNTDOWN, IGNITION, THRUSTING, AND THRUST TERMINATION OF A GNCS CONTROLLED RCS MANEUVER.
- (5) TO PROVIDE CAPABILITY FOR RAPID TRIMMING OF RESIDUAL STEERING ERRORS LEFT AT SPS CUTOFF.
- (6) TO PROVIDE SUITABLE DISPLAYS FOR MANUAL EXECUTION IN THE ATTITUDE HOLD MODE.

ASSUMPTIONS:

- (1) THE TARGET PARAMETERS HAVE BEEN CALCULATED AND STORED IN THE CMC BY PRIOR EXECUTION OF A PRE-THRUSTING PROGRAM.
- (2) THE REQUIRED STEERING EQUATIONS ARE IDENTIFIED BY THE PRIOR PRETHRUST PROGRAM, WHICH SET EITHER THE LAMBERT OR EXTERNAL DELTA V STEERING FLAG.
- (3) IT IS NORMALLY REQUIRED THAT THE ISS BE ON FOR ONE HOUR PRIOR TO A THRUSTING MANEUVER.
- (4) THE TTE CLOCK IS SET TO COUNT TO ZERO AT TIG.
- (5) THE GNCS START-UP PROGRAM (P05) AND THE IMU ORIENTATION DETERMINATION PROGRAM (P51) HAVE BEEN COMPLETED BEFORE SELECTION OF THIS PROGRAM.
- (6) ENGINE IGNITION MAY BE SLIPPED BEYOND THE ESTABLISHED TIG IF DESIRED BY THE CREW.
- (7) IN EVENT CONTROL IS TAKEN FROM THE GNCS THE CMC IS ONLY RESPONSIBLE FOR COMPUTATION OF POSITION AND VELOCITY.
- (8) THIS PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY AT LEAST 5 MIN. BEFORE THE ESTIMATED TIME OF IGNITION.
- (9) THE DOCKED CONFIGURATION OF THE VEHICLE(S) HAS BEEN MADE KNOWN TO THE CMC BY THE APPLICABLE DISCRETE:
 - (A) CM ALONE - BY CM/SM SEP DISCRETE
 - (B) CSM - BY NO CM/SM SEP DISCRETE OR LM DOCKED DISCRETE (BACKED UP BY V--)
 - (C) LM/CSM - BY LM DOCKED DISCRETE. (BACKED UP BY V--)

WAIT FOR KEYBOARD
ENTRY

KEY IN PROCEED
V33E

#110

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW DATA

KEY IN V25 AND LOAD
THE DESIRED PARA-
METERS

#120

.P .NEW
.R .DATA
.O
.C
.E
.E STORE DATA
.D

IS TRIM
FLAG SET?

#130

.Y .N

POSS
HOLD
FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY OPTION CODE
FOR ASSUMED TRANSLA-
TION AXIS:
V06N--
R1-000--
R2-0000X
R3-BLANK

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST RE-
SPONSE AND DISPLAY
OF OPTION CODE FOR
ASSUMED TRANSLATION
AXIS.

#140

R1 IS THE OPTION
CODE FOR ASSUMED
TRANSLATION AXIS.

#150

R2 IS THE CMC ASSUM-
ED OPTION:
00001 +X
00002 -X
00003 +Y
00004 -Y
00005 +Z
00006 -Z

#160

104

4 5048

WAIT FOR KEYBOARD
ENTRY

IS THE ASSUMED TRANS-
LATION AXIS CORRECT?

.Y .N

KEY IN PROCEED
V33E

#170

KEY IN V22
AND LOAD DESIRED
AXIS CODE IN R2.

#180

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW AXIS CODE

.P .NEW
.R .CODE
.O .
.C
.E STORE NEW
.E AXIS CODE
.D

#190

SET C=0 IN STEER LAW
AND COMPUTE INITIAL
THRUST DIRECTION AND
INITIAL VALUE OF VG
VECTOR

#200

166

4 5847

POSS
HOLD

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY COMPONENTS
OF VG VECTOR AT TIME
OF IGNITION RESOLVED
ALONG VEHICLE AXES:

- V06 N--
- R1- VGX(CSM)
- R2- VGY(CSM)
- R3- VGZ(CSM)

VGX(CSM), VGY(CSM),
VGZ(CSM)-THE COMPON-
ENTS OF VG VECTOR AT
TIG RESOLVED ALONG
PRESENT CSM X, Y, Z
AXES RESPECTIVELY.
IN FPS TO NEAREST .1
FPS.

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF VG COMPONENTS

#210

BY COMPARING VG
COMPONENTS ESTIMATE
APPROXIMATE THRUST
DIRECTION AND AMOUNT
OF ATTITUDE CHANGE
ASSOCIATED WITH
TRANSLATION ALONG
EACH CSM AXIS.

#220

SHALL I CHANGE AXIS
OPTION TO MINIMIZE
ATTITUDE MANEUVER?

- .N
- .Y

#230

#240

WAIT FOR KEYBOARD
ENTRY

KEY IN PROCEED
V33E

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR RECYCLE

KEY IN RECYCLE
V32E

#250

- .P
- .R
- .O
- .C
- .E
- .E
- .D

RECYCLE

#260

FROM STORED INITIAL
THRUST DIRECTION
COMPUTE THE PREFERR-
ED IMU ORIENTATION:

X = UNIT (T)
-SM -

Y = UNIT (T X R)
-SM - -

Z = UNIT (X X Y)
-SM -SM -SM

WHERE:

UNIT (T) = THE
INITIAL
THRUST
DIRECTION

R = THE GEOCENTRIC
- RADIUS VECTOR
AT TIG.

STORE FOR USE BY
SUBSEQUENT COMPUTA-
TIONS.

COMPUTE GIMBAL
ANGLES AT THE
PREFERRED VEHICLE
ATTITUDE IF THE
PRESENT IMU
ORIENTATION IS HELD.
THE PREFERRED
VEHICLE ATTITUDE IS
DEFINED AS FOLLOWS:

(1) AXIS CODE =
00001 OR 00002 =
(+ OR - X):

+ OR - X = UNIT (T)
-CSM -

+ OR - Y = UNIT (T X R)
-CSM - -

#270

#280

#290

#300

#310

THIS IS A WINGS
 LEVEL, HEADS UP
 ATTITUDE AS SEEN
 FROM THE COUCH LOOK-
 ING OUT ALONG THE +X
 AXIS.

(2) AXIS CODE =
 00003 OR 00004=
 (+ OR - Y):

+ OR - Y = UNIT (T)
 -CSM

- OR + Z = UNIT (T X R)
 -CSM

THIS IS A LOS LEVEL,
 HEADS UP ATTITUDE
 AS SEEN FROM THE CSM
 LOOKING OUT ALONG
 THE +Z AXIS.

(3) AXIS CODE =
 00005 OR 00006=
 (+ OR - Z):

+ OR - Z = UNIT (T)
 -CSM

+ OR - Y = UNIT (T X R)
 -CSM

THIS IS A WINGS
 LEVEL HEADS UP
 ATTITUDE AS SEEN
 FROM THE CSM LOOKING
 OUT ALONG THE +Z
 AXIS.

 SET PREFERRED
 ORIENTATION FLAG

#320

#330

#340

#350

#360

POSS

HOLD

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY THE GIMBAL
ANGLES THAT WOULD
EXIST AT THE
PREFERRED VEHICLE
ATTITUDE IF THE
PRESENT IMU ORIENTA-
TION IS HELD:

V06 N17
R1-OG ROLL
R2-IG PITCH
R3-MG YAW

ALL GIMBAL ANGLES
IN DEGREES TO
NEAREST .01 DEG.
NOTE THAT ALL GIMBAL
ANGLES WILL BE ZERO
IF THE IMU IS ALIGN-
ED TO THE PREFERRED
ORIENTATION AND +X
TRANSLATION WAS SEL-
ECTED

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF GIMBAL ANGLES AT
THE PREFERRED
VEHICLE ATTITUDE
WITH THE PRESENT
IMU ORIENTATION.
IF THE IMU IS AT THE
PREFERRED ORIENTA-
TION THE MG ANGLE
WILL BE ZERO.

#370

#380

RECORD THESE ANGLES
FOR POSSIBLE LATER
USE BY CREW
FOR MANUAL
MANEUVER OPTION
ABOUT THE INITIAL
THRUST VECTOR
DURING ATTITUDE
MANEUVER ROUTINE
(R60)

#390

#400

WAIT FOR KEYBOARD
ENTRY

IS MIDDLE GIMBAL
ANGLE GREATER THAN
45 DEGREES AFTER
HAVING SELECTED + OR
- X TRANSLATION?
(NOTE: IF Y OR Z
AXIS TRANSLATION HAS
BEEN CHOSEN AND THE
MG ANGLE DISPLAYED
IS EXCESSIVE, THEN
IT MAY BE REDUCED BY
ROTATION ABOUT THE
INITIAL THRUST VEC-

#410

170

4 3845

TOR BY THE CREW USING THEIR MANUAL MANEUVER OPTION AFTER THE CMC SPECIFIED ATTITUDE MANEUVER.)

#420

.Y .N

SHALL I RETAIN PRESENT THRUSTING AXIS SELECTION?

#430

N. .Y

•SELECT CSM/IMU
•REALIGN PROGRAM (P53) OR IMU REALIGN PROGRAM (P52).
•KEY IN:
• V37E 53E
• OR 52E
• WHEN COMPLETE
• RESELECT P41

#440

EXIT P41

#450

KEY IN RECYCLE FOR SUBSEQUENT CHANGE OF TRANSLATION AXIS
KEY IN: V32E

#460

#470

ADVISE CREW
WITHIN
GROUND
CAPABILITY

DO I WISH TO MAKE
THE THRUSTING
MANEUVER WITH THE
PRESENT IMU ORIENTA-
TION
CONSIDER:

(A) THE TIME SINCE
THE LAST FINE
ALIGNMENT OF THE
IMU.

#480

(B) IS TIME
CRITICAL?

(C) IS RCS FUEL
CRITICAL?

(D) DOES THE
GROUND CONCUR WITH
THE THRUSTING
MANEUVER AT THIS
ORIENTATION?

#490

N Y
.
.

SELECT CSM/IMU
REALIGN PROGRAM
(P53) OR IMU
REALIGN PRO-
GRAM (P52).
KEY IN
V37E 53E OR 52E
WHEN COMPLETE
RESELECT P41

#500

.....
EXIT P41

#510

TERMINATE FLASH UPON
RECEIPT OF PROCEED,
RECYCLE OR NEW
PROGRAM

KEY IN PROCEED
V 33 E

#520

P R NEW
R E PROGRAM
O C
C Y
E C GO TO PRO-
E L GRAM SELECT-
D E ED

EXIT P41

#530

#540

HOLD

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY INITIAL VG
VECTOR COMPONENTS:
V06 N--
R1-VGX(LV)
R2-VGY(LV)
R3-VGZ(LV)

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF VG COMPONENTS

#550

VGX(LV)-COMPONENT OF
VG AT TIG ALONG
(RXV)XR. IN FPS TO
NEAREST .1 FPS.

VGY(LV)-COMPONENT OF
VG AT TIG ALONG VXR.
IN FPS TO NEAREST
.1 FPS.

VGZ(LV)-COMPONENT OF
VG AT TIG ALONG -R.
IN FPS TO NEAREST
.1 FPS.

RECORD FOR POSSIBLE
FUTURE TRANSMISSION
TO CSM OR GROUND

#560

WHERE R IS GEOCENTRIC RADIUS VECTOR AND V IS VEHICLE INERTIAL VELOCITY VECTOR AT TIG.

#570

WAIT FOR KEYBOARD ENTRY

KEY IN PROCEED V33E

#580

TERMINATE FLASH UPON RECEIPT OF PROCEED

EXTRAPOLATE STATE VECTOR TO TIG-15 SEC

#590

STORE DESIRED ATTITUDE SPECIFICATION (SELECTED TRANSLATION AXIS IN DIRECTION OF INITIAL THRUST) FOR USE BY ATTITUDE MANEUVER ROUTINE (R60). THE FINAL ATTITUDE WILL BE COMPUTED DURING R60 AND WILL POINT THE SELECTED TRANSLATION AXIS IN THE INITIAL THRUST DIRECTION.

#600

HOWEVER, IN ORDER TO CONSERVE RCS FUEL AND NOT CONSTRAIN THE NONCRITICAL ROLL ATTITUDE, WINGS (OR LOS IN THE CASE OF Y TRANSLATION) MAY NOT BE LEVEL IN THE COMPUTED FINAL ATTITUDE.

#610

#620

4 5843

.
 .
 .
 .
 .-----
 . RESET TRACK FLAG
 . (SEE P20). AN ATTITUDE MANEUVER TO THE
 . PREFERRED RENDEZVOUS TRACKING ATTITUDE.
 . IF IN PROCESS, WOULD BE TERMINATED AT
 . THIS POINT.
 .-----
 .
 .

#630

.
 .-----
 . SET .5 DEGREE DEADBAND IN DAP
 .-----
 .
 .

#640

.
 .-----
 . DO ATTITUDE MANEUVER ROUTINE (R60)
 .-----
 .
 .

.-----
 . DO ATTITUDE MANEUVER ROUTINE (R60)
 .-----
 .

#650

.
 .-----
 . FLASH VERB-NOUN TO REQUEST PLEASE PERFORM
 . GNCS A/P AND AUTO MODE SELECTION:
 . V50 N25
 . R1-000--
 . R2-BLANK
 . R3-BLANK
 .-----
 .
 .

.
 .-----
 . MONITOR DSKY: OBSERVE VERB-NOUN FLASH TO REQUEST
 . PLEASE PERFORM GNCS A/P AND AUTO MODE SELECTION
 .-----
 .
 .

#660

.-----
 . AM I PREPARING FOR A TRIM MANEUVER?
 .-----
 .

.N .Y

#670

DO I WISH TO
PERFORM THRUS-
ING MANEUVER
MANUALLY.

#680

.N .Y.

SET A/P CONTROL
SWITCH TO GNCS
AND MODE SWITCH
TO AUTO

#690

WAIT FOR KEY-
BOARD ENTRY

KEY IN ENTER

#700

SET A/P
CONTROL
SWITCH TO
GNCS AND
MODE SWITCH
TO ATTITUDE
HOLD

#710

TERMINATE FLASH
UPON RECEIPT OF
ENTER OR
PROCEED

KEY IN PROC-
EED
V33E

#720

.P .ENTER
.R .
.O -----
.C IS GNCS A/P
.E AND AUTO
.E MODE SELECTED

.D .Y .N

#730

176

IS TRIM FLAG SET?

.Y .N

TTI <30 SEC?

.Y .N

SET NEW TIG
EQUAL TO PRE-
SENT TIME
PLUS 30 SEC

EXTRAPOLATE
STATE VECTOR
TO TIG-15 SEC

CALL AVERAGE G
INTEGRATION AND
VG UPDATE ON AT
TIG-15 SEC

HAS HOLD MODE
BEEN SELECTED?

.Y .N

WAIT UNTIL
TTI= 15 SEC

#740

#750

#760

#770

#780

POSS	FLASH VERB-NOUN TO REQUEST RESPONSE AND DISPLAY:	MONITOR DSKY: OBSERVE VERB-NOUN FLASH TO REQUEST RESPONSE AND DISPLAY OF VG COMPONENTS (NOTE: FOR NON-TRIM MANEUVERS, IF IGNI- TION HAS SLIPPED, THE TTI ON THE TTE CLOCK IS NO LONGER VALID. THIS DISPLAY WILL COMMENCE AT TTI = 15 SEC IN ANY CASE.)	#790
HOLD	V06 N-- R1-VGX(CSM) R2-VGY(CSM) R3-VGZ(CSM) (VGX(CSM), VGY(CSM) VGZ(CSM) - COMPON- ENTS OF THE VG VECTOR RESOLVED ALONG PRESENT CSM X, Y, AND Z AXES RESPECTIVELY. THE VG VECTOR WILL BE UP- DATED BY THE STEERING LOOPS DURING EACH COMPUTATION CYCLE. IN FPS TO NEAREST .1 FPS.		#800
		COMMAND MANUAL TRAN- SLATIONS TO NULL VG COMPONENTS	#810
	WAIT FOR KEYBOARD ENTRY	KEY IN PROCEED V33E	#820
	TERMINATE VERB-NOUN FLASH UPON RECEIPT OF PROCEED		#830
	DISPLAY ON DSKY: V06 N51 R1-TTI R2-VG R3-DELTA VM	MONITOR DSKY: OBSERVE DISPLAY OF TTI, VG AND DELTA VM	#840

178

TTI - TIME TO GO TO
 IGNITION. IN MIN,
 SEC, TO NEAREST SEC
 MAX READING IS
 59 59. SIGN IS + BE-
 FORE NOMINAL TIG, -
 THEREAFTER.

VG - MAGNITUDE OF
 THE VELOCITY TO BE
 GAINED BY THRUSTING
 MANEUVER. IN FPS TO
 NEAREST .1 FPS.

DELTA VM - MAGNITUDE
 OF DELTA V. IN FPS
 TO NEAREST .1 FPS.
 THIS DISPLAY WILL BE
 0000 UNTIL THRUST-
 IS STARTED.

 UPDATE TTE CLOCKS
 IF DESIRED. CLOCKS
 WILL NOT AGREE WITH
 DSKY DISPLAY IF
 IGNITION HAS SLIPPED

#850

#860

POSS
 TEMP
 HOLD

 AT TTI = 5 SEC
 CHANGE VERB-NOUN BUT
 RETAIN PRESENT DIS-
 PLAYS IN R1, R2, R3,
 FLASH VERB-NOUN TO
 REQUEST PLEASE
 PERFORM ENGINE ON
 ENABLE:
 V50 N11
 R1-TTI
 R2-VG
 R3-DELTA VM

 MONITOR DSKY:
 OBSERVE V50 N11
 FLASHING TO REQUEST
 PLEASE PERFORM
 ENGINE ON ENABLE

#870

#880

 SHALL I PERMIT
 IGNITION?

.N .Y

 WAIT FOR KEYBOARD
 ENTRY

 KEY IN TERMINATE.
 V34E

#890

TERMINATE FLASH UPON
RECEIPT OF ENTER OR
TERMINATE

KEY IN ENTER

.E .TERMINATE
.N
.T
.E
.R

#900

FLASH VERB-
NOUN TO RE-
QUEST PLEASE
PERFORM SEL-
ECTION OF CMC
IDLING PRO-
GRAM (P00)
V50 N07
R1-00000
R2-BLANK
R3-BLANK

OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM
SELECTION OF P00

#910

WAIT FOR KEY-
BOARD ENTRY
TERMINATE
FLASH UPON
RECEIPT OF
REQUEST FOR
NEW PROGRAM

KEY IN PROGRAM
SELECTION
V37E--E

#920

GO TO PROGRAM
SELECTED.

#930

GO TO PROGRAM
SELECTED

EXIT P41

#940

IS TTI GREATER THAN
ZERO?

MONITOR DSKY:
IS R1 DISPLAY OF TTI
POSITIVE AND GREATER
THAN ZERO?

.Y .N

.Y .N

#950

WAIT UNTIL
TTI = 0

STANDBY FOR
THRUST ON WHEN
TTI = 0

COMMAND TRANSLATION
ALONG SELECTED AXIS

STANDBY FOR
THRUST ON
IMMEDIATELY

CHANGE TTI DISPLAY
TO TG IN R1

MONITOR RCS
THRUSTING:

TG - TIME TO GO TO
ENGINE CUTOFF IN
MIN, SEC, TO NEAREST
SEC

1. DSKY:
VG, TG
SHOULD BE
DECREASING

2. DELTA VM INCREAS-
ING

2. FDAI-ATT. ERROR
SHOULD BE LESS THAN
OR EQUAL TO --DEGREE
ATT RATES SHOULD BE
LESS THAN OR EQUAL
TO -- DEGREE/SEC.

•Y •N
•
•

GO TO BACKUP
PROCEDURES

BASED ON TIME-TO-GO
EQUATION, CMC
COMMANDS TRANSLATION
OFF

#960

#970

#980

#990

#1000

MAINTAIN VG COMPUTATION FOR NULLING BY RCS THRUSTING MANEUVER

#1010

SET MAX DEADBAND LIMITS IN DAP.

#1020

FLASH VERB-NOUN TO REQUEST RESPONSE.
HOLD DISPLAY OF TG AT ITS VALUE AT ENGINE CUT-OFF:
V06N51
R1-TG
R2-VG
R3-DELTA VM

MONITOR DSKY: OBSERVERB-NOUN
FLASH TO REQUEST RESPONSE AND DISPLAY OF TG, VG, AND DELTA VM.

#1030

CONSIDERING MAGNITUDE OF VG DO I WISH TO MAKE A FINAL TRIMMING THRUSTING MANEUVER?

#1040

WAIT FOR KEYBOARD ENTRY.

KEY IN
PROCEED
V33E

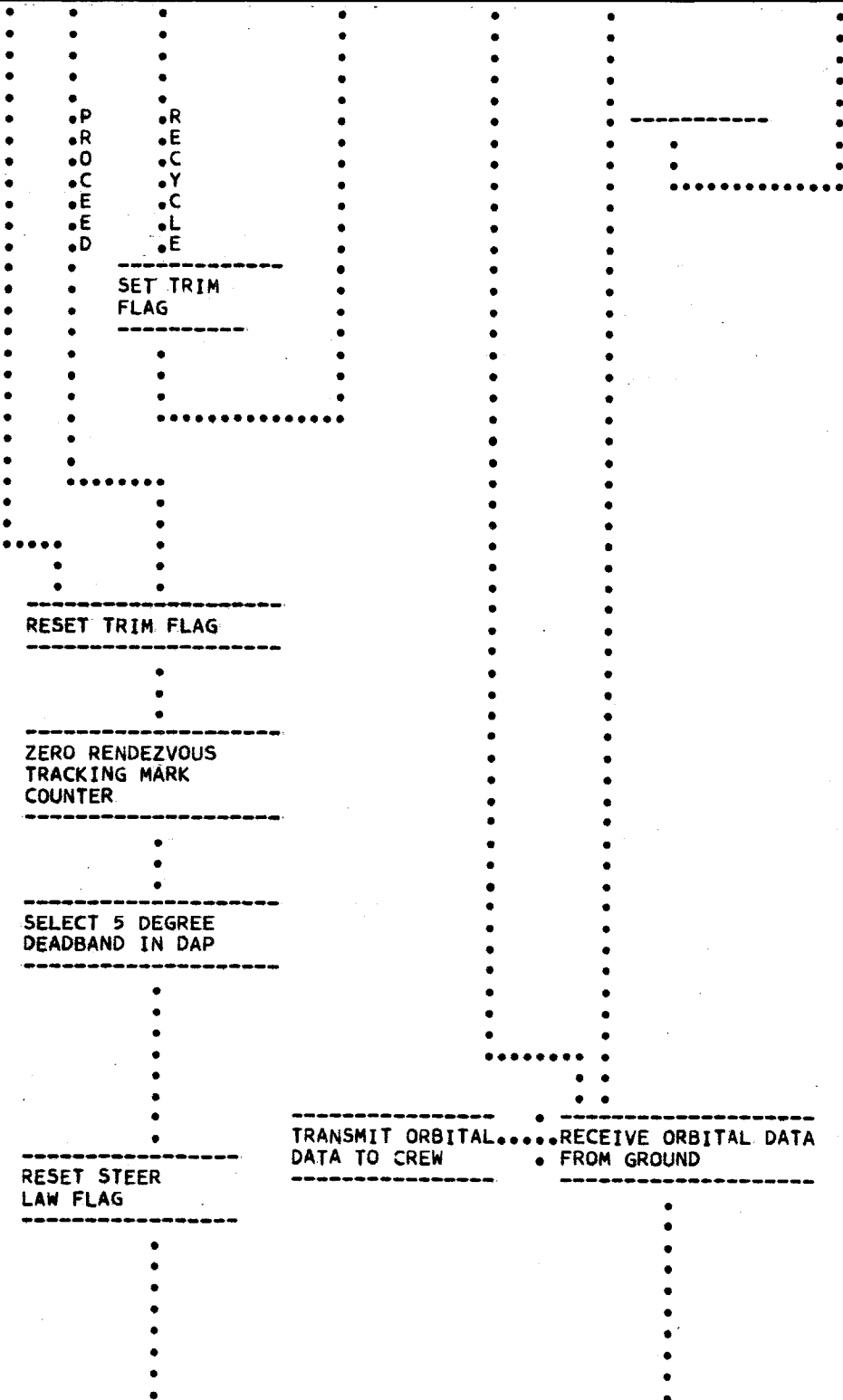
#1050

TERMINATE FLASH UPON RECEIPT OF PROCEED OR RECYCLE

KEY IN
RECYCLE
V32E

182

4 5839



#1060

#1070

#1080

#1090

#1100

#1110

DO ORBITAL PARAMETER
DISPLAY ROUTINE
(R 30)

DO ORBITAL PARAMETER
DISPLAY ROUTINE
(R 30)

IS RENDEZVOUS FLAG
SET?
(SEE P20)

IS THE RENDEZVOUS
NAVIGATION PROGRAM
(P20) IN PROCESS?

#1120

.Y .N
.

.Y .N
.

SET TRACK FLAG
(SEE P20).

#1130

SET UPDATE
FLAG

#1140

DISPLAY P20

MONITOR DSKY:
OBSERVE DISPLAY OF
P20 UPON COMPLE-
TION OF RENDEZ-
VOUS BURN

#1150

EXIT P41

EXIT P41

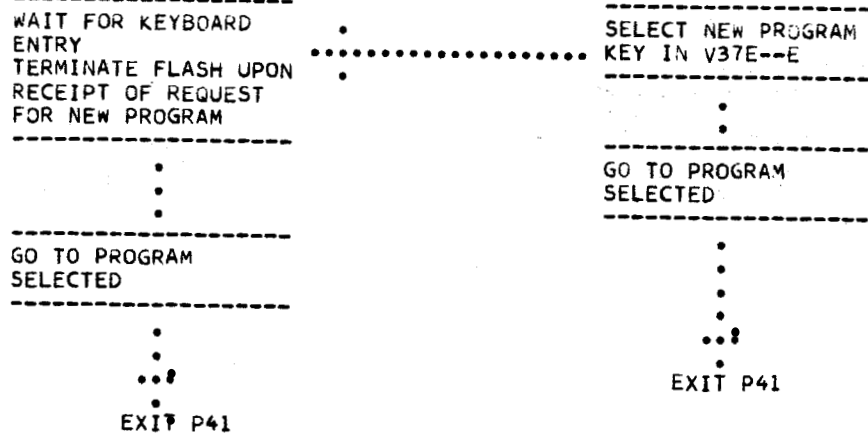
#1160

POSS . FLASH VERB-NOUN TO
..... REQUEST PLEASE
HOLD . PERFORM SELECTION OF
CMC IDLING PROGRAM
(P00)

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM
SELECTION OF P00.

V50N25
R1-00000
R2-BLANK
R3-BLANK

184



#1170

#1180

#1190

END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

THRUST MONITOR PROGRAM (P47)

REV 1 10/31/66

PURPOSE: (1) TO MONITOR VEHICLE ACCELERATION DURING A NON GNCS CONTROLLED THRUSTING MANEUVER.
 (2) TO DISPLAY THE DELTA V APPLIED TO THE VEHICLE BY THIS THRUSTING MANEUVER.

ASSUMPTIONS: (1) THE ISS MAY BE IN STANDBY OR OPERATE. THE GNCS STARTUP PROGRAM (P05) AND THE IMU ORIENTATION DETERMINATION PROGRAM (P51) WOULD NORMALLY BE COMPLETED BEFORE THE SELECTION OF THIS PROGRAM. THE ISS THUS MAY BE:

(A) OFF (STANDBY).

(B) ON, AND NOT ALIGNED SINCE TURN ON

(C) ON AND AT AN INERTIAL ORIENTATION KNOWN ONLY INACCURATELY BY THE CMC, I.E. HAVING BEEN ALIGNED AT LEAST ONCE SINCE TURN ON BUT NOT WITHIN THE LAST --HRS

(D) ON AND AT AN INERTIAL ORIENTATION KNOWN ACCURATELY BY THE CMC, I.E. HAVING BEEN ALIGNED WITHIN THE LAST --HRS

IF (A) IS TRUE PROGRAM 05 SELECTION WILL BE REQUESTED BY THIS PROGRAM.

IF (B) IS TRUE PROGRAM 51 SELECTION WILL BE REQUESTED BY THIS PROGRAM.

IF (C) IS TRUE THE CMC MAY OR MAY NOT HAVE A SATISFACTORY INERTIAL REFERENCE TO ACCURATELY COMPLETE THE PROGRAM.

IF (D) IS TRUE THE CMC HAS A SATISFACTORY INERTIAL REFERENCE TO ACCURATELY COMPLETE THE PROGRAM. CASES (B), (C) AND (D) HOWEVER ARE FURTHER SUBJECT TO THE CONSTRAINT OF LARGE MIDDLE GIMBAL ANGLE, I.E. THE EXISTING INERTIAL ORIENTATION MAY CAUSE A MIDDLE GIMBAL ANGLE GREATER THAN 45 DEGREES AT THE THRUSTING ORIENTATION OF THE CSM, WHICH IS UNSATISFACTORY.

(2) THE CSM STATE VECTOR WILL HAVE BEEN AUTOMATICALLY INTEGRATED FORWARD TO THE PRESENT TIME EVERY 9 MINUTES. THEREFORE THE INTEGRATION TIME NECESSARY TO OBTAIN A CORRECT STATE VECTOR FOR USE BY THIS PROGRAM WILL ALWAYS BE LESS THAN 1 MINUTE.

(3) THE RESPONSIBILITY OF AVOIDING GIMBAL LOCK DURING EXECUTION OF THIS PROGRAM IS UPON THE ASTRONAUT.

(4) THIS PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY AT LEAST 1 MINUTE PRIOR TO ANY NON GNCS CONTROLLED THRUSTING MANEUVER EXCEPT THOSE INITIATED UNDER GNCS CONTROL AND MANUALLY TAKEN OVER.

PROG
CONT

CMC

GROUND

CREW

CHECKLIST

TIME

TOTAL
TIME

• CREW
• PROGRAM
• SELECTION

•
•••
•
•
•
•
•
•
•
•

#10

P47/CSM2/278

DO PROGRAM
SELECTION
CHECK ROUTINE (R01)

KEY IN THRUST
MONITOR PROGRAM
(P47)
V37E47E

#20

DO PROGRAM SELECTION
CHECK ROUTINE (R01)

START THRUST
MONITOR PROGRAM
(P47)
DISPLAY P47.

MONITOR DSKY:
OBSERVE DISPLAY
OF PROGRAM 47.

#30

DO IMU STATUS
CHECK ROUTINE
(R02)

DO IMU STATUS
CHECK ROUTINE
(R02)

#40

RESET TRACK AND
UPDATE FLAGS
(SEE P20)

#50

INTEGRATE STATE
VECTOR FORWARD TO
PRESENT TIME (T)
PLUS 1 MINUTE

#60

WAIT UNTIL T +
1 MINUTE

```

-----
CALL AVERAGE
G ROUTINE.
-----

```

*70

```

-----
FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY DELTA V
(IMU)=

```

```

V16N--
R1-DELTA VX(IMU)
R2-DELTA VY(IMU)
R3-DELTA VZ(IMU)

```

```

DELTA VX(IMU) - COM-
PONENT OF INTEGRATED
ACCELERATION ALONG
IMU +X AXIS. IN FPS
TO NEAREST .1 FPS.

```

```

DELTA VY(IMU) - COM-
PONENT OF INTEGRATED
ACCELERATION ALONG
IMU +Y AXIS. IN FPS
TO NEAREST .1 FPS.

```

```

DELTA VZ(IMU) - COM-
PONENT OF INTEGRATED
ACCELERATION ALONG
IMU +Z AXIS. IN FPS
TO NEAREST .1 FPS.

```

```

NOTE: R1,2, AND 3
WILL READ 00000 IN-
ITIAALLY AND WILL RE-
MAIN SO UNTIL A
THRUSTING MANEUVER
IS STARTED. THEY
WILL BE UPDATED
EVERY - SEC.
-----

```

```

-----
MONITOR DSKY:
OBSERVE FLASHING
VERB-NOUN TO REQUEST
RESPONSE AND DISPLAY
OF EACH COMPONENT OF
DELTA V(IMU).
-----

```

#80

```

-----
PERFORM THRUSTING
MANEUVER(S) AS
DESIRED.
MONITOR FDAI BALL
TO AVOID GIMBAL
LOCK
-----

```

#90

#100

#110

#120

START MONITOR OF
ACCELEROMETERS BUT
DO NOT INTEGRATE
ACCELEROMETER
OUTPUT.

DOES THE ACCELEROM-
ETER OUTPUT ABOUT
ANY IMU AXIS EXCEED
---FPSPS?

.Y .N

START INTEGRATION OF
ACCELEROMETER
OUTPUT.

WAIT FOR KEYBOARD
ENTRY

ARE ALL THRUSTING
MANEUVERS COMPLETE?

.Y .N

TERMINATE FLASH UPON
RECEIPT OF PROCEED

KEY IN PROCEED
V33E

#130

#140

#150

#160

#170

190

4 5835

IS RENDEZVOUS
FLAG SET?

.N .Y

SET TRACK FLAG
(SEE P20)

SET UPDATE FLAG
(SEE P20)

DISPLAY P20

EXIT P47

FLASH VERB-NOUN TO
REQUEST PLEASE PER-
FORM SELECTION OF
IDLING PROGRAM (P00)
V50 N07
R1-00000
R2-BLANK
R3-BLANK

IS RENDEZVOUS NAVI-
GATION PROGRAM (P20)
IN PROCESS?

.Y .N

MONITOR DSKY:
OBSERVE DISPLAY
OF P20 UPON COM-
PLETION OF P47

EXIT P47

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM
SELECTION OF P00

#180

#190

#200

#210

#220

•
•
•
•
•

WAIT FOR KEYBOARD
ENTRY

TERMINATE FLASH UPON
RECEIPT OF REQUEST
FOR NEW PROGRAM

•
•
•
•
•

GO TO PROGRAM
SELECTED

•
•
•••
•
EXIT P47

•
•
•
•
•

KEY IN REQUEST FOR
NEW PROGRAM
V37E--E

•
•
•
•
•

GO TO PROGRAM
SELECTED

•
•
•••
•
EXIT P47

#230

#240

192

END OF RUIN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

IMU ORIENTATION DETERMINATION PROGRAM (P51)

REV 10

10/31/66

PURPOSE: (1) TO DETERMINE THE INERTIAL ORIENTATION OF THE IMU.

ASSUMPTIONS: (1) THE ISS MAY BE:

(A) OFF (STANDBY)

(B) ON, AND ALIGNED OR NOT ALIGNED SINCE TURN ON.

IF (A) IS TRUE, PROGRAM 05 MUST BE PERFORMED BEFORE THIS PROGRAM CAN BE COMPLETED.
IF (B) IS TRUE THIS PROGRAM CAN BE COMPLETED.

(2) THERE ARE NO RESTRAINTS UPON THE CSM ATTITUDE CONTROL MODES UNTIL A GNC'S CONTROLLED MANEUVER IS CALLED BY A PROGRAM OR THE CREW WISHES TO MANUALLY MANEUVER THE VEHICLE. THE AUTOPILOT CONTROL MAY BE GNC OR SCS AND IF GNC MAY BE AUTO, HOLD OR FREE. PRIOR TO GNC'S CONTROLLED MANEUVERS THE CMC WILL REQUEST THE CORRECT MODE IF IT IS NOT IN EFFECT. FOR MANUALLY CONTROLLED MANEUVERS THE CREW MUST SELECT THE CORRECT MODES.

(3) THE PROGRAM IS DESIGNED FOR ONE-MAN OPERATION.

(4) TIME AND RCS FUEL MAY BE SAVED, AND SUBSEQUENT IMU ALIGNMENT DECISIONS GREATLY SIMPLIFIED IF THIS PROGRAM IS PERFORMED IN SUCH A WAY AS TO LEAVE THE IMU INERTIALLY STABILIZED AT AN ORIENTATION AS CLOSE AS POSSIBLE TO THE OPTIMUM ORIENTATION REQUIRED BY FUTURE CMC PROGRAMS.

(5) THE OPTICS EYE PIECES, WORK TABLE, AND ROTATION CONTROL ARE IN POSITION FOR USE. THE OPTICS DOOR IS OPEN.

(6) THE PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY.

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
			. CREW PROG . SELECTION			#10
					
	----- DO PROGRAM SELECTION CHECK ROUTINE (R01)	. . . . .	----- KEY IN IMU ORIENTATION DETERMI- NATION PROGRAM (P51) V37E 51E -----			#20
			. .			

P51/CSM2/278

194

1
2
3
4
5

DO PROGRAM SELECTION
CHECK ROUTINE (R01)

START IMU ORIENTATION
DETERMINATION
PROGRAM (P51)
DISPLAY PROGRAM 51

MONITOR DSKY:
OBSERVE DISPLAY OF
PROGRAM 51

#30

IS ISS ZERO FLAG
SET?

#40

.Y .N

POSS .
.....
HOLD .

FLASH VERB=NOUN
TO REQUEST
PLEASE PERFORM
SELECTION OF
GNCS START UP
PROGRAM(P05):
V50N07
R1=00005
R2=BLANK
R3=BLANK

MONITOR DSKY:
OBSERVE
FLASHING VERB=NOUN
TO REQUEST PLEASE
PERFORM SELECTION
OF P05.

#50

.Y .N

WAIT FOR
KEYBOARD ENTRY

SELECT
PROGRAM
AS DESIRED
KEY IN
V37E--E

#60

TERMINATE FLASH
UPON RECEIPT
OF NEW PROGRAM

#70

GO TO PROGRAM
SELECTED

GO TO PROGRAM
SELECTED

EXIT P51

EXIT P51

#80

#90

FLASH VERB-NOUN TO
REQUEST PLEASE PER-
FORM STAR ACQUI-
SITION:

V50 N25
R1-00015
R2 - BLANK
R3 - BLANK

HOLD

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM STAR
ACQUISITION

#100

SHALL I MANEUVER THE
CSM TO POSITION THE
IMU INNER GIMBAL
AXIS IN A PREFERRED
DIRECTION?

#110

N Y

WITH THE ROTATION
CONTROL ROTATE
THE CSM UNTIL THE
PITCH AXIS IS IN
THE PREFERRED
DIRECTION

#120

ARE 2 NAVIGATION
VISIBLE IN
THE SXT FIELD OF
VIEW?

#130

.Y .N

WITH THE ROTA-
TION CONTROL
ORIENT THE CSM
UNTIL 2 NAVI-
GATION STARS
ARE VISIBLE IN
THE SXT

#140

MONITOR FDAI BALL
IS GIMBAL LOCK
IMPENDING?

#150

.Y .N

#160

WAIT FOR KEYBOARD
ENTRY

KEY IN
ENTER

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR ENTER

KEY IN PROCEED
V33E

#170

.E
.N
.T
.E
.R

.P
.R
.O
.C
.E
.E
.D

#180

 DISPLAY ON DSKY:
 V41 N20
 R1-00000
 R2-00000
 R3-00000

WHERE R1, R2,
 AND R3 REPRESENT
 CDU/ISS ANGLES
 TO BE COARSE
 ALIGNED TO (DG,
 IG, MG, RESPEC-
 TIVELY).

 COMMAND ISS TO
 COARSE ALIGN
 MODE

 TURN ON "NO ATT"
 LIGHT

 COARSE ALIGN ISS

 COMMAND ISS TO
 ATTITUDE CONTROL
 MODE

 TURN OFF "NO
 ATT" LIGHT

 MONITOR DSKY:
 OBSERVE DISPLAY
 OF COARSE ALIGN
 VERB AND ICDJ
 ANGLES (ALL
 00000) FOR COARSE
 ALIGNMENT

 OBSERVE "NO ATT"
 LIGHT ON

 WAIT +OR NN- +TTN
 LIGHT OFF

#190

#200

#210

#220

#230

DO STAR DATA TEST
ROUTINE (R 54)

DO STAR DATA TEST
ROUTINE (R 54)

#300

CALCULATE IMU INERTIAL
ORIENTATION W.R.T.
CELESTIAL COORDIN-
ATES AS DEFINED BY
STAR # 1 AND # 2 .
STORE AS PRESENT
PLATFORM ORIENTATION
(REFSMMAT)

#310

SET "IMU ORIENTATION
KNOWN" FLAG
(REFSMFLG)

#320

TERMINATE P 51 AND
GO TO CMC
IDLING PROGRAM
(P 00)

MONITOR DSKY:
OBSERVE TERMINATION
OF P 51 AND DISPLAY
OF P 00

#330

EXIT P51

EXIT P51

#340

200

END OF RUI.

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

IMU REALIGN PROGRAM (P52)

REV 16

11/01/66

PURPOSE:

(1) TO ALIGN THE IMU FROM A "KNOWN" (SEE ASSUMPTION 4) ORIENTATION TO ONE OF THREE ORIENTATIONS SELECTED BY THE ASTRONAUT:

(A) PREFERRED ORIENTATION

AN OPTIMUM ORIENTATION FOR A PREVIOUSLY CALCULATED MANEUVER. THIS ORIENTATION MUST BE CALCULATED AND STORED BY A PREVIOUSLY SELECTED PROGRAM.

(B) NOMINAL ORIENTATION

X = UNIT(Y XZ)
 -SM -SM -SM

Y = UNIT(V X R)
 -SM - -

Z = UNIT(-R)
 -SM -

WHERE:

R = THE GEOCENTRIC RADIUS VECTOR AT TIME T (ALIGN) SELECTED BY THE ASTRONAUT
 -

V = THE INERTIAL VELOCITY VECTOR AT TIME T (ALIGN) SELECTED BY THE ASTRONAUT.
 -

(C) REFSMMAT

SEE ASSUMPTION (4)

ASSUMPTIONS:

(1) THE DOCKED CONFIGURATION MAY BE SIVB/CSM, LM/CSM, OR CSM. THE PRESENT CONFIGURATION IS KNOWN BY THE CMC DUE TO THE DISCRETES PROVIDED TO THE CMC.

(2) THERE ARE NO RESTRAINTS UPON THE CSM ATTITUDE CONTROL MODES UNTIL A GNCS CONTROLLED MANEUVER IS CALLED BY A PROGRAM OR THE CREW WISHES TO MANUALLY MANEUVER THE VEHICLE. THE AUTOPILOT CONTROL MAY BE GNC OR SCS AND IF GNC MAY BE AUTO, HOLD OR FREE. PRIOR TO GNCS CONTROLLED MANEUVERS THE CMC WILL REQUEST THE CORRECT MODE IF IT IS NOT IN EFFECT. FOR MANUALLY CONTROLLED MANEUVERS THE CREW MUST SELECT THE CORRECT MODES.

(3) THIS PROGRAM MAKES NO PROVISION FOR AN ATTITUDE MANEUVER TO RETURN THE VEHICLE TO A SPECIFIC ATTITUDE. SUCH A MANEUVER, IF DESIRED, MUST BE DONE MANUALLY. AN OPTION IS PROVIDED HOWEVER TO POINT THE SXT AT ASTRONAUT OR CMC SELECTED STARS EITHER MANUALLY BY CREW INPUT OR AUTOMATICALLY UNDER CMC CONTROL.

(4) THE ISS IS ON AND HAS BEEN ALIGNED TO A KNOWN ORIENTATION WHICH IS STORED IN THE CMC (REFSMMAT). THE PRESENT IMU ORIENTATION DIFFERS FROM THAT TO WHICH IT WAS LAST ALIGNED ONLY DUE TO GYRO DRIFT (I.E. NEITHER GIMBAL LOCK NOR IMU POWER INTERRUPTION HAS OCCURED SINCE THE LAST ALIGNMENT).

(5) THE OPTICS EYE PIECES, WORK TABLE, AND ROTATION CONTROL ARE IN POSITION FOR USE. THE OPTICS DOOR IS OPEN.

(6) THE PROGRAM IS DESIGNED FOR ONE-MAN OPERATION.

(7) THE PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY.

60124

PROG
CONT

CMC

GROUND

CREW

CHECKLIST

TIME

TOTAL
TIME

• CREW PROG
• SELECTION
•
•••
•

#10

DO PROGRAM SELECTION CHECK ROUTINE (R01)	•	KEY IN IMU REALIGN PROGRAM (P52) V37E 52E
---	---	---

•	•••••	DO PROGRAM SELECTION CHECK ROUTINE (R01)
---	-------	---

#20

•	•	•
START IMU REALIGN PROGRAM (P52) DISPLAY P52	•••••	MONITOR DSKY: OBSERVE DISPLAY OF PROGRAM 52

#30

•	•
RESET TRACK FLAG (SEE P20)	•

#40

•	•	•
DO IMU STATUS CHECK ROUTINE (R02)	•••••	DO IMU STATUS CHECK ROUTINE (R02)

#50

•	•••••	•••••
•	•	•
•	•	•
•	•	•
•	•	•
•	•	•
•	•	•
•	•	•
•	•	•
•	•	•

P52/CSM2/278

HOLD

FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY OPTION CODE
 FOR ASSUMED IMU
 ORIENTATION
 SELECTION:
 V06 N--
 R1-000--
 R2-0000X
 R3-BLANK

R1 IS THE OPTION
 CODE FOR ASSUMED
 IMU ORIENTATION
 SELECTION

R2 IS THE CMC
 ASSUMED OPTION;
 00001-PREFERRED
 00002-NOMINAL
 00003-REFSMMAT

WAIT FOR KEYBOARD
 ENTRY

TERMINATE FLASH UPON
 RECEIPT OF PROCEED
 OR NEW DATA

.P .NEW
 .R .CODE
 .O
 .C
 .E
 .E STORE CODE
 .D

MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF OPTION CODE FOR
 ASSUMED IMU
 ORIENTATION
 SELECTION

IS THIS THE IMU
 ORIENTATION I DESIRE?

.Y .N

KEY IN PROCEED
 V33E

KEY IN V22
 AND LOAD THE
 DESIRED ORIEN-
 TATION CODE IN
 R2

#60

#70

#80

#90

#100

204

4 5828

IS STORED ORIENTATION CODE 00001

.N .Y

IS PREFERRED ORIENTATION FLAG SET?

.Y .N

GO TO "A" BELOW

FLASH VERB-NOUN TO REQUEST RESPONSE AND DISPLAY ALARM CODE:

V05N31
R1-
R2-
R3-

POSS .
.....
HOLD .

WAS PREFERRED IMU ORIENTATION SELECTED

.Y .N

MONITOR DSKY: DOES ALARM CODE DISPLAY INDICATE THAT A PREFERRED IMU ORIENTATION HAS NOT BEEN

.Y .N

GO TO "A" BELOW

IS THE NOMINAL IMU ORIENTATION SATISFACTORY OR DO I WANT A PREFERRED IMU ORIENTATION?

.NOM .PREF

#110

#120

#130

#140

#150

#160

WAIT FOR KEY-
BOARD ENTRY

KEY IN
RECYCLE
V32E

TERMINATE FLASH
UPON RECEIPT OF
RECYCLE OR NEW
PROGRAM

.NEW .RECYCLE
.PROG.

SELECT DESIRED
PROGRAM TO
DEFINE A PRE-
FERRED IMU
ORIENTATION
AND THEN RE-
SELECT THIS
PROGRAM.
KEY IN
V37--E

GO TO PROGRAM
SELECTED

GO TO PROGRAM
SELECTED

EXIT P53

EXIT P53

IS THE STORED
ORIENTATION CODE
00002?

.Y .N
(NOM) (REFSM)

GO TO
"B"
BELOW

WAS NOMINAL IMU
ORIENTATION SELEC-
TED?

.Y .N
(NOM) (REFSM)

GO TO
"B"
BELOW

#170

#180

#190

#200

#210

#220

```

FLASH VERB-NOUN
TO REQUEST
RESPONSE AND
DISPLAY T(ALIGN:)
V06 N--
R1-T(ALIGN)-HRS
R2-T(ALIGN)-MINS
R3-T(ALIGN)-SECS

```

```

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF T(ALIGN)

```

#230

```

T(ALIGN) - TIME
(GET) AT WHICH
VEHICLE POSITION
AND VELOCITY
VECTORS ARE
SELECTED TO
DEFINE IMU AND
CSM NOMINAL
ORIENTATION. IN
HRS, MINS, SECS,
TO NEAREST .01
SEC.

```

```

AM I SATISFIED WITH
THIS VALUE

```

#240

```

.Y .N

```

#250

```

WAIT FOR KEY-
BOARD ENTRY

```

```

KEY IN PROCEED
V33E

```

```

TERMINATE FLASH
UPON RECEIPT OF
PROCEED OR NEW
DATA

```

```

KEY IN
V25 AND
LOAD
DESIRED
T(ALIGN)

```

#260

```

.PROCEED .NEW
.DATA

```

```

STORE DATA

```

#270

SELECT NOMINAL
IMU ORIENTATION
FOR GIMBAL
ANGLE COMPUTA-
TION

#280

"A"
SEE ABOVE

#290

SELECT PREFERRED
IMU ORIENTATION
FOR GIMBAL ANGLE
COMPUTATION

#300

"B"
SEE ABOVE

READ VEHICLE ATTI-
TUDE FROM GIMBAL
ANGLES

#310

COMPUTE GIMBAL
ANGLES AT SELECTED
IMU ORIENTATION AND
PRESENT VEHICLE
ATTITUDE

#320

"A"
SEE
ABOVE

#330

208

4 3826

HOLD

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY THE RESULT-
ING GIMBAL ANGLES:
V06 N17
R1-OG ROLL
R2-IG PITCH
R3-MG YAW

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF GIMBAL ANGLES
AFTER PROPOSED CSM/
IMU ALIGNMENT

#340

ALL GIMBAL ANGLES IN
DEGREES TO NEAREST
.01 DEGREE

IS MIDDLE GIMBAL
ANGLE SATISFACTORY?

#350

.Y .N

BY SUITABLE MODE
SELECTION ENSURE
THAT VEHICLE IS
AS INERTIALLY
STABLE AS
POSSIBLE TO EN-
SURE ACCURACY OF
IMU COARSE
ALIGNMENT.

#360

.Y

WAIT FOR KEYBOARD
ENTRY

KEY IN PROCEED
V33E

#370

DO I WISH TO
MANEUVER VEHICLE
TO AN ATTITUDE
WHICH WILL PRO-
VIDE A MORE
SUITABLE MGA?

#380

.N .Y

MANEUVER VEH-
ICLE WITH
ROTATION
CONTROLLER

#390

UPDATE THE
DISPLAY OF
RESULTING
GIMBAL ANGLES
KEY IN RECY-
CLE
V32E

#400

TERMINATE FLASH UPON
RECEIPT OF PROCEED
RECYCLE OR NEW PRO-
GRAM

SELECT NEW PRO-
GRAM AS DESIRED
KEY IN V37E--E

#410

RECYCLE P NEW
R PROG
O
C
E
E GO TO
D PROGRAM
SELECTED

GO TO PROGRAM
SELECTED

#420

EXIT P52

EXIT P52

#430

SELECT FINAL DESIRED
IMU ORIENTATION FROM
STORAGE FOR USE BY
THE COARSE ALIGN
ROUTINE (R50)

#440

DO COARSE ALIGN
ROUTINE (R50)

WAIT--SECONDS
FOR COMPLETION OF
COARSE ALIGMENT

DO STAR SELECTION
ROUTINE (REFER TO
SECTION 5.5.3 OF
R547 VOL I).

"B"
SEE ABOVE

TWO TWO
STARS STARS
AVAILABLE NOT
AVAILABLE AVAILABLE

FLASH VERB-NOUN
TO REQUEST RES-
PONSE AND DIS-
PLAY ALARM CODE:

V05N31
R1-
R2-
R3-

MONITOR DSKY:
DOES ALARM
CODE DISPLAY
INDICATE THAT TWO
STARS ARE NOT AVAIL-
ABLE IN THE SCT
FIELD OF VIEW?

.Y .N

SHALL I BYPASS
R56 AND AT-
TEMPT MANUAL
STAR ACQUI-
SITION?

.Y .N

MANEUVER
VEHICLE UN-
TIL A SUIT-
ABLE STAR
IS ACQUIRED

#450

#460

#470

#480

#490

WAIT FOR KEY-
BOARD ENTRY

KEY IN PRO-
CEED
V33E

#500

MANEUVER
VEHICLE UN-
TIL A SUIT-
ABLE STAR
MAY BE AC-
QUIRED.
MONITOR
FDAI BALL
TO AVOID
GIMBAL LOCK.
(NOTE: AS-
TRONAUT MAY
USE OPTICS
TO ASSIST
ATTITUDE
CHOICE OR
MAY MANEU-
VER AT
RANDOM.)

#510

TERMINATE FLASH
UPON RECEIPT OF
PROCEED OR RE-
CYCLE.

KEY IN RE-
CYCLE
V32E

#530

P
R
O
C
E
E
D

R
E
C
Y
C
L
E

#540

DO FINE ALIGN
ROUTINE (R51)

DO FINE ALIGN
ROUTINE (R51)

#550

IS RENDEZVOUS
FLAG SET?

.N .Y

SET TRACK FLAG
(SEE P20)

SET UPDATE FLAG
(SEE P20)

DISPLAY P20

EXIT P52

FLASH VERB-NOUN TO
REQUEST PLEASE PER-
FORM SELECTION OF
IDLING PROGRAM
(POO):

V50 N07
R1-00000
R2-BLANK
R3-BLANK

IS RENDEZVOUS
NAVIGATION PROGRAM
(P20) IN PROCESS?

.Y .N

MONITOR DSKY:
OBSERVE DISPLAY
OF P20 UPON COM-
PLETION OF P52

EXIT P52

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM
SELECTION OF POO

#560

#570

#580

#590

#600

•
•
•
•
•

WAIT FOR KEYBOARD
ENTRY

TERMINATE FLASH UPON
RECEIPT OF REQUEST
FOR NEW PROGRAM

•
•

GO TO PROGRAM
SELECTED

•
•
•••
•
EXIT P52

•
•
•
•
•

KEY IN REQUEST FOR
NEW PROGRAM
V37E--E

•
•
•
•

GO TO PROGRAM
SELECTED

•
•
•••
•
EXIT P52

#610

214

END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

CSM/IMU REALIGN PROGRAM (P53)

REV 17

10/31/66

PURPOSE: (1) TO ALIGN THE IMU TO ONE (D)* OF TWO ORIENTATIONS SELECTED BY THE ASTRONAUT:

(A) PREFERRED ORIENTATION

AN OPTIMUM ORIENTATION FOR A PREVIOUSLY CALCULATED MANEUVER. THIS ORIENTATION MUST BE CALCULATED AND STORED BY A PREVIOUSLY SELECTED PROGRAM. IF THE PREFERRED IMU ORIENTATION IS SELECTED THE CMC WILL AUTOMATICALLY SELECT THE PREFERRED CSM ATTITUDE (SEE BELOW).

(B) NOMINAL ORIENTATION

$$X = \text{UNIT}(Y \quad XZ \quad) \\ -SM \quad \quad -SM \quad -SM$$

$$Y = \text{UNIT}(V \quad X \quad R) \\ -SM \quad \quad - \quad -$$

$$Z = \text{UNIT}(-R) \\ -SM \quad \quad -$$

WHERE:

R = THE GEOCENTRIC RADIUS VECTOR AT TIME T (ALIGN) SELECTED BY THE ASTRONAUT.

V = THE INERTIAL VELOCITY VECTOR AT TIME T (ALIGN) SELECTED BY THE ASTRONAUT.

(2) TO ALIGN THE CSM TO ONE (3)* OF TWO ATTITUDES SELECTED BY THE ASTRONAUT:

(A) PREFERRED ATTITUDE

AN OPTIMUM VEHICAL THRUSTING ATTITUDE FOR A PREVIOUSLY CALCULATED MANEUVER. THIS ATTITUDE MUST BE CALCULATED AND STORED BY A PREVIOUSLY SELECTED PROGRAM. IF THE PREFERRED IMU ORIENTATION IS SELECTED THE CMC WILL AUTOMATICALLY SELECT THE PREFERRED CSM ATTITUDE (SEE ABOVE)

(B) NOMINAL ATTITUDE

$$X = \text{UNIT}(Y \quad X \quad Z \quad) \\ -CSM \quad \quad -CSM \quad -CSM$$

$$Y = \text{UNIT}(V \quad X \quad R) \\ -CSM \quad \quad - \quad -$$

$$Z = \text{UNIT}(-R) \\ -CSM \quad \quad -$$

ASSUMPTIONS: (1) THE DOCKED CONFIGURATIONS MAY BE LM/CSM OR CSM. THE PRESENT CONFIGURATION IS KNOWN BY THE CMC DUE TO THE DISCRETES PROVIDED TO THE CMC.

(2) THERE ARE NO RESTRAINTS UPON THE CSM ATTITUDE CONTROL MODES UNTIL A GNCS CONTROLLED MANEUVER IS CALLED BY A PROGRAM OR THE CREW WISHES TO MANUALLY MANEUVER THE VEHICLE. THE AUTOPILOT CONTROL MAY BE GNC OR SCS AND IF GNC MAY BE AUTO, HOLD OR FREE. PRIOR TO GNCS CONTROLLED MANEUVERS THE CMC WILL REQUEST THE CORRECT MODE IF IT IS NOT IN EFFECT. FOR MANUALLY CONTROLLED MANEUVERS THE CREW MUST SELECT THE CORRECT MODES.

(3) THE ISS IS ON AND HAS BEEN ALIGNED TO A KNOWN ORIENTATION WHICH IS STORED IN THE CMC (REFSMAT). THE PRESENT IMU ORIENTATION DIFFERS FROM THAT TO WHICH IT WAS LAST ALIGNED ONLY DUE TO GYRO DRIFT (I.E. NEITHER GIMBAL LOCK NOR IMU POWER INTERRUPTION HAS OCCURED SINCE THE LAST ALIGNMEN).

(4) AN INTERIM VEHICLE ATTITUDE (2)* MAY BE NECESSARY BETWEEN THE INITIAL (1)* AND FINAL (3)* ATTITUDES TO ALLOW STAR SIGHTINGS TO BE MADE FOR THE FINAL IMU ALIGNMENT. THIS ATTITUDE WILL BE NECESSARY IF 2 NAVIGATION STARS CANNOT BE ACQUIRED EITHER FROM THE PRESENT (1)* OR FINAL (3)* VEHICLE ATTITUDES. IT WILL ALSO BE REQUIRED IF 2 NAVIGATION STARS CAN BE ACQUIRED FROM THE PRESENT VEHICLE ATTITUDE (1)* BUT NOT THE FINAL VEHICLE ATTITUDE (3)* AND AN INTERIM IMU ORIENTATION (B)* (SEE ASSUMPTION #5 BELOW) IS REQUIRED.

(5) AN INTERIM IMU ORIENTATION (B)* MAY BE NECESSARY BETWEEN THE INITIAL (A)* AND FINAL (C)/(D)* ORIENTATIONS IF A COMBINATION OF IMU ORIENTATION AND VEHICLE ATTITUDE WOULD RESULT IN GIMBAL LOCK.

(6) STAR SIGHTINGS MUST BE TAKEN WHEN THE IMU HAS BEEN COARSE ALIGNED TO ORIENTATION (C)* WHICH IS SLIGHTLY IN ERROR FROM (D)* DUE TO THE INACCURACIES OF THE COARSE ALIGNMENT PROCEDURE. THESE SIGHTINGS WILL BE USED TO FINE ALIGN THE IMU TO FINAL ORIENTATION (D)*.

(7) THE PROGRAM IS DESIGNED FOR ONE MAN OPERATION.

(8) THE PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY.

*REFER TO FIGURE 4-3 OF R-547 VOL I SECT 4

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
			• CREW PROG • SELECTION • • •			#10
	----- DO PROGRAM SELECTION CHECK ROUTINE (R01)	• • •	----- KEY IN CSM/IMU RE- ALIGN PROGRAM (P53) V37 E 53E ----- • •			
		• • •	----- DO PROGRAM SELECTION CHECK ROUTINE (R01) -----			#20
	• • • • • • • • •					

START CSM/IMU RE-
ALIGN PROGRAM (P53)
DISPLAY PROGRAM 53

MONITOR DSKY:
OBSERVE DISPLAY OF
PROGRAM 53

#30

STORE NUMBER OF
PRIOR PROGRAM

#40

RESET INTERIM
VEHICLE FLAG

#50

RESET INTERIM PLAT-
FORM FLAG

#60

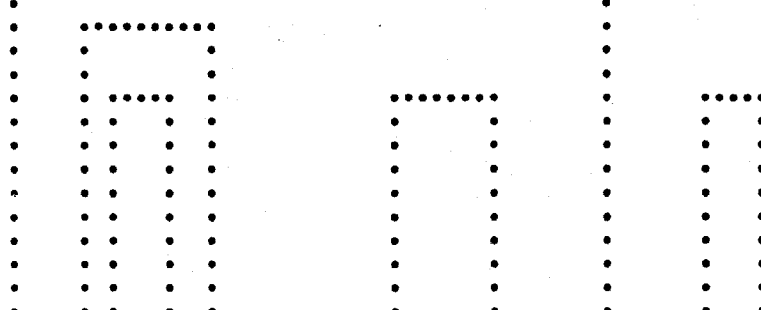
RESET INITIAL STAR
SIGHT FLAG

RESET TRACK FLAG
(SEE P20)

#70

DO IMU STATUS CHECK
ROUTINE (R02)

DO IMU STATUS CHECK
ROUTINE (R02)



278

4 5021

.....
 HOLD .

FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY OPTION CODE
 FOR ASSUMED IMU
 ORIENTATION SELE-
 CTION:
 V06 N--
 R1-000--
 R2-000X
 R3-BLANK

R1 IS THE OPTION
 CODE FOR ASSUMED IMU
 ORIENTATION SELE
 TION

R2 IS THE CMC
 ASSUMED OPTION:
 00001-PREFERRED
 00002-NOMINAL

MONITOR DSKY:
 OBSERVE VERB-NOJN
 TO REQUEST RESPONSE
 AND DISPLAY OF
 OPTION CODE FOR
 ASSUMED IMU ORIENTA
 TION SELECTION

#80

#90

IS THIS THE IMU
 ORIENTATION I
 DESIRE?

.Y .N

#100

WAIT FOR KEYBOARD
 ENTRY

KEY IN PROCEED
 V33E

#110

TERMINATE FLASH UPON
 RECEIPT OF PROCEED
 OR NEW DATA

KEY IN V22
 AND LOAD THE
 DESIRED ORIENTA
 TION
 CODE IN R2

#120

.P .NEW
 .R .CODE
 .O
 .C
 .E
 .E
 .D

NEW CODE

#130

IS STORED ORIENTATION CODE 00001?

.N .Y

IS PREFERRED ORIENTATION FLAG SET?

.Y .N

GO TO "A" BELOW

FLASH VERB-NOUN TO REQUEST RESPONSE AND DISPLAY ALARM CODE:

V05N31
R1-
R2-
R3-

POSS
HOLD

WAS PREFERRED IMU ORIENTATION SELECTED

.Y .N

MONITOR DSKY: DOES ALARM CODE DISPLAY INDICATE THAT A PREFERRED IMU ORIENTATION HAS NOT BEEN SPECIFIED?

.Y .N

GO TO "A" BELOW

IS THE NOMINAL IMU ORIENTATION SATISFACTORY OR DO I WANT A PREFERRED IMU ORIENTATION?

.NOM .PREF

#140

#150

#160

#170

#180

WAIT FOR KEY-
BOARD ENTRY

KEY IN
RECYCLE
V32E

#190

TERMINATE FLASH
UPON RECEIPT OF
RECYCLE OR NEW
PROGRAM

SELECT DESIRED
PROGRAM TO
DEFINE A PRE-
FERRED IMU
ORIENTATION
AND THEN RE-
SELECT THIS
PROGRAM.
KEY IN
V37--E

#200

NEW RECYCLE
PROG.

GO TO PROGRAM
SELECTED

EXIT P53

GO TO PROGRAM
SELECTED

#210

#220

EXIT P53

SELECT T (ALIGN)
EQUAL TO TIG OF
NEXT MANEUVER IF
AVAILABLE, OTHER-
WISE EQUAL TO
PRESENT TIME
+ - MINUTES

#230

#240

P53/CSM2/278

HOLD

FLASH VERB-NOUN
 TO REQUEST
 RESPONSE AND
 DISPLAY T(ALIGN:)
 V06 N--
 R1-T(ALIGN)-HRS
 R2-T(ALIGN)-MINS
 R3-T(ALIGN)-SECS

T(ALIGN) - TIME
 (GET) AT WHICH
 VEHICLE POSITION
 AND VELOCITY
 VECTORS ARE
 SELECTED TO
 DEFINE NOMINAL
 IMU ORIENTATION
 AND NOMINAL
 CSM ATTITUDE. IN
 HRS, MINS, SECS,
 TO NEAREST .01
 SEC.

WAIT FOR KEY-
 BOARD ENTRY

TERMINATE FLASH
 UPON RECEIPT OF
 PROCEED OR NEW
 DATA

.PROCEED .NEW
 .DATA
 STORE DATA

MONITOR DSKY;
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF T(ALIGN)

AM I SATISFIED WITH
 THIS VALUE?

.Y .N

KEY IN PROCEED
 V33E

KEY IN
 V25 AND
 LOAD
 DESIRED
 T(ALIGN)

#250

#260

#270

#280

#290



TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW DATA

.P .NEW
.R .CODE
.O .
.C .
.E .
.E .
.D .NEW CODE

KEY IN V22
AND LOAD THE
DESIRED
ATTITUDE
CODE IN R2

#350

IS STORED ATTITUDE
CODE 00001

.N .Y
. .
. .
. .
GO TO
"B"
BELOW

WAS PREFERRED CSM
ATTITUDE SELECTED

.Y .N

#360

IS PREFERRED
ORIENTATION FLAG
SET?

.Y .N

#370

#380

POSS
HOLD

FLASH VERB-NOUN TO
REQUEST RESPONSE
AND DISPLAY ALARM
CODE:
V05 N31
R1-
R2-
R3-

MONITOR DSKY:
DOES ALARM CODE
DISPLAY INDICATE
THAT A PREFERRED
CSM ATTITUDE HAS
NOT BEEN
SPECIFIED?

.Y .N

#390

4 3018

GO TO
"A"
BELOW

#400

IS THE NOMINAL
CSM ATTITUDE
SATISFACTORY
OR DO I STILL
WANT A PRE-
FERRED CSM
ATTITUDE?

#410

•NOM •PREF

WAIT FOR KEYBOARD
ENTRY

KEY IN
RECYCLE
V32E

#420

TERMINATE FLASH
UPON RECEIPT OF
RECYCLE OR NEW
PROGRAM

SELECT DESIRED
PROGRAM TO
DEFINE A PRE-
FERRED CSM ATTITUDE AND THEN
RESELECT THIS
PROGRAM.
KEY IN
V37--E

#430

•NEW •RECYCLE
•PROG. •

#440

GO TO PROGRAM
SELECTED

GO TO PROGRAM
SELECTED

EXIT P53

EXIT P53

#450

4 5817

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR RECYCLE

KEY IN RECYCLE
V32E

•R	•P
•E	•R
•C	•O
•Y	•C
•C	•E
•L	•E
•E	•D

RETURN TO
START OF
THIS PROGRAM

RETURN TO
START OF
THIS PROGRAM

"A"
SEE ABOVE

SELECT PREFERRED
IMU ORIENTATION
AND PREFERRED CSM
ATTITUDE FOR
USE BY FOLLOWING
COMPUTATIONS

SELECT PREFERRED
CSM ATTITUDE
FOR USE BY
FOLLOWING
COMPUTATIONS

"B"
SEE ABOVE

#500

#510

#520

#530

#540

#550

4 3816

:
 :
 :
 :
 :
 :

 DO STAR SELECTION
 ROUTINE (REFER TO
 SECTION 5.5.3 OF
 R547 VOL I)
 (NOTE: THIS ROUTINE
 WILL SELECT ONE SET
 OF STARS FROM THE
 FOLLOWING CASES IN
 ORDER OF SELECTION
 PRIORITY:

(A) THE OPTICS
 CAN ACQUIRE 2
 NAVIGATION STARS
 FROM THE PRESENT
 VEHICLE ATTITUDE
 (1) AND AN INTER-
 IM IMU ORIENTAT-
 ION IS NOT REQUI-
 RED (INTERIM
 PLATFORM FLAG
 IS RESET). DESIG-
 NATE THESE STARS
 AS #1 AND #2, AND
 SET INITIAL STAR
 SIGHT FLAG.

#610

(B) THE OPTICS
 CAN ACQUIRE 2
 NAVIGATION STARS
 FROM THE FINAL
 VEHICLE ATTITUDE
 (3). DESIGNATE
 THESE STARS AS #1
 AND #2.

#620

#630

(C) NEITHER CASE
 (A) OR (B) ABOVE
 APPLIES.
 CALCULATE AN IN-
 TERIM VEHICLE AT-
 TITUDE (2) FROM
 WHICH 2 NAVIGA-
 TION STARS CAN BE
 ACQUIRED AND
 WHICH DOES NOT
 RESULT IN GIMBAL
 LOCK WHEN THE IMU
 IS AT THE FINAL
 ORIENTATION (D).
 DESIGNATE THESE
 STARS AS #1 AND
 #2. SET THE
 INTERIM VEHICLE
 FLAG.)

#640

#650

IS INTERIM PLATFORM
FLAG SET?

.Y .N
.
.
.
.
.
.
.
.
.
.

#660

IS INTERIM VEHICLE
FLAG SET?

.Y .N
.
.
.
.

#670

IS INITIAL STAR
SIGHT FLAG SET?

.N .Y
.
.
.
.

"A"
SEE ABOVE

#680

DISPLAY ON DSKY
10 SEC:
V01 N25
R1-00050
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE 10 SEC DIS-
PLAY OF CODE INDICA-
TING SEQUENCE FOR
IMU ORIENTATION AND
VEHICLE ATTITUDE FOR
STAR SIGHTINGS.

#690

00050- FINAL IMU
ORIENTATION(C/D).
STAR SIGHTINGS
REQUIRED AT PRES-
ENT VEHICLE AT-
TITUDE (1).

#700

DISPLAY ON DSKY 10
SEC:
V01 N25
R1-00051
R2-BLANK
R3-BLANK

#710

4 3015

00051-FINAL IMU
 ORIENTATION (C/D).
 STAR SIGHTINGS
 REQUIRED AT FINAL
 VEHICLE ATTITUDE
 (3).

#720

 DISPLAY ON DSKY 10
 SEC:
 V01 N25
 R1-00053
 R2-BLANK
 R3-BLANK

#730

00053-FINAL IMU
 ORIENTATION(C/D).
 STAR SIGHTINGS
 REQUIRED AT INTERIM
 VEHICLE ATTITUDE
 (2).

#740

 IS INTERIM VEHICLE
 FLAG SET?

Y. .N

#750

 DISPLAY ON
 DSKY 10 SEC:
 V01 N25
 R1-00052
 R2-BLANK
 R3-BLANK

#760

00052-INTERIM

IMU ORIENTA-
TION(B).
STAR SIGHT-
INGS REQUIRED
AT FINAL VE-
HICLE ATTI-
TUDE(3).

#770

DISPLAY ON
DSKY 10 SEC:
V01 N25
R1-00054
R2-BLANK
R3-BLANK

#780

00054-INTERIM
IMU ORIENTA-
TION(B).
STAR SIGHT-
INGS REQUIRED
AT INTERIM
VEHICLE ATTI-
TUDE (2).

#790

CALCULATE AN
INTERIM IMU
ORIENTATION(B)
WHICH DOES NOT
CAUSE GIMBAL
LOCK WHEN VEH-
ICLE IS AT
ITS INTERIM
ATTITUDE (2)
OR PRESENT
ATTITUDE (1).

#800

#810

232

A 5814

```

-----
CALCULATE AN
INTERIM IMU
ORIENTATION(B)
WHICH DOES NOT
CAUSE GIMBAL
LOCK WHEN VEH-
ICLE IS AT
ITS FINAL
ATTITUDE (3)
OR PRESENT
ATTITUDE (1).
-----

```

#820

```

-----
SELECT INTERIM
IMU INERTIAL
ORIENTATION(B)
FOR USE BY
COARSE ALIGN
ROUTINE (R50).
-----

```

#830

```

-----
SELECT FINAL
IMU INERTIAL
ORIENTATION (D)
FOR USE BY
COARSE ALIGN
ROUTINE (R50).
-----

```

#840

#850

```

-----
DO COARSE ALIGN
ROUTINE (R 50)
-----

```

#860

IS INITIAL STAR
SIGHT FLAG SET?

.N .Y

IS INTERIM VEHICLE
ATTITUDE FLAG SET

Y. .N

RESET
INTERIM
VEHICLE
FLAG

SELECT INTERIM
VEHICLE ATTITUDE (2) FOR
ATTITUDE
MANEUVER
ROUTINE (R60).

SELECT FINAL
VEHICLE ATTITUDE
(3) FOR ATTITUDE
MANEUVER ROUTINE
(R60).

SET THREE - AXIS FLAG
FOR USE BY ATTITUDE
MANEUVER ROUTINE
(R60).

DID PREVIOUS DSKY
DISPLAY INDICATE
THAT STAR SIGHTINGS
WERE NECESSARY FROM
THE PRESENT VEHICLE
ATTITUDE (1)
(R1-00050)?

.Y .N

#870

#880

#890

#900

#910

#920

4 5813

DO ATTITUDE MANEUVER
ROUTINE (R 60).

DO ATTITUDE MANEUVER
ROUTINE (R 60).

IS INTERIM PLATFORM
FLAG SET?

DID PREVIOUS DSKY
DISPLAY INDICATE
THAT AN INTERIM IMU
ORIENTATION WAS
REQUIRED. (R1-00053
OR 00054)?

.N .Y

.Y .N

RESET IN-
TERIM
PLATFORM
FLAG

SELECT FINAL
IMU ORIENTA-
TION (D) FOR
USE BY COARSE
ALIGN ROUTINE
(R50)

DO COARSE
ALIGN ROUTINE
(R50)

WAIT --SEC-
ONDS FOR
COMPLETION
OF COARSE
ALIGNMENT

DO FINE ALIGN
ROUTINE (R51).

DO FINE ALIGN
ROUTINE (R51).

#930

#940

#950

#960

#970

4 5812

WAS TRACK FLAG SET
AT P53 INITIATION?

.Y .N

SET TRACK FLAG

#1040

DEPENDING UPON THE
ORIGINAL PROGRAM
CALLING P53 FLASH
VERB-NOUN TO REQUEST
PLEASE PERFORM
SELECTION OF
PROGRAM (P--).

V50 N07
R1-000--
R2-BLANK
R3-BLANK

RELATIONSHIP OF
ORIGINAL PROGRAM
TO REQUESTED PROGRAM
IS AS FOLLOWS:

P40/P40
P41/P41
P22/P22

MONITOR DSKY:
OBSERVE FLASHING
VERB-NOUN TO REQUEST
SELECTION OF
ORIGINAL PROGRAM
CALLING FOR IN-
FLIGHT ALIGNMENT

#1050

.....
HOLD

#1060

WAIT FOR DSKY ENTRY

KEY IN DESIRED
PROGRAM

V37E --E

#1070

TERMINATE P53 AND
GO TO PROGRAM
SELECTED

MONITOR DSKY:
OBSERVE TERMINATION
OF P 53 AND DISPLAY
OF P --

#1080

EXIT P 53

EXIT P 53

238

END OF RUN

IS AVERAGE G INTE-
GRATION ON?

*40

.Y .N

EXTRAPOLATE STATE
VECTOR TO T1=
PRESENT TIME +
60 SEC

*50

WAIT UNTIL T1

TURN ON AVERAGE G

*60

IS UNIT (V X R)

WITHIN 30 DEG OF

+Y ?

-SM

*70

.Y .N

IS UNIT (V X R)

WITHIN 30 DEG OF

-Y ?

-SM

.Y .N

*80

VPRED- PREDICTED
 INERTIAL VELOCITY
 AT 400,000 FT
 ALTITUDE ABOVE
 LAUNCH PAD RADIUS.
 IN FPS TO NEAREST
 FPS.

#140

GAMMA EI - FLIGHT
 PATH ANGLE. ANGLE
 BETWEEN INERTIAL
 VELOCITY AND THE
 LOCAL HORIZONTAL
 AT THE ENTRY INTER-
 FACE ALTITUDE
 (400,000 FT). IN
 DEGREES TO NEAREST
 .01 DEG.

#150

 RECORD DATA IF
 NECESSARY

#160

 WAIT FOR KEYBOARD
 ENTRY

 KEY IN PROCEED
 V 33 E

#170

 TERMINATE FLASH UPON
 RECEIPT OF PROCEED

#180

.....
 HOLD FLASH VERB-NOUN
 TO REQUEST RESPONSE
 AND DISPLAY:
 V06 N--
 R1 - RTGO
 R2 - VIO
 R3 - TTE

 MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF EMS INITIALIZATION
 PARAMETERS

#190

RTGO -- RANGE TO GO
FROM 21,210,384 FT.
GEOCENTRIC RADIUS
MAGNITUDE TO THE
SPLASH POINT. IN
NAUTICAL MILES TO
NEAREST .1 NM.

VIO -- PREDICTED
INERTIAL VELOCITY
AT 21,210,384 FT.
RADIUS IN FPS TO
NEAREST FPS.

TTE -- TIME TO GO
FROM NOW TO
21,210,384 FT.
RADIUS IN
MIN AND SEC TO
NEAREST SEC. MAX
READING IS 59-59.

:.
:.
:.

WAIT FOR KEYBOARD
ENTRY

TERMINATE FLASH UPON
RECEIPT OF PROCEED

:.
:.
:.

SELECT CSM ORIENTA-
TION FOR CM/SM SEP-
ARATION FROM STORAGE
CSM +X AXIS POINTED
IN DIRECTION OF
FLIGHT AND 60 DE-
GREES ABOVE VELOCITY
VECTOR. +Y AXIS IN
DIRECTION OF ANGULAR
MOMENTUM VECTOR.
R X V. THIS ATTITUDE
IS ARRIVED AT BY
MEANS OF A SIMPLE
PITCH UP MANEUVER
FROM THE NOMINAL
HEADS UP RETRO BURN
ATTITUDE

RECORD DATA FOR
EMS INITIALIZATION

KEY IN PROCEED
V33E

#200

#210

#220

#230

#240

244

.....

 CALCULATE CSM INER-
 TIAL ORIENTATION FOR
 CM/SM SEPARATION AND
 STORE FOR USE BY
 ATTITUDE MANEUVER
 ROUTINE (R60)

#250

.....

 SET THREE AXIS FLAG

#260

.....

 DO ATTITUDE MANEUVER
 ROUTINE (R60)

.....

 DO ATTITUDE MANEUVER
 ROUTINE (R60)

#270

.....

 TERMINATE PROGRAM
 61 AND GO ON TO
 ENTRY - CM/SM SEP-
 ARATION AND PRE-
 ENTRY MANEUVER
 PROGRAM (P 62)

.....

 MONITOR DSKY:
 OBSERVE TERMINATION
 OF P 61 AND DISPLAY
 OF P 62

#280

.....

 EXIT P 61

.....

 EXIT P 61

#290

END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

ENTRY - CM/SM SEPARATION AND PRE-ENTRY MANEUVER PROGRAM (P62)

REV 7

10/31/66

- PURPOSE: (1) TO NOTIFY CREW WHEN GNC SYSTEM IS PREPARED FOR CM/SM SEPARATION.
 (2) TO ORIENT THE CM TO THE CORRECT ATTITUDE FOR ATMOSPHERIC ENTRY.

- ASSUMPTIONS: (1) THE PROGRAM IS ENTERED WITH ADEQUATE FREE FALL TIME TO ACCOMPLISH CM/SM SEPARATION AND TO COMPLETE THE MANEUVER FROM A WORST CASE STARTING ATTITUDE.
 (2) THE IMU IS SATISFACTORILY ALIGNED FOR ENTRY.
 (3) THE PROGRAM IS AUTOMATICALLY SELECTED BY THE ENTRY MANEUVER TO CM/SM SEPARATION ATTITUDE PROGRAM (P61) OR IT MAY BE SELECTED MANUALLY.
 (4) THE SPLASH POINT COORDINATE MAY HAVE BEEN LOADED INTO THE CORRECT ERASABLE REGISTER PRIOR TO THE DE-ORBIT BURN.

PROG CONT	CMC	MESC	CREW	CHECKLIST	TIME	TOTAL TIME
	.CMC PROG .SELECTION . . . . .		.CREW PROG .SELECTION			#10
	-----		-----			
	DO PROGRAM SELECTION CHECK ROUTINE (R01)	.....	KEY IN ENTRY: CM/SM SEPARATION AND PRE-ENTRY MANEUVER PROGRAM (P62) V37E 62E			

			. . .			#20
		.....	-----	DO PROGRAM SELECTION CHECK ROUTINE (R01)		
	-----		-----			
	. . .					
	-----		-----			
	START ENTRY- CM/SM SEPARATION AND PRE-ENTRY MANEUVER PROGRAM (P 62) DISPLAY PROGRAM 62	.....	MONITOR DSKY: OBSERVE DISPLAY OF PROGRAM 62			#30
	-----		-----			
					

#40

IS AVERAGE G INTEG-
RATION ON?

Y . N

EXTRA-
POLATE
STATE
VECTOR
TO T2 =
PRESENT
TIME +
60 SEC

#50

#60

WAIT
UNTIL
T2

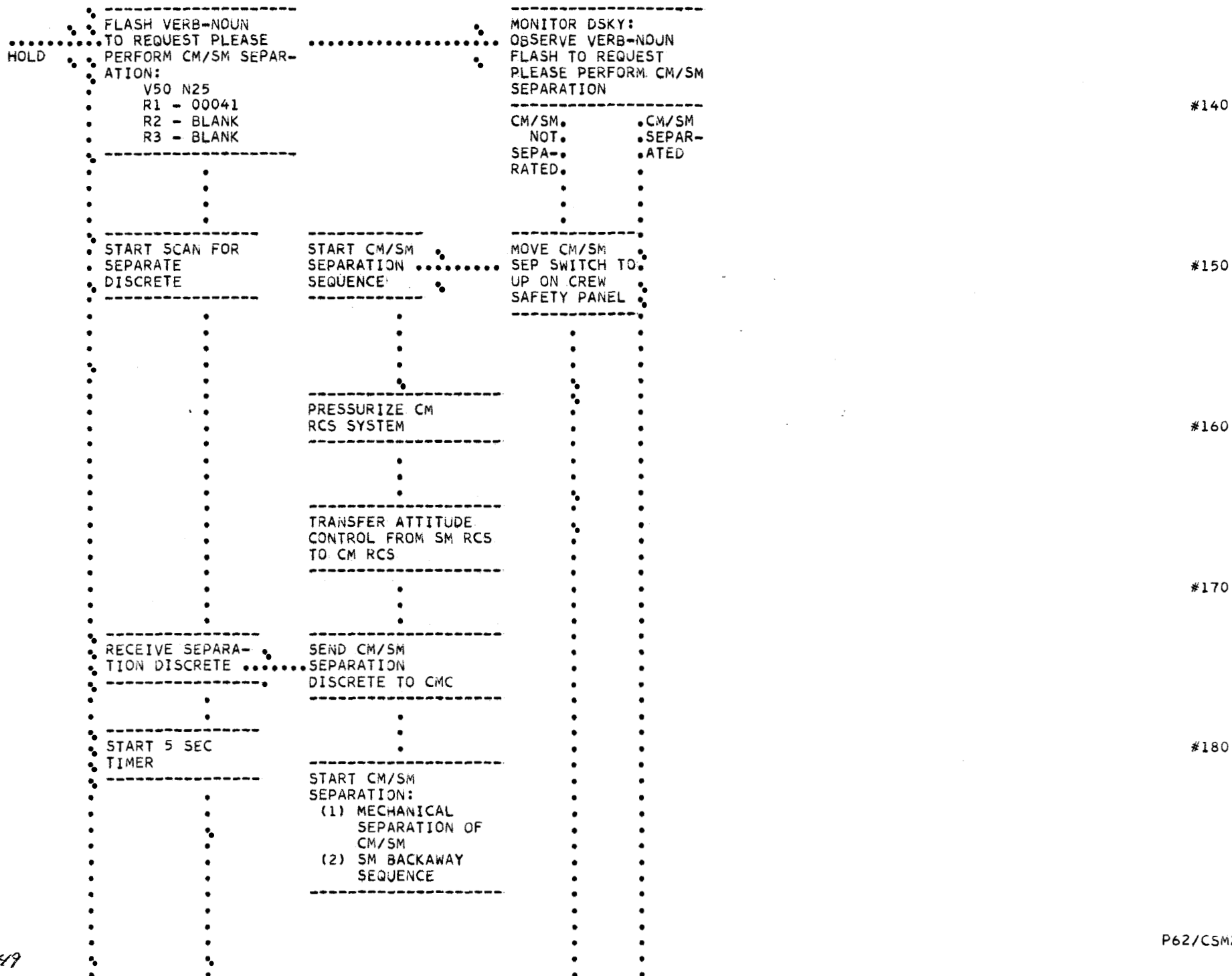
#70

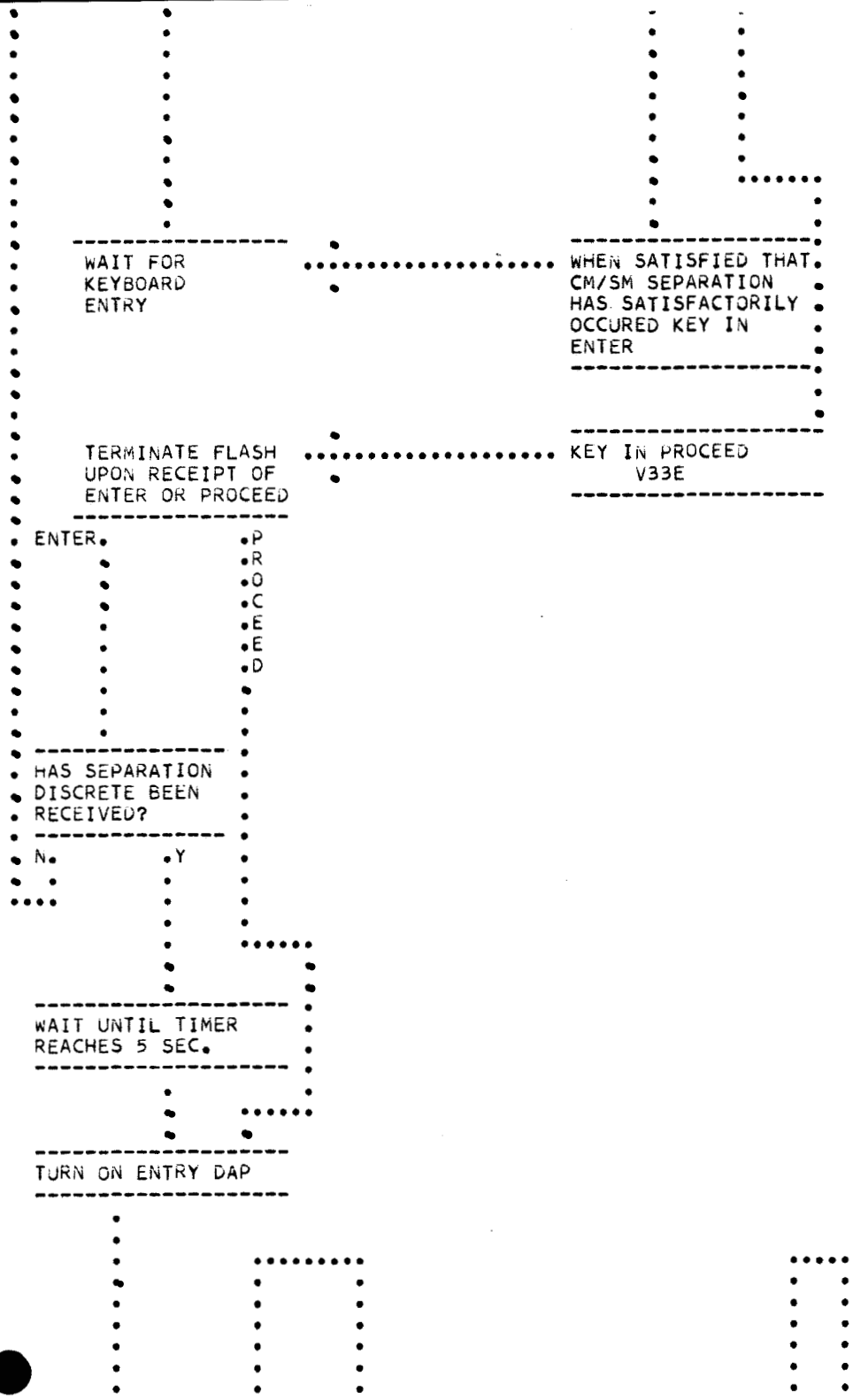
TURN ON
AVERAGE
G

#80

IS UNIT (V X R)
WITHIN 30 DEG OF
+Y ?
-SM

Y . N





#190

#200

#210

#220

#230

#240

.....
 HOLD
 FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY STORED DATA
 V06 N62
 R1-IMPACT LAT
 R2-IMPACT LONG
 R3-HEADS UP/DOWN

IMPACT LAT - LATI-
 TUDE OF DESIRED
 IMPACT POINT. IN
 DEGREES TO NEAREST
 .01 DEG. + IS NORTH

IMPACT LONG - LONG-
 ITUDE OF DESIRED
 IMPACT POINT. IN
 DEGREES TO NEAREST
 .01 DEG. + IS EAST

HEADS UP/DOWN -
 DEFINES ENTRY ROLL
 ATTITUDE
 +00001 FOR HEADS UP/
 LIFT DOWN
 -00001 FOR HEADS DOWN
 /LIFT UP

 WAIT FOR KEYBOARD
 ENTRY

TERMINATE FLASH
 UPON RECEIPT OF
 PROCEED OR NEW DATA

P. .NEW
 R. .DATA
 O. .
 C. .
 E. -----
 E. STORE DATA
 D. -----
 .
 .
 .
 .
 .
 .

 MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF S/C ENTRY DATA
 NOTE THAT LAT AND
 LONG MAY HAVE BEEN
 LOADED BEFORE RETRO-
 BURN TO SPEED UP
 THIS LOAD ROUTINE

 AM I SATISFIED WITH
 THESE VALUES?

.Y .N
 .
 .

 KEY IN PROCEED
 V33E

 KEY IN
 V25
 AND LOAD
 DESIRED
 PARAMETERS

 .
 .
 .
 .
 .
 .

#250

#260

#270

#280

#290

#300

.....
 COMPUTE CM
 INERTIAL ATTITUDE
 NECESSARY TO GIVE
 THE CORRECT ANGLE
 OF ATTACK (ALPHA)
 AT ENTRY INTO
 THE ATMOSPHERE. FOR
 LIFT DOWN THIS ATTITUDE
 WILL BE OBTAINED AFTER A SIMPLE
 PITCH DOWN MANEUVER
 FROM THE SEPARATION
 ATTITUDE. FOR LIFT
 UP AN ADDITIONAL 180
 DEG. ROLL IS
 REQUIRED

#310

.....
 DISPLAY ON DSKY DESIRED
 FINAL GIMBAL ANGLES:
 V06 N17
 R1- OG ROLL
 R2- IG PITCH
 R3- MG YAW

#320

IN DEGREES TO
 NEAREST .01 DEG.

#330

.....
 DO MANEUVER CALCULATION
 AND DAP DRIVE
 AT 4 DEG/SEC

#340

.....
 TERMINATE PROGRAM
 62 AND GO TO ENTRY-
 INITIALIZATION PROG.
 (P 63)

.....
 MONITOR DSKY:
 OBSERVE TERMINATION
 OF P 62 AND DISPLAY
 OF P 63

#350

END OF RUN

254

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

ENTRY-INITIALIZATION PROGRAM (P63)

REV 6

10/20/66

- PURPOSE:
- (1) TO INITIALIZE THE ENTRY EQUATIONS.
 - (2) TO CONTINUE TO HOLD THE CM TO THE CORRECT ATTITUDE WITH RESPECT TO THE ATMOSPHERE FOR THE ONSET OF ENTRY DECELERATION.
 - (3) TO ESTABLISH ENTRY DSKY DISPLAYS.
 - (4) TO SENSE .05G AND DISPLAY THIS EVENT TO THE CREW BY SELECTING THE ENTRY-POST 0.05G PROGRAM (P64).
- ASSUMPTIONS: (1) THE PROGRAM IS AUTOMATICALLY SELECTED BY THE ENTRY-CM/SM SEPARATION AND PRE-ENTRY MANEUVER PROGRAM (P62).

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
	.CMC PROG .SELECTION -----					#10
	START ENTRY - INITIALIZATION PROGRAM (63) DISPLAY PROGRAM 63 -----			----- . MONITOR DSKY: . OBSERVE DISPLAY OF PROGRAM 63 -----		#20
	. . . -----					
	PERFORM ENTRY INITIALIZATION ROUTINE WHICH INCLUDES: A-CONTINUE CALCU- LATION OF INITIAL ROLL ANGLE AS A FUNCTION OF INERTIAL VELOCITY AND FLIGHT PATH ANGLE.					#30

255

256

B-CONTINUE CALCULATION
OF DESIRED CM
PITCH AND YAW
ATTITUDE AS DETERMI-
NED BY THE VEHICLES
POSITION AND VEL-
OCITY W.R.T. THE
ATMOSPHERE. PRIOR
TO .05G THIS
ATTITUDE IS ZERO
SIDESLIP AND ANGLE
OF ATTACK NEAR
TRIM VALUE.

*40

•
•
•

MAINTAIN CM ATTITUDE
FOR LIFT VECTOR UP/
DOWN, AS SELECTED,
ZERO SIDESLIP,
AND TRIM ANGLE OF
ATTACK

*50

•
•
•

DISPLAY ON DSKY:
V06 N54
R1-BETA
R2-VI
R3-R TO TARG

.....

• MONITOR DSKY:
• OBSERVE DISPLAY OF
BETA, VI AND R TO
TARG

*70

BETA-COMMANDED BANK
ANGLE IN DEGREES
TO NEAREST .01
DEGREE.

•

MONITOR GNCS CONTROL
OF PRE - .05G CM
ATTITUDE:

VI-INERTIAL VELOCITY
IN FPS TO NEAREST
FPS

(1) DSKY:

R TO TARG - RANGE TO
GO TO THE DESIRED
SPLASH POINT
ASSUMING SPLASH
POINT LOCATED AT
CALCULATED IMPACT
TIME. IN NAUTICAL
MILES TO NEAREST
.1 NM.

R1-BETA REMAINS
AT 180 DEG FOR
LIFT DOWN/HEADS
UP OR AT 0 DEG
FOR LIFT UP/
HEADS DOWN DE-
PENDING UPON
ATTITUDE REQUES-
TED BY CREW IN
P62

*80

•
•
•

R2-VI-NOMINAL

*90

R3-R TO TARG-
DECREASING:

(2) FDAI:

ATTITUDE RATES
LESS THAN--DEG./
SEC.

#100

ATTITUDE ERRORS
LESS THAN --DEG.

BALL: ROLL= DEG
CORRESPONDING TO
BETA IN R1 DSKY
DISPLAY

PITCH= --- DEG
AT ---
YAW= 0 DEG

#110

WAIT FOR .05G
INDICATION

ENTRY LOGIC DETECTS
.05G

#120

TERMINATE P63 AND GO
TO ENTRY-POST 0.05G
PROGRAM (P64)

.....

MONITOR DSKY:
OBSERVE TERMINATION
OF P63 AND DISPLAY
OF P64

#130

.Y .N

.....
EXIT P63

#140

258

HAS .05G OCCURED
YET ACCORDING TO
SEAT OF PANTS

.Y .N
. . .
. . .

#150

GO TO BACKUP
PROCEDURES

#160

EXIT P63

END OF RUN

260

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

10/26/66

REV 5

ENTRY - POST 0.05 G PROGRAM (P64)

PURPOSE:

- 1. TO START ENTRY GUIDANCE AT .05G AND CONTINUE IT TO .2G.
- 2. TO ESTABLISH THE 0.05 G MODE IN THE SCS.
- 3. TO SENSE .2G AND THEREJON TO SELECT THE ENTRY-FINAL PHASE PROGRAM (P67)
- 4. TO CONTINUE ENTRY DSKY DISPLAYS

ASSUMPTIONS: (1) THE PROGRAM IS AUTOMATICALLY SELECTED BY THE ENTRY INITIALIZATION PROGRAM (P 63).

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
--------------	-----	--------	------	-----------	------	---------------

```

.CMC PROG.
.SELECTION
.
.
.
.

```

#10

```

-----
START ENTRY-POST
0.05 G PROGRAM
(P 64)
-----

```

```

-----
DISPLAY PROGRAM 64
-----

```

#20

```

-----
MONITOR DSKY:
OBSERVE DISPLAY OF
PROGRAM 64
-----

```

```

-----
SET 0.05 G ENTRY
SWITCH ON SCS
CONTROL PANEL TO ON
-----

```

#30

DISPLAY ON DSKY:
V06 N54
R1-BETA
R2-VI
R3-H DOT

BETA-COMMANDED BANK
ANGLE. IN DEGREES
TO NEAREST .01
DEGREE

VI - INERTIAL
VELOCITY. IN FPS TO
NEAREST FPS

H DOT - RATE
OF CHANGE OF
ALTITUDE.
IN FPS TO
NEAREST FPS.

COMMAND CM ATTITUDE
IN ACCORDANCE WITH
CMC ENTRY LOGIC

FOR A NOMINAL MISS-
ION 278 OR 503 ENTRY.....
(EITHER FROM ORBIT
OR BOOST ABORT) THE
CMC WILL GO DIRECTLY
P 64 TO P 67 WHEN G=
.2

TERMINATE P64 AND GO
TO ENTRY-FINAL PHASE
PROGRAM (P 67)

.....
EXIT P 64

MONITOR G+N CONTROL
OF ENTRY:

(A) FDAI:
ATT ERRORS LESS
THAN --DEG

ATT RATES LESS
THAN --DEG/SEC

BALL INDICATES
LIFT VECTOR
DIRECTION COR-
RELATION WITH
BETA

(B) DSKY:
R1-BETA VARIES
TO LIMIT G AND
CONTROL LIFT
VECTOR

R2 - VI
DECREASING
R3-H DOT
NOMINAL

MONITOR DSKY:
OBSERVE TERMINATION
OF P 64 AND DISPLAY
OF P 67

.Y .N

.....
GO TO BACKUP
PROCEDURES

.....
EXIT P 64

#40

#50

#60

#70

#80

#90

267

END OF RUN

.....

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

ENTRY - FINAL PHASE PROGRAM (P67)

REV 5

10/26/66

PURPOSE: (1) TO CONTINUE ENTRY GUIDANCE AFTER .2G UNTIL TERMINATION OF STEERING WHEN THE CM VELOCITY WRT EARTH = 1000 FT/SEC (ALTITUDE IS APPROXIMATELY .65,000 FT.).

(2) TO CONTINUE ENTRY DSKY DISPLAYS.

ASSUMPTIONS: (1) THE PROGRAM IS AUTOMATICALLY SELECTED BY THE ENTRY-POST 0.05G PROGRAM (P64).

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
	.CMC PROG. .SELECTION				#10	
	----- START ENTRY-FINAL PHASE PROGRAM (P 67) -----				#20	
	----- DISPLAY PROGRAM 67 ----- . . . .	.....		----- MONITOR DSKY: OBSERVE DISPLAY OF PROGRAM 67 -----		
	----- DISPLAY ON DSKY: V06 N71 R1-BETA R2-X RNG ERR R3-DWN RNG ERR	.....		----- MONITOR G+N CONTROL OF ENTRY: (A)FDAI: ATT ERRORS LESS THAN --DEG ATT RATES LESS THAN --DEG/SEC.	#30	

LONG - LONGITUDE OF
PRESENT POSITION. IN
DEGREES TO NEAREST
.01 DEG.
(+ IS EAST)

#90

MONITOR ALTIMETER
AND STANDBY TO BACK-
UP MESC FOR CHUTE
DEPLOYMENT

#100

WAIT FOR KEYBOARD
ENTRY

WHEN CM IS ON THE
CHUTES KEY IN
PROCEED
V33E

#110

TERMINATE FLASH UPON
RECEIPT OF PROCEED

TURN OFF ENTRY DAP

#120

TERMINATE P67 AND GO
TO AGC IDLING
PROGRAM (P00)

OBSERVE TERMINATION
OF P67 AND DISPLAY
OF P00

#130

EXIT P67

EXIT P67

266

END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

LM TRANSFER PHASE INITIATION (TPI) TARGETING PROGRAM (P74)

REV 9

10/26/66

PURPOSE:

(1) TO CALCULATE THE REQUIRED DELTA V AND OTHER INITIAL CONDITIONS REQUIRED BY THE LGC FOR LM EXECUTION OF THE TRANSFER PHASE INITIATION MANEUVER, GIVEN:

(A) TIME OF IGNITION TIG (TPI) OR THE ELEVATION ANGLE (E) OF THE CSM/LM LOS AT TIG(TPI).

(B) TRANSFER DURATION (DELTA T TRANS) FROM TIG(TPI) TO INTERCEPT TIME.

(2) TO CALCULATE TIG (TPI) GIVEN E OR E GIVEN TIG (TPI).

(3) TO CALCULATE THESE PARAMETERS BASED UPON MANEUVER DATA APPROVED AND KEYED INTO THE CMC BY THE ASTRONAUT.

(4) TO DISPLAY TO THE ASTRONAUT AND THE GROUND CERTAIN DEPENDENT VARIABLES ASSOCIATED WITH THE MANEUVER FOR APPROVAL BY THE ASTRONAUT/GROUND.

(5) THIS PROGRAM IS DESIGNED FOR ONE-MAN OPERATION.

ASSUMPTIONS:

(1) STATE VECTOR UPDATES BY P27 ARE DISALLOWED DURING STATE VECTOR UPDATING INITIATED BY P20 (SEE ASSUMPTION (3)).

(2) THE PROGRAM MUST BE DONE OVER A TRACKING STATION FOR REAL TIME GROUND PARTICIPATION IN CMC DATA INPUT AND OUTPUT. CMC COMPUTED VARIABLES MAY BE STORED FOR LATER VERIFICATION BY THE GROUND. THESE STORAGE CAPABILITIES ARE LIMITED ONLY TO THE PARAMETERS FOR ONE THRUSTING MANEUVER AT A TIME EXCEPT FOR CONCENTRIC FLIGHT PLAN MANEUVER SEQUENCES.

(3) THIS PROGRAM MAY BE PERFORMED CONCURRENTLY WITH THE RENDEZVOUS NAVIGATION PROGRAM (P20) TO UPDATE THE LM OR CSM STATE VECTORS WITH OPTICAL TRACKING OF THE LM. THIS PROGRAM MAY ALSO BE PERFORMED INDEPENDANTLY OF P20. IF OPTICAL TRACKING IS DESIRED THE OPTICS SHOULD BE LOCKED ON THE LM BY PREVIOUS SELECTION OF P20. THE RENDEZVOUS TRACKING MARK COUNTER IS ZEROED BY THE SELECTION OF P20 AND AFTER EACH THRUSTING MANEUVER.

IF P20 IS IN EFFECT, OPTICAL TRACKING MARKS MAY BE MADE BY SELECTION OF THE RENDEZVOUS TRACKING DATA PROCESSING ROUTINE (R22). R22 IS SELECTED BY V--E WHICH MAY BE ENTERED WHENEVER THE CMC IS HOLDING FOR A V/N FLASHING DATA DISPLAY (NOTE: FOR SIMPLICITY IT IS ONLY SHOWN BELOW AT THE V06N--DISPLAY.) R22 RETURNS TO THIS PROGRAM AT THE INTERRUPTED DISPLAY.

(4) THERE IS NO REQUIREMENT FOR ISS OPERATION DURING THIS PROGRAM UNLESS STATE VECTOR UPDATING IS DESIRED BY THE RENDEZVOUS NAVIGATION PROGRAM (P20). IF SELECTED (SEE ASSUMPTION 3) P20 WILL DEFINE THE STATUS OF THE ISS.

(5) THE OPERATION OF THE PROGRAM UTILIZES THE FOLLOWING FLAGS:

ACTIVE VEHICLE FLAG - DESIGNATES THE VEHICLE WHICH IS DOING RENDEZVOUS THRUSTING MANEUVERS TO THE PROGRAM WHICH CALCULATES THE MANEUVER PARAMETERS. SET AT THE START OF EACH RENDEZVOUS PRE-THRUSTING PROGRAM.

FINAL COMPUTATION FLAG - SELECTS FINAL PROGRAM DISPLAYS AFTER CREW HAS SELECTED THE FINAL MANEUVER COMPUTATION AND DISPLAY CYCLE.

(6) IN THE CREW LOGIC BELOW ASSOCIATED WITH THE FINAL ACCEPTANCE OF THE CMC COMPUTED PARAMETERS, THE FOLLOWING PERFORMANCE TIMES ARE ASSUMED:

(A) PARTIAL DATA LOAD - 1 MIN

(B) CMC MANEUVER COMPUTATION - SIGNIFICANTLY LESS THAN 1 MIN; DISREGARD

(C) MANEUVER PARAMETER DISPLAY AND CREW EVALUATION - 1 MIN

(D) TRANSMISSION OF ALL PARAMETERS TO THE LM - 5 MIN

(E) EXTERNAL DELTA V PROGRAM SELECTION AND EXECUTION BY THE LM CREW - 5 MIN

(F) THRUSTING PROGRAM SELECTION BY LM CREW AND COUNT DOWN TO TIG (TPI)-5 MIN (ASSUMES IMU ALIGNMENT IS SATISFACTORY)

(7) THIS PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY AT LEAST -- MIN BEFORE THE ESTIMATED TIME OF THE IGNITION.

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
			.CREW .PROG .SELECTION ...			#10
----- DO PROGRAM SELECTION CHECK ROUTINE (R01) -----		----- KEY IN LM TRANSFER PHASE INITIATION (TPI) TARGETING PROGRAM (P74) V37E 74E -----	I. KEY V37E 74E		#20
----- -----		----- DO PROGRAM SELECTION CHECK ROUTINE (R01) -----	II. PERFORM PROGRAM SELECTION CHECK ROUTINE(R01)		
----- -----		----- MONITOR DSKY: OBSERVE DISPLAY OF PROGRAM 74 -----			#30
----- -----						#40
----- SET ACTIVE VEHICLE FLAG TO LM -----						
----- -----						

RESET FINAL
COMPUTATION FLAG.

#50

SET TRACK FLAG
(SEE P20)

#60

SET UPDATE FLAG
(SEE P20)

#70

.....
HOLD
FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY OPTION CODE
FOR ASSUMED TPI
DATA LOAD OPTION:
V06 N--
R1-000--
R2-0000X
R3-BLANK

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF OPTION CODE FOR
TPI DATA LOAD OPTION

III. CHECK CMC FLASHES VERB-NOUN TO
REQUEST RESPONSE AND DISPLAYS
OPTIONS CODE FOR TPI DATA LOAD

#80

FL V06 N--

OPTION CODE 000-- OCTAL
OPTION 0000X OCTAL
BLANK

R1 IS THE OPTION
CODE FOR ASSUMED TPI
DATA LOAD OPTION.

#90

R2 IS THE CMC ASSU-
MED OPTION:
00001-LOAD TIG (TPI)
CMC COMPUTES
E.
00002-LOAD E: CMC
COMPUTES TIG
(TPI)

IS THIS DATA LOAD
OPTION CORRECT?

R1 IS THE OPTION CODE FOR ASSUMED
TPI DATA LOAD OPTION.

R2 IS THE CMC ASSUMED OPTION:
00001-LOAD TIG (TPI) CMC
COMPUTES E.
00002-LOAD E: CMC COMPUTES

#100

TIG (TPI)
 ACCEPT OPTION(R2):
 V33E

#110

REJECT OPTION(R2):
 V22E
 LOAD CORRECT OPTION(1E OR 2E)

#120

#130

#140

#150

IV. 1. IF TPI DATA LOAD OPTION 00001
 (TIG) SELECTED:
 CHECK CMC FLASHES VERB-NOUN TO
 REQUEST RESPONSE AND DISPLAYS
 TIG (TPI)
 FL V06 N34
 TIG (TPI) 00XXX. HRS (GET)

 KEY IN PROCEED
 V33E

 KEY IN V22
 AND LOAD
 DESIRED
 OPTION CODE
 IN R2

 DID I SPECIFY TIG
 (TPI) OR E TO THE
 LGC?

 MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF STORED TIG (TPI)
 CALCULATED FROM
 PREVIOUS PROGRAMS

 WAIT FOR KEYBOARD
 ENTRY

 TERMINATE FLASH
 UPON RECEIPT OF
 PROCEED OR NEW
 CODE

 NEW
 CODE

 STORE CODE

 CHECK DATA LOAD
 OPTION CODE

 00001
 TIG(TPI) E

 FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY STORED TIG
 (TPI) CALCULATED
 FROM PREVIOUS
 PROGRAMS:
 V06 N34
 R1-TIG (TPI)-HRS
 R2-TIG (TPI)-MIN
 R3-TIG (TPI)-SEC

PGSS

 HOLD

000X. MIN
0XX.XX SEC

TIG(TPI)-TIME OF TPI
IGNITION (GET).
IN HRS, MIN, SEC
TO NEAREST .01 SEC.

AM I SATISFIED WITH
THESE VALUES?

Y. N

RECORD THIS
VALUE FOR
FUTURE TRANS-
MISSION TO THE
LM

WAIT FOR KEYBOARD
ENTRY

KEY IN PROCEED
V 33 E

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW DATA

NEW DATA
STORE DATA

TIG (TPI): TIME OF TERMINAL
PHASE INITIATION IGNITION.

#160

ACCEPT:

RECORD TIG (TPI)

#170

V33E

GO TO STEP V

REJECT:

V25E
LOAD DESIRED TIG (TPI)

#180

#190

#200

POSS
.....
HOLD

FLASH VERB-NOUN
TO REQUEST RES-
PONSE AND DISPLAY
STORED E.
V06 N--
R1-BLANK
R2-E
R3-BLANK

E-ELEVATION ANGLE
THE ANGLE BE-
TWEEN THE LM/CSM
LOS AND THE LOCAL
LM HORIZONTAL AT
TIG(TPI). MEAS-
URED FROM THE
DIRECTION OF
FLIGHT. IN DEG-
REES TO NEAREST
.01 DEGREE

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF STORED E.

2. IF TPI DATA LOAD OPTIO, 00002
(ELEVATION) SELECTED:
CHECK CMC FLASHES VERB-NOUN
TO REQUEST RESPONSE AND
DISPLAYS E.

#210

FL V06 N--

BLANK
E XXX.XX DEG
BLANK

E-ELEVATION ANGLE . THE ANGLE
BETWEEN THE LM/CSM LOS AND THE
LOCAL HORIZONTAL AT TIG(TPI) .
MEASURED FROM THE DIRECTION OF
FLIGHT.

#220

#230

AM I SATISFIED WITH
THIS VALUE?

.Y .N

RECORD THIS
VALUE FOR
FUTURE TRANS-
MISSION TO THE
LM

ACCEPT:
RECORD E

#240

WAIT FOR KEY-
BOARD ENTRY

KEY IN PROCEED

V33E

#250

TERMINATE FLASH
UPON RECEIPT OF
PROCEED OR NEW
DATA

.P .NEW
.R .DATA
.O .
.C .
.E .
.E STORE DATA
.D .

KEY IN V21
AND LOAD THE
DESIRED E IN R2

REJECT:

V22E
LOAD DESIRED ELEVATION IN R2

#260

DOES A TIG
EXIST FOR THE
ELEVATION ANGLE
(E)?

.Y .N

#270

#280

FLASH VERB-
NOUN TO RE-
QUEST RESPONSE
AND DISPLAY
ALARM CODE:

V05N31
R1-
R2-
R3-

MONITOR DSKY:
IS THERE AN ALARM
CODE DISPLAY
INDICATING COMPUTA-
TIONAL DIFFICULTY

.Y .N

NOTE: POSSIBLE PROGRAM ALARM IF
TIG DOES NOT EXIST FOR
THIS E.

FL V05 N31
R1-000--

PROG LIGHT-ON
PGNS LIGHT-ON

#290

WAIT FOR KEY-
BOARD ENTRY.

TERMINATE
FLASH UPON RE-
CEIPT OF RE-
CYCLE.

RETURN TO DIS-
PLAY OF STOR-
ED E AND ADJUST
INPUT PARA-
METER.
KEY IN RECYCLE
V32E

KEY IN V32E TO RECYCLE TO
STEP IV, 2. AND READJUST
INPUT PARAMETERS.

#300

R
E
C
Y
C
L
E

#310

#320

V. CHECK CMC FLASHES VERB-NOUN TO
REQUEST RESPONSE AND DISPLAYS
DELTA T TRANSFER.

FL V06 N--

DELTA T TRANS 00XXX. HRS
000XX. MIN
0XX.XX SEC

#330

DELTA T TRANS - TIME REQUIRED FOR
TRANSFER FROM TIG(TPI) TO TIME
OF INTERCEPT.

#340

ACCEPT:

RECORD DELTA T TRANS

#350

V33E

FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY STORED
DELTA T TRANS:

HOLD

V06 N--
R1- DELTA T TRANS:
HRS
R2-DELTA T TRANS-
MINS
R3-DELTA T TRANS-
SECS

DELTA T TRANS - TIME
REQUIRED FOR
TRANSFER FROM
TIG(TPI) TO TIME OF
INTERCEPT. IN HRS,
MINS, SEC TO NEAREST
.01 SEC.

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF STORED DELTA T
TRANS

AM I SATISFIED WITH
THESE VALUES?

.Y .N

RECORD THIS
VALUE FOR
FUTURE TRANS-
MISSION TO THE
LM

WAIT FOR KEYBOARD
ENTRY

KEY IN PROCEED
V33E

TERMINATE FLASH
UPON RECEIPT OF
PROCEED OR NEW DATA

P NEW
R DATA
O
C
E
E
D

STORE DATA

KEY IN V25
AND LOAD THE
DESIRED DELTA T
TRANS.

REJECT:

V25E

RELOAD DELTA T TRANS

#360

#370

#380

#390

#400

#410

BASED ON THE STORED
TARGET PARAMETERS
COMPUTE THE TRANSFER
TRAJECTORY, INITIAL
CONDITIONS AND THE
NECESSARY DEPENDENT
VARIABLES FOR EVAL-
UATION OF THE
TRANSFER PHASE
INITIATION MANEUVER
AS DESCRIBED IN
SECTION 5.3 OF
R547 VOL I.
ESTABLISH ALARM IF:

(A) A TIG DOES NOT
EXIST FOR THE RE-
QUIRED ELEVATION
ANGLE IN THE 00002
OPTION CASE.

(B) FOR THE SPECI-
FIED ORBITAL PARA-
METERS AT TIG(TPI)
THE SPECIFIED DEL-
TA T TRANS RESULTS
IN HYPERBOLIC CSM
VELOCITY.

NO ALARM
ALARM

275

FLASH VERB-
 NOUN TO REQUEST
 RESPONSE AND DIS-
 PLAY ALARM CODE:
 V05N31
 R1-
 R2-
 R3-

MONITOR DSKY:
 IS THERE AN ALARM
 CODE DISPLAY
 INDICATING COMPUTA-
 TIONAL DIFFICULTY

.Y .N

WAIT FOR KEYBOARD
 ENTRY.

RETURN TO START
 OF PROGRAM
 AND ADJUST IN-
 PUT PARAMETERS.
 KEY IN RECYCLE
 V32E

TERMINATE FLASH
 UPON RECEIPT OF
 RECYCLE.

.R
 .E
 .C
 .Y
 .L
 .E

PUT TARGET PARA-
 METERS ON DOWNLINK
 TO REMAIN THERE
 UNTIL TERMINATION OF
 PROGRAM

FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY COMPUTED
 COMPONENTS OF
 DELTA V(LV):
 V06 N--
 R1-DELTA VX(LV)
 R2-DELTA VY(LV)
 R3-DELTA VZ(LV)

DELTA VX(LV) -
 COMPONENT OF

MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF THREE COMPONENTS
 OF IMPULSIVE DELTA V
 ALONG LM LOCAL
 VERTICAL AXES AT
 TIG(TPI).

NOTE: POSSIBLY PROGRAM ALARM IF
 COMPUTATION GIVES HYPER-
 BOLIC CSM VELOCITY

FL V06 N31
 R1-000--

PROG LIGHT-ON
 PGNS LIGHT-ON

KEY IN V32E TO RECYCLE TO
 STEP III AND RELOAD INPUT
 PARAMETERS.

VI. CHECK CMC FLASHES VERB-NOUN
 TO REQUEST PROCEED AND DISPLAYS
 COMPONENTS OF DELTA V

FL V06 N--

DELTA VX(LV) XXX.X FPS
 DELTA VY(LV) XXXX.X FPS
 DELTA VZ(LV) XXXX.X FPS

DELTA VX(LV) - COMPONENT OF

#420

#430

#440

#450

#460

IMPULSIVE DELTA V
AT TIG(TPI) ALONG
(RXV)XR. IN FPS TO
NEAREST .1 FPS.

DELTA VY(LV) -
COMPONENT OF
IMPULSIVE DELTA V
AT TIG(TPI) ALONG
VXR. IN FPS TO
NEAREST .1 FPS.

DELTA VZ(LV) -
COMPONENT OF
IMPULSIVE DELTA V
AT TIG(TPI) ALONG
-R. IN FPS TO
NEAREST .1 FPS.

WHERE R IS GEO-
CENTRIC RADIUS
VECTOR AND V IS LM
INERTIAL VELOCITY
VECTOR AT TIG(TPI).

WAIT FOR KEYBOARD
ENTRY
TERMINATE FLASH UPON
RECEIPT OF PROCEED

CHECK THE DATA
LOAD OPTION

.00001 .00002
.TIG(TPI) .E

RECORD THESE VALUES
FOR FUTURE TRANS-
MISSION TO THE LM

KEY IN PROCEED
V33E

DID I SPECIFY TIG
(TPI) OR E TO THE
LGC

.TIG(TPI) .E

IMPULSIVE DELTA V AT TIG(TPI)
ALONG(RXV)XR.

#470

DELTA VY(LV) - COMPONENT OF

IMPUS
IMPULSIVE DELTA V AT TIG(TPI)
ALONG VXR.

DELTA VZ(LV) - COMPONENT OF
IMPULSIVE DELTA V AT TIG(TPI)

#480

ALONG -R.

WHERE R IS GEORCENTRIC RADIUS
VECTOR AND V IS LM INERTIAL VEL-
OCITY VECTOR AT TIG(TPI).

#490

RECORD DELTA V

#500

V33E

#510

#520

POSS
 HOLD
 FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY CALCULATED E:
 V06 N--
 R1-BLANK
 R2-E
 R3-BLANK

E - ELEVATION ANGLE.
 THE ANGLE BETWEEN
 LM/CSM LOS AND THE
 LM LOCAL HORIZONTAL
 AT TIG(TPI) MEASURED
 FROM THE DIRECTION
 OF FLIGHT. IN DE-
 GREES TO NEAREST
 .01 DEG

WAIT FOR KEYBOARD
 ENTRY
 TERMINATE FLASH UPON
 RECEIPT OF PROCEED

FLASH VERB-NOUN
 TO REQUEST RES-
 PONSE AND DISPLAY
 CALCULATED
 TIG(TPI):
 V06 N34
 R1-TIG(TPI) -
 HRS
 R2-TIG(TPI) -
 MIN
 R3-TIG(TPI) -
 SEC

POSS
 HOLD

MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND
 DISPLAY OF
 CALCULATED E.

RECORD THIS VALUE
 FOR FUTURE TRANS-
 MISSION TO THE
 LM

KEY IN PROCEED
 V33E

MONITOR DSKY:
 OBSERVE VERB-NOJN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF CALCULATED TIG
 (TPI)

VII
 1. IS TPI DATA LOAD OPTION 00001
 (TIG) WAS SELECTED: CHECK CMC
 FLASHES VERB-NOUN TO REQUEST
 PROCEED AND DISPLAYS ELEVATION(E). #530

FL V06 N--
 BLANK
 E XXX.XX DEG
 BLANK

E-ELEVATION ANGLE.
 E-ELEVATION ANGLE. THE ANGLE
 BETWEEN LM/CSM LOS AND THE LOCAL
 HORIZONTAL AT TIG(TPI) MEASURED
 FROM THE DIRECTION OF FLIGHT. #540

RECORD E

#550

V33E

#560

OR 2. IF TPI DATA LOAD OPTION 00002
 (E) WAS SELETED: CHECK
 (E) WAS SELECTED: CHECK
 CMC FLASHES VERB-NOUN TO
 REQUEST PROCEED AND
 DISPLAYS TIG(TPI). #570

FL V06 N34
 TIG(TPI) 00XXX. HRS
 000XX. MIN
 0XX.XX SEC

#580

TIG(TPI) - TIME OF TPI IGNITION (GET). IN HRS, MIN, SEC TO NEAREST .01 SEC

RECORD THIS VALUE FOR FUTURE TRANSMISSION TO THE LM

RECORD TIG (TPI)

WAIT FOR KEYBOARD ENTRY TERMINATE FLASH UPON RECEIPT OF PROCEED

KEY IN PROCEED V33E

V33E

#590

FLASH VERB-NOUN TO REQUEST RESPONSE AND DISPLAY CALCULATED TERMINAL PHASE PARAMETERS.

MONITOR DSKY: OBSERVE VERB-NOUN FLASH TO REQUEST RESPONSE AND DISPLAY OF CALCULATED TERMINAL PHASE PARAMETERS.

VIII. CHECK CMC FLASHES VERB-NOUN TO REQUEST PROCEED AND DISPLAYS CALCULATED TERMINAL PHASE PARAMETERS

#600

V06 N-- R1-DELTA V (TPI) R2-PERIGEE ALT(TPI) R3-DELTA V(TPF)

FL V06 N-- DELTA V(TPI) XXXX.X FPS PERIGEE ALT(TPI) XXXX.X NM DELTA V (TPF) XXXX.X FPS

#610

DELTA V (TPI) - REQUIRED IMPULSIVE DELTA V TO ACCOMPLISH TPI MANEUVER AT TIG(TPI). IN FPS TO NEAREST .1 FPS

DELTA V (TPI) - REQUIRED IMPULSIVE DELTA V TO ACCOMPLISH TPI MANEUVER AT TIG(TPI)

PERIGEE ALT (TPI) - POST TPI ALTITUDE OF PERIGEE ABOVE LAUNCH PAD RADIUS. IN NAUTICAL MILES TO NEAREST .1NM.

PERIGEE ALT (TPI) - POST TPI ALTITUDE OF PERIGEE ABOVE LAUNCH

PAD RADIUS.

#620

DELTA V (TPF)- REQUIRED IMPULSIVE DELTA V TO ACCOMPLISH INTERCEPT (TPF) MANEUVER AT CALCULATED TIME OF INTERCEPT. IN FPS TO NEAREST .1 FPS.

DELTA V (TPF) - REQUIRED IMPULSIVE DELTA V TO ACCOMPLISH INTERCEPT (TPF) MANEUVER AT CALCULATED TIME OF INTERCEPT.

#630

RECORD THESE VALUES

RECORD VALUES

FOR FUTURE TRANSMISSION TO THE LM

*640

WAIT FOR KEYBOARD ENTRY
TERMINATE FLASH UPON RECEIPT OF PROCEED

KEY IN PROCEED
V33E

V33E

FLASH VERB-NOUN TO REQUEST RESPONSE AND DISPLAY TTI;
V06 N35
R1-TTI - HRS
R2-TTI - MINS
R3-TTI - SECS

MONITOR DSKY: OBSERVE VERB-NOUN FLASH TO REQUEST RESPONSE AND DISPLAY OF TTI.

IX. CHECK CMC FLASHES VERB-NOUN TO REQUEST RESPONSE AND DESPLAYS TTI.

FL V06 N35
TTI 000XX HRS
000XX MIN
0XX.XX SEC

*650

*660

TTI - TIME TO GO TO TIG(TPI). IN HRS,MINS,SECS, TO NEAREST .01 SEC.

RECORD THIS VALUE FOR FUTURE TRANSMISSION TO THE LM

TTI: TIME TO GO TIG(TPI)
RECORD TTI.

SET LEB CLOCK (AND MDC CLOCK IF DESIRED) TO TTI

SET CLOCKS TO TTI(MDC CLOCK OPTIONAL)

*670

WAIT FOR KEYBOARD ENTRY.

KEY IN PROCEED
V 33 E

V33E

TERMINATE FLASH UPON RECEIPT OF PROCEED

*680

IS FINAL COMPUTATION FLAG SET?

.N .Y

*690

 RESET FINAL COM-
 PUTATION FLAG

 HAS THE FINAL
 COMPUTATION
 CYCLE BEEN SELECTED?

.Y .N

#700

.....
 HOLD
 FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY TOTAL MARKS
 SINCE THE LAST BURN
 AND THE TTI:

V06 N--
 R1-N
 R2-TTI
 R3-BLANK

N-NUMBER OF MARKS
 MADE SINCE LAST
 THRUSTING MANEUVER
 OR INITIATION OF P20

TTI-TIME TO GO TO
 TIG(TPI), IN MINS AND
 SECS TO NEAREST SEC.
 MAX READING IS 59 59

(NOTE: MGA IS NEVER
 DISPLAYED IN THIS
 PROGRAM. R3 RE-
 MAINS BLANK FOR
 THE DISPLAY.)

 MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF TOTAL MARKS AND
 TIME TO TIG(TPI)

X. IF LM TRACKING HAS NOT BEEN
 TERMINATED:

1. CHECK CMC FLASHES VERB-NOUN TO
 REQUEST RESPONSE AND DISPLAYS
 NUMBER OF MARKS SINCE LAST BURN
 AND TTI

#710

FL V06 N--

#720

N 000XX MARKS
 TTI XX0XX MIN-SEC
 BLANK

N-NUMBER OF MARKS MADE SINCE LAST
 THRUSTING MANEUVER OR INITIATION
 OF P20

#730

2. 2F TTI IS LESS THAN 16 MINUTES
 RESELECT P74 AND ADJUST INPUT
 PARAMETERS. TIG(TPI) MUST BE SLIPPED.

 IS TTI LESS THAN
 16 MIN?

.Y .N

 IS A GROUND STA-
 TION AVAILABLE
 FOR CONFIRMATION
 OF ALL THE PARA-
 METERS WHICH ARE
 ON DOWN LINK?

.Y .N

#740

 .MONITOR CMC
 .DOWNLINK
 .TELEMETRY OF
 .MANEUVER DATA
 .COORDINATE
 .EVALUATION OF
 .CMC COMPUTED
 .PARAMETERS

 .COORDINATE
 .EVALUATION
 .OF THE CMC
 .COMPUTATION
 .PARAMETERS
 .WITH THE
 .GROUND

3. COORDINATE EVALUATION OF CMC
 COMPUTED PARAMETERS WITH GROUND
 SELECTION
 STATION (IF AVAILABLE).

IF PARAMETERS ARE UNSATISFACTORY
 RESELECT P74 AND ADJUST INPUT
 PARAMETERS.

282

WITH ASTRO-
NAUT

IF TTI IS LESS THAN 18 MINUTES TIG
(TPI) MUST BE SLIPPED.

#750

AM I SATISFIED
WITH THE DISPLAYED
MANEUVER PARA-
METERS (I.E. HAVE
I COMPLETED MAN-
IPULATION OF THE
INPUT PARAMETERS?)

#760

.N .Y

IS TTI LESS
THAN 18 MIN:

#770

.Y N.

WAIT FOR KEYBOARD
ENTRY

TIG(TPI) MUST
BE SLIPPED.
RESELECT P74
AND ADJUST IN-
PUT PARAMETERS
KEY IN
V37E74E

#780

EXIT P74

RESELECT P74
AND READJUST
INPUT PARAMETERS
KEY IN
V37E74E

#790

EXIT P74

#800

IS TTI LESS THAN
17 MIN?

.N Y.

#810

IS THE RENDEZVOUS
NAVIGATION PROGRAM
(P20) IN PROCESS

.Y N.

4. IF RENDEZVOUS NAVIGATION PROGRAM
(P20) IS IN PROGRESS
AND
A. MORE MARKS ARE DESIRED
V--E

#820

SHALL I ATTEMPT
TO MAKE ADDIT-
IONAL OPTICS
MARKS AT THIS
TIME?

.Y .N

NOTE: DO NOT PERFORM MARKS LATER
THAN TTI = 17 MINUTES AND
PREFERABLY FOR NOT LONGER
THAN 2 MINUTES.

OR

#830

KEY IN V--E

B. MORE MARKS ARE NOT DESIRED AND
FINAL COMPUTATION CYCLE IS
DESIRED
V33E

RECYCLE TO STEP VI

DO I WISH
TO INCORP-
ORATE THE
PRESENT ST-
ATE VECTORS
INTO THE
MANEUVER
COMPUTATION
AND TERMIN-
ATE FURTHER
UPDATES?
I.E. SELECT
THE FINAL
COMPUTAT-
TION AND
DISPLAY
CYCLE?

OR

#840

C. MOST MARKS ARE NOT DESIRED AND
FINAL COMPUTATION CYCLE IS
NOT DESIRED
V32E

RECYCLE TO STEP VI

.N Y.

#850

KEY IN

#860

RECYCLE
V32E

TERMINATE FLASH UPON
RECEIPT OF NEW PRO-
GRAM, RECYCLE, PRO-
CEED OR V--E

SELECT THE
FINAL COMPUTA-
TION AND DIS-
PLAY CYCLE.
KEY IN
PROCEED
V33E

5. WHEN TTI EQUALS 17 MINUTES SELECT
FINAL COMPUTATION CYCLE.

#870

R P N V
E R E
C O W
Y C P E
C E R
L E O
E D G

V33E

RECYCLE TO STEP VI

GO TO
PROG-
RAM
SELEC-
ED

#880

EXIT
P74

#890

SET FINAL
COMPUTATION
FLAG

#900

RESET UPDATE
FLAG (SEE
P20)

#910

DO RENDEZVOUS
TRACKING
DATA PROCESS-
ING ROUTINE
(R22)

DO RENDEZVOUS.
TRACKING DATA
PROCESSING
ROUTINE (R22)
(NOTE: PERFORM
MARKS PREFER-
ABLY FOR NOT
LONGER THAN 2
MINUTES BUT IN
NO CASE LATER
THAN TTI EQUAL
TO 17 MIN.)

#920

#930

TRANSMIT ALL
MANEUVER PARAMETERS
TO THE LM

XI. TRANSMIT ALL MANEUVER PARAMETERS
TO THE LM.

#940

IS THE RENDEZVOUS
FLAG SET(SEE P20)

.N .Y

IS THE RENDEZVOUS
NAVIGATION PROGRAM
(P20) IN PROCESS?

.Y .N

#950

DISPLAY P20

OBSERVE DISPLAY
OF P20

XII. CHECK CMC DISPLAYS P20 OR FLASHES
VERB-NOUN TO REQUEST SELECTION OF
CMC IDLING PROGRAM

#960

EXIT P74

EXIT P74

FL V06 N07
00000
BLANK
BLANK

286

..... HOLD	FLASH VERB-NOUN TO REQUEST PLEASE PERFORM SELECTION OF CMC IDLING PROGRAM (POO) V5ON07 R1-00000 R2-BLANK R3-BLANK	.....	MONITOR DSKY: OBSERVE VERB-NOUN FLASH TO REQUEST PLEASE PERFORM SELECTION OF CMC IDLING PROGRAM (POO)	
	:		:	#970
	WAIT FOR KEYBOARD ENTRY	.....	SELECT DESIRED PRO- GRAM. KEY IN V37E--E	#980
	TERMINATE FLASH UPON RECEIPT OF NEW PRO- GRAM.	.....	SELECT DESIRED PROGRAM V37E --E	#990
	:		:	
	GO TO PROGRAM SELECTED		GO TO PROGRAM SELECTED	
	:		:	
	:		:	
	:		:	
	:		:	
	:		:	
	:		:	
	:		:	
	:		:	
	:		:	#1000
	EXIT P74		EXIT P74	

END OF RUN

LM TRANSFER PHASE (MIDCOURSE) TARGETING PROGRAM (P75)

REV 10

10/31/66

PURPOSE:

- (1) TO CALCULATE THE REQUIRED DELTA V AND OTHER INITIAL CONDITIONS REQUIRED BY THE LGC FOR LM EXECUTION OF THE NEXT POSSIBLE MIDCOURSE CORRECTION OF THE TRANSFER PHASE OF AN ACTIVE LM RENDEZVOUS.
- (2) TO COMPUTE AND DISPLAY SUITABLE INFORMATION WHICH UPON TRANSMISSION TO THE LM WILL ENABLE THE LM CREW TO ENTER THE FINAL RENDEZVOUS PHASE AT THE CORRECT TIME TO COMPLETE THE REQUIRED THRUSTING MANEUVER AT THE FIRST RANGE GATE.
- (3) THIS PROGRAM IS DESIGNED FOR ONE-MAN OPERATION.

ASSUMPTIONS:

- (1) THE ISS IS ON AND PRECISELY ALIGNED.
- (2) STATE VECTOR UPDATES BY P27 ARE DISALLOWED DURING STATE VECTOR UPDATING INITIATED BY P20 (SEE ASSUMPTION (3)).
- (3) THIS PROGRAM MAY BE PERFORMED CONCURRENTLY WITH THE RENDEZVOUS NAVIGATION PROGRAM (P20) TO UPDATE THE LM OR CSM STATE VECTORS WITH OPTICAL TRACKING OF THE LM. THIS PROGRAM MAY BE PERFORMED INDEPENDANTLY OF P20. IF OPTICAL TRACKING IS DESIRED THE OPTICS SHOULD BE LOCKED ON THE LM BY PREVIOUS SELECTION OF P20. THE RENDEZVOUS TRACKING MARK COUNTER IS ZEROED BY THE SELECTION OF P20 AND AFTER EACH THRUSTING MANEUVER.
IF P20 IS IN EFFECT, OPTICAL TRACKING MARKS MAY BE MADE BY SELECTION OF THE RENDEZVOUS TRACKING DATA PROCESSING ROUTINE (R22). R22 IS SELECTED BY V--E WHICH MAY BE ENTERED WHENEVER THE CMC IS HOLDING FOR A V/N FLASHING DATA DISPLAY (NOTE: FOR SIMPLICITY IT IS ONLY SHOWN BELOW AT THE V06N--DISPLAY.) R22 RETURNS TO THIS PROGRAM AT THE INTERRUPTED DISPLAY.

- (4) THE OPERATION OF THIS PROGRAM UTILIZES THE FOLLOWING FLAG:

ACTIVE VEHICLE FLAG - DESIGNATES THE VEHICLE WHICH IS DOING RENDEZVOUS THRUSTING MANEUVERS TO THE PROGRAM WHICH CALCULATES THE MANEUVER PARAMETERS. SET AT THE START OF EACH RENDEZVOUS PRE-THRUSTING PROGRAM.

- (5) IN THE LOGIC BELOW ASSOCIATED WITH THE FINAL ACCEPTANCE OF THE LGC COMPUTED PARAMETERS, THE FOLLOWING PERFORMANCE TIMES ARE ASSUMED:

- (A) MANEUVER PARAMETER DISPLAY AND CREW EVALUATION - 1 MIN
- (B) TRANSMISSION OF ALL PARAMETERS TO THE LM - 2 MIN
- (C) EXTERNAL DELTA V PROGRAM (P30) SELECTION AND EXECUTION BY LM CREW - 5 MIN
- (D) THRUSTING PROGRAM SELECTION BY LM CREW AND COUNT DOWN TO TIG(MID) - 5 MIN (ASSUMES IMU ALIGNMENT IS SATISFACTORY.
- (E) NO MIDCOURSE MANEUVERS WILL BE PERFORMED WITHIN 10 MINUTES OF THE CALCULATED TIME OF INTERCEPT.

- (6) THE PROGRAM IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY PRIOR TO ANY ANTICIPATED LM RENDEZVOUS MIDCOURSE CORRECTION REQUIRING CMC PARAMETER COMPUTATION.

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
			.CREW .PROGRAM .SELECTION . . .			#10
	----- DO PROGRAM SELECTION CHECK ROUTINE (R01)	.....	----- KEY IN LM TRANSFER PHASE (MIDCOURSE) TARGETING PROGRAM (P75) V37E75E -----	I KEY V37E 75E		
	----- : :	.....	----- DO PROGRAM SELECTION CHECK ROUTINE (R01) -----	II PERFORM PROGRAM SELECTION CHECK ROUTINE (R01)		#20
	----- START LM TRANSFER PHASE (MIDCOURSE) TARGETING PROGRAM (P75) DISPLAY P75 -----	.....	----- MONITOR DSKY: OBSERVE DISPLAY OF PROGRAM 75 -----			#30
	----- : : :					
	----- SET ACTIVE VEHICLE FLAG TO LM -----					#40
	----- : : :					
	----- SET TRACK FLAG (SEE P20) -----					
	----- : : :					#50
	----- SET UPDATE FLAG (SEE P20) -----					
	----- : : :					

*60

```

-----
DEFINE THE TIME OF
ARRIVAL AT INTERCEPT
AS TIG(TPI) PLUS
DELTA T TRANS
-----

```

#70

```

.....
HOLD .....
-----
FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY TT INT:
V06 N35
R1-TT INT - HRS
R2-TT INT - MINS
R3-TT INT - SECS

```

```

-----
TT INT - TIME TO GO
TO INTERCEPT, IN
HRS, MINS, SECS TO
MEAREST .01 SEC.
-----

```

```

-----
MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST RE-
SPONSE AND DISPLAY
OF IT INT
-----

```

```

-----
TRANSMIT THIS VALUE
TO THE LM
-----

```

```

-----
SET LEB CLOCK
(AND MDC CLOCK IF
DESIRED) TO TT INT
-----

```

```

-----
WAIT FOR KEYBOARD
ENTRY
TERMINATE FLASH UPON
RECEIPT OF PROCEED
-----

```

```

-----
KEY IN PROCEED
V33E
-----

```

```

III CHECK CMC FLASHES VERB-NOUN TO
REQUEST RESPONSE AND DISPLAYS
TT INT.

```

#80

FL V06 N35

```

TT INT          00XXX. HRS
                000XX. MIN

```

0XX.XX SEC

```

TT INT: TIME TO GO TO INTERCEPT
TRANSMIT TT INT TO LM.

```

#90

```

SET CLOCKS TO TT INT (MDC CLOCK
OPTIONAL)

```

#100

V33E

#110

IV.

1 CHECK CMC FLASHES VERB-NOUN TO REQUEST RESPONSE AND DISPLAYS MARKS SINCE LAST BURN AND TT INT

FL V06 N--

N 000XX
TT INT XXBXX MIN-SEC
BLANK

#120

N-NUMBER OF MARKS MADE SINCE LAST THRUSTING MANEUVER OR INITIATION OF P20

#130

FLASH VERB-NOUN TO REQUEST RESPONSE AND DISPLAY TOTAL MARKS SINCE THE LAST BURN AND THE TT INT:

VO6N--
R1-N
R2-TT INT
R3-BLANK

N-NUMBER OF MARKS MADE SINCE LAST THRUSTING MANEUVER OR INITIATION OF P20

TT INT-TIME TO GO TO INTERCEPT. IN MIN AND SEC TO NEAREST SECOND. MAX READING IS 59 59.

NOTE: MGA IS NEVER DISPLAYED IN THIS PROGRAM. R3 REMAINS BLANK FOR THIS DISPLAY.

MONITOR DSKY: OBSERVE VERB-NOUN FLASH TO REQUEST RESPONSE AND DISPLAY OF TOTAL MARKS AND TIME TO GO TO INTERCEPT.

IS TT INT GREATER THAN 10 MIN.

.N .Y

ADVISE LM CREW TO SELECT TRANSFER PHASE, FINAL (TPF) PROGRAM (P36) AND COMPLETE RENDEZVOUS MANUALLY.

2. IF TT INT IS LESS THAN 10 MINUTES ADVISE LM CREW TO SELECT P36 AND COMPLETE RENDEZVOUS MANUALLY.

#140

#150

WAIT FOR KEYBOARD ENTRY

SELECT PROGRAM AS DESIRED KEY IN V37E--E

#160

292

GO TO
PROGRAM
SELECTED

#170

EXIT P75

#180

IS THE RENDEZVOUS
NAVIGATION PROGRAM
(P20) IN PROCESS?

3. IF RENDEZVOUS NAVIGATION PROGRAM
(P20) IS IN PROCESS AND

A. ADDITIONAL MARKS ARE DESIRED

•Y •N

V--E

SHALL I ATTEMPT
TO MAKE
ADDITIONAL
OPTICS MARKS
AT THIS TIME?

PERFORM RENDEZVOUS TRACKING DATA
PROCESSING ROUTINE (R22)

#190

NOTE: DO NOT MAKE MARKS LATER
THAN TT INT = 17 MINUTES
AND PREFERABLY NOT LONGER

THAN 2 MINUTES

•Y •N

KEY IN
V--E

OR B. IF NO MORE MARKS ARE DESIRED
V33E

#200

TERMINATE FLASH UPON
RECEIPT OF NEW MARK
NOTIFICATION OR
PROCEED OR REQUEST
FOR NEW PROGRAM

KEY IN PROCEED
V33E

4. IF RENDEZVOUS NAVIGATION PROGRAM
(P20) IS NOT IN PROCESS AND TT INT
IS GREATER THAN 20 MINUTES

V33E

#210

•P •N •V
•R •E •-
•O •W •-
•C •E
•E •P
•E •R
•D •O DO RE-
•G NDEZ-
•R VOUS-
•A TRACK-
•M ING

DO RENDEZVOUS
TRACKING DATA
PROCESSING ROUTINE
(R22).

(NOTE:PERFORM
MARKS PREFERABLY
FOR NOT LONGER THAN
2 MINUTES BUT IN
NO CASE LATER
THAN TT INT
EQUAL TO 17 MIN.

#220

IF A LM MIDCOURSE
CORRECTION BURN IS
CONTEMPLATED

#230

#240

#250

#260

#270

DATA
PROC-
ESSING
ROU-
TINE
(R2Z)

GO TO
PROGRAM
SELECTED

EXIT P75

TERMINATE UPDATE
FLAG (SEE P20)

SET TIG(MID) =
T + 12 MIN

EXTRAPOLATE LM AND
CSM ORBITS TO
TIG(MID)

DO LAMBERT ROUTINE
TO CALCULATE RE-
QUIRED VELOCITY FOR
MIDCOURSE CORRECTION

294

CALCULATE THRUST
INITIAL CONDITION
PARAMETERS

#280

.....
HOLD
FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY COMPUTED
COMPONENTS OF
DELTA V(LV):
V06 N--
R1-DELTA VX(LV)
R2-DELTA VY(LV)
R3-DELTA VZ(LV)

DELTA VX(LV) -
COMPONENT OF
IMPULSIVE DELTA V
AT TIG(MID) ALONG
(RXV)XR. IN FPS TO
NEAREST .1 FPS.

DELTA VY(LV) -
COMPONENT OF
IMPULSIVE DELTA V
AT TIG(MID) ALONG
VXR. IN FPS TO
NEAREST .1 FPS.

DELTA VZ(LV) -
COMPONENT OF
IMPULSIVE DELTA V
AT TIG(MID) ALONG
-R. IN FPS TO
NEAREST .1 FPS.

WHERE R IS GEO-
CENTRIC RADIUS
VECTOR AND V IS LM
INERTIAL VELOCITY
VECTOR AT TIG(MID).

MONITOR DSKY:
OBSERVE VERB-NOJN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF THREE COMPONENTS
OF IMPULSIVE DELTA V
ALONG LM LOCAL
VERTICAL AXES AT
TIG(MID).

V. CHECK CMC FLASHES VERB-NOUN TO
REQUEST RESPONSE AND DISPLAYS
DELTA V.

FL V06 N--

#290

DELTA VX (LV) XXXX.X FPS
DELTA VY (LV) XXXX.X FPS
DELTA VZ (LV) XXXX.X FPS

DELTA VX(LV) - COMPONENT OF
IMPULSIVE DELTA V AT TIG(MID)
ALONG (RXV)XR. IN FPS TO NEAREST
.1 FPS.

#300

DELTA VY(LV) - COMPONENT OF
IMPULSIVE DELTA V AT TIG(MID)
ALONG VXR. IN FPS TO NEAREST
.1 FPS.

DELTA VZ(LV) - COMPONENT OF
IMPULSIVE DELTA V AT TIG(MID)
ALONG -R. IN FPS TO NEAREST
.1 FPS.

#310

WHERE R IS GEOCENTRIC RADIUS
VECTOR AND V IS LM INERTIAL
VELOCITY VECTOR AT TIG(MID).

#320

RECORD THESE VALUES
FOR FUTURE TRANS-
MISSION TO THE LM.

RECORD VALUES

#330

 WAIT FOR KEYBOARD
 ENTRY
 TERMINATE FLASH UPON
 RECEIPT OF PROCEED

 KEY IN PROCEED
 V33E

V33E

#340

.....
 HOLD .
 FLASH VERB-NOUN
 TO REQUEST
 RESPONSE AND
 DISPLAY TIG(MID):
 V06N34
 R1- TIG(MID)-HRS
 R2- TIG(MID)-MINS
 R3- TIG(MID)-SECS

 MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASHING TO
 REQUEST RESPONSE
 AND DISPLAY OF
 TIG(MID)

VI. CHECK CMC FLASHES VERB-NOUN TO
 REQUEST RESPONSE AND DISPLAYS
 TIG(MID)

FL V06 N34

TIG(MID) 00XXX HRS (GET)
 000XX MIN
 0XX.XX SEC

#350

 TIG(MID)-TIME OF
 IGNITION OF
 MIDCOURSE CORRECTION
 MANEUVER (GET).
 MINS. SECS.
 TO NEAREST .01 SEC.

TIG(MID):TIME OF IGNITION OF MID-
 COURSE CORRECTION MANEUVER (GET).
 MINS. SECS. TO NEAREST .01 SEC.

 RECORD THESE VALUES
 FOR FUTURE TRANS-
 MISSION TO THE LM

RECORD TIG(MID)

#360

 WAIT FOR KEYBOARD
 ENTRY

 TERMINATE FLASH UPON
 RECEIPT OF PROCEED

 KEY IN PROCEED
 V33E

V33E

#370

.....
 HOLD .
 FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 DISPLAY CALCULATED
 TERMINAL PHASE
 PARAMETERS:
 V06 N--
 R1-DELTA V (MID)
 R2-TTI
 R3-DELTA V (TPF)

 MONITOR DSKY:
 OBSERVE VERB-NOUN
 FLASH TO REQUEST
 RESPONSE AND DISPLAY
 OF CALCULATED
 TERMINAL PHASE
 PARAMETERS

VII.
 1. CHECK CMC FLASHES VERB-NOUN TO
 REQUEST RESPONSE AND DISPLAYS
 TERMINAL PHASE PARAMETERS

FL V06 N--

DELTA V (MID) XXXX.X FPS
 TTI XXBXX MIN-SEC
 DELTA V (TPF) XXXX.X FPS

#380

 WAIT FOR KEYBOARD
 ENTRY

 KEY IN RECYCLE
 V32E

V32E

#440

 RECORD THESE VALUES
 FOR FUTURE TRANS-
 MISSION TO THE LM

RECYCLE TO STEP III

#450

3. IF A MIDCOURSE CORRECTION BURN
 IS NOT REQUIRED

 TERMINATE FLASH UPON
 RECEIPT OF REQUEST
 FOR RECYCLE OR
 PROCEED

 KEY IN PROCEED
 V33E

V33E

#460

 .P .R
 .R .E
 .O .C
 .C .Y
 .E .C
 .E .L
 .D .E

 TRANSMIT ALL
 MANEUVER PARAMETERS
 TO THE LM

VIII. TRANSMIT ALL MANEUVER PARAMETERS
 TO THE LM.

#470

 IS THE RENDEZVOUS
 FLAG SET(SEE P20)?

 IS THE RENDEZVOUS
 NAVIGATION PROGRAM
 (P20) IN PROCESS?

#480

 .N .Y

 .Y .N

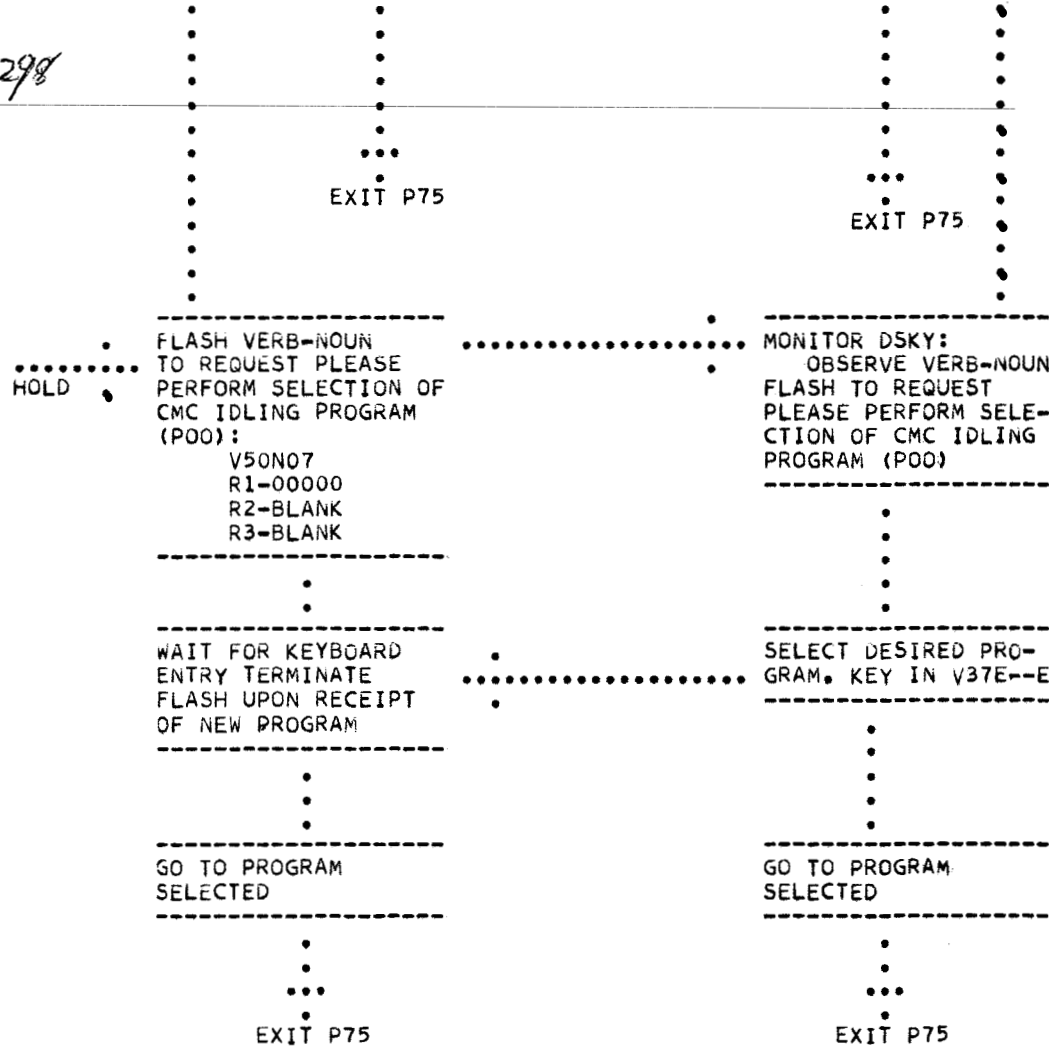
 DISPLAY P20

 OBSERVE DISPLAY
 OF P20.

IX. CHECK CMC DISPLAY P20

OR
 FLASHES VERB-NOUN TO REQUEST CMC

298



IDLING PROGRAM

#490

FL V50 N07
00000
BLANK
BLANK

#500

SELECT DESIRED PROGRAM
V37E--E

#510

#520

END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

PROGRAM SELECTION CHECK ROUTINE (R01)

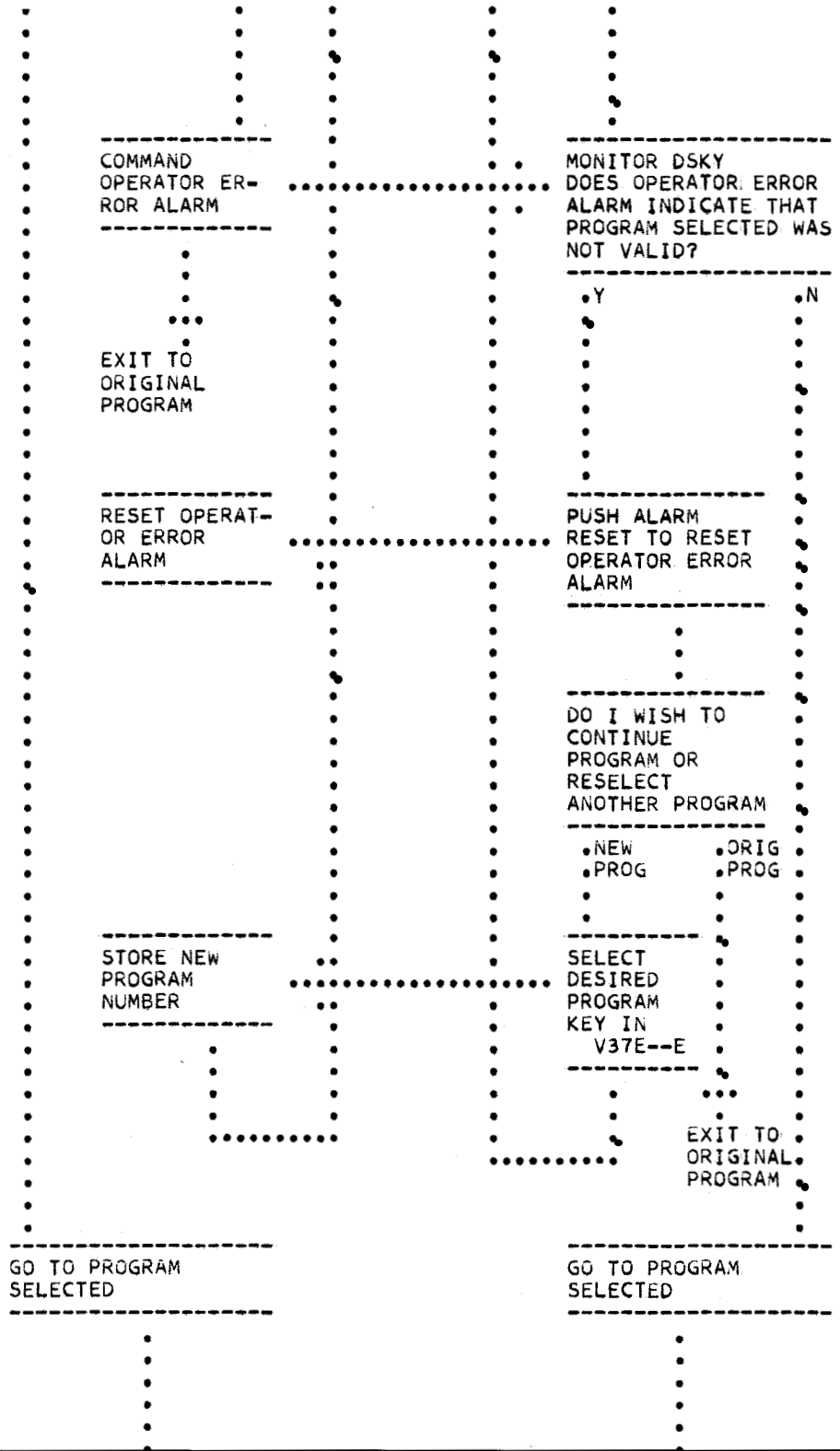
REV 3

10/31/66

PURPOSE (1) TO CHECK IF A NEW PROGRAM MAY BE ENTERED FROM THE PROGRAM IN PROCESS.

ASSUMPTIONS (1) A TABLE (V37 TABLE) IS STORED IN THE CMC WHICH DEFINES ALL PROGRAMS FROM WHICH ANY OTHER PROGRAM MAY BE ENTERED. (2) THIS ROUTINE IS AUTOMATICALLY CALLED BY THE CMC WHENEVER ANY NEW PROGRAM IS CALLED (EITHER AUTOMATICALLY BY THE CMC OR MANUALLY BY THE CREW).

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
	CMC ROUTINE SELECTION					#10
	----- START PROGRAM SELECTION CHECK ROUTINE (R01) -----					
	· · ·					#20
	----- OBTAIN PRESENT PROGRAM NUMBER AND DESIRED PROGRAM NUMBER FROM STORAGE -----					
	· · ·					#30
	----- CONSULT V37 TABLE FOR VALIDITY OF NEW PROGRAM SELECTION. IS NEW PROGRAM VALID? -----					
	·Y ·N					
	· · · · · · ·			..... · · · · · · ·		#40



#50

#60

#70

#80

#90

301

302-

.....
.....
.....

EXIT R01
TO NEW PROGRAM

.....
.....
.....

EXIT R01
TO NEW PROGRAM

END OF RUN

WAIT FOR KEY-
BOARD ENTRY

TERMINATE
FLASH UPON
RECEIPT OF
NEW PROGRAM

GO TO PROGRAM
SELECTED.

EXIT R02
AND P---

FLASH VERB-
NOUN TO RE-
QUEST PLEASE
PERFORM SELEC-
TION OF IMU
ORIENTATION
DETERMINATION
PROGRAM
(P51):
V50N07
R1-00051
R2-BLANK
R3-BLANK

WAIT FOR KEYBOARD
ENTRY

TERMINATE FLASH
UPON RECEIPT OF
NEW PROGRAM

SELECT DESIRED
PROGRAM.
KEY IN
V37E--E

GO TO PROGRAM
SELECTED.

EXIT R02
AND P---

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM
SELECTION OF IMU
ORIENTATION DETER-
MINATION PROGRAM
(P51).

SELECT DESIRED
PROGRAM.
KEY IN
V37E--E

```

.
.
.
.
-----
GO TO PROGRAM
SELECTED
-----
.
.
.
.
EXIT R02
AND P--

```

```

.
.
.
.
-----
GO TO PROGRAM
SELECTED
-----
.
.
.
.
EXIT R02
AND P--
.
.
.
.
EXIT R02

```

306

END OF RUN

SELECT MANUAL OPTICS
MODE

WAIT FOR KEYBOARD
ENTRY

MARK

WHEN LM IS AT
CENTER OF RETICULE
PRESS MARK BUTTON

#40

WAS SIGHTING SATIS-
FACTORY?

#50

.N .Y

MARK REJECT

PRESS MARK
REJECT BUTTON

TERMINATE FLASH
UPON RECEIPT
OF MARK, MARK
REJECT OR ENTER

#60

ENTER

.M .M .E
.A .A .N
.R .R .T
.K .K .E
.R .R .R
.E .E .R
.J .J .R
.E .E .R
.C .C .R
.T .T .R

#70

IS MARK
FLAG SET?

.N .Y

#80

RESET MARK
FLAG

IS THERE MARK DATA
IN POSITION #1

.Y .N
.
.

TRANSFER
MARK DATA
FROM POSITION
#1 TO POSITION
#2.

.
.
.
.
.

EXIT R21

EXIT R21

#150

#160

END OF RUN

312

#40

#50

#60

#70

#80

MONITOR DSKY:
 DOES PROGRAM
 ALARM INDICATE
 THAT THE RENDEZVOUS
 NAVIGATION PROGRAM
 (P20) IS NOT IN
 PROCESS?

.Y .N
 .
 .

THIS ROUTINE
 MAY NOT BE SE-
 LECTED AT THIS
 TIME. PRESS
 ALARM RESET TO
 RESET PROGRAM
 ALARM

EXIT R22

TURN ON PRO-
 GRAM ALARM
 LIGHT NOTE:
 ALARM CODE
 IF CALLED BY
 ASTRONAUT
 IS:

V05N31
 R1-
 R2-
 R3-

EXIT R22

CALL RENDEZVOUS
 TRACKING SIGHTING
 MARK ROUTINE (R21)

WAIT 1 MINUTE

DO RENDEZVOUS
 TRACKING SIGHTING
 MARK ROUTINE (R21)
 (NOTE: DURING REN-
 DEZVOUS TRACKING
 SIGHTING MARKS THE
 ASTRONAUT SHOULD
 PERIODICALLY MONITOR
 THE DSKY FOR A POSS-
 IBLE DISPLAY OF AN
 EXCESSIVE UPDATE
 CONDITION.)

514

IS THERE DATA IN
MARK DATA POSITION
#2 (REFER TO R21 FOR
DESCRIPTION OF
MARK DATA POSITIONS)

#90

.N .Y

HAS TERMINATE
FLAG BEEN SET
BY R21?

#100

.N .Y

RESET TERMINATE
FLAG

#110

EXIT R22

TRANSFER MARK DATA
FROM POSITION #2
TO POSITION #3

#120

CALCULATE THE LOS
TO THE LM BASED ON
THE MARK DATA IN
POSITION #3.

#130

DELTA P - MAGNI-
TUDE OF THE DIF-
FERENCE BETWEEN
THE POSITION
VECTOR BEFORE
AND AFTER
INCORPORATION OF
THIS MARK DATA.
IN N.M. TO NEAR-
EST 0.1 N.M.

DELTA V - MAGNI-
TUDE OF THE DIF-
FERENCE BETWEEN
THE VELOCITY
VECTOR BEFORE
AND AFTER
INCORPORATION OF
THIS MARK DATA.
IN FT/SEC TO
NEAREST FT/SEC.

N Y

#190

DO I WISH TO
INCORPORATE
THIS UPDATE?

#210

Y N

WAIT FOR KEY-
BOARD ENTRY.

KEY IN PROCEED
V33E

#220

DO I WISH TO
CEASE RENDEZVOUS
TRACKING?

#230

N Y

KEY IN RE-
CYCLE
V32E

318

#240

IS ANOTHER PROGRAM
BESIDES P20 IN
PROCESS?

.N .Y

#250

P20 MAY BE
TERMINATED
IN TWO WAYS.

#260

SELECT CMC
IDLING PRO-
GRAM (POO)
KEY IN
V37E00E

#270

KEY IN
V--E

TERMINATE FLASH
UPON RECEIPT OF
PROCEED, RECYCLE
V--E OR NEW
PROGRAM.

#280

KEY IN
V--E

.P .R .V .V
.R .E .- .3
.O .C .- .7
.C .Y .E .E
.E .C . .O
.E .L . .O
.D .E . .E

EXIT R22
AND P20

322 END OF RUM

POSS . FLASH VERB-NOUN TO
 REQUEST RESPONSE AND
 HOLD . DISPLAY T PERIGEE:
 V06 N35
 R1-T PERIGEE-HRS
 R2-T PERIGEE-MIN
 R3-T PERIGEE-SEC

MONITOR DSKY:
 OBSERVE FLASHING
 VERB-NOUN TO
 REQUEST RESPONSE
 AND DISPLAY OF T
 PERIGEE

T PERIGEE-TIME TO
 PERIGEE. IN HRS,
 MINS, SECS TO
 NEAREST .01 SEC.

WAIT FOR KEYBOARD
 ENTRY
 TERMINATE FLASH UPON
 RECEIPT OF PROCEED

WHEN FINISHED
 WITH DISPLAY
 KEY IN PROCEED
 V 33 E

EXIT R30

EXIT R30

#100

#110

#120

END OF RUN

326

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

RENDEZVOUS PARAMETER DISPLAY ROUTINE (R31)

REV 3

10/07/66

- PURPOSE: (1) TO DISPLAY AT ASTRONAUT REQUEST CMC CALCULATED RENDEZVOUS PARAMETERS (RANGE, RANGE RATE, THETA)
- ASSUMPTIONS: (1) RANGE AND RANGE RATE ARE CALCULATED BY THE CMC ON THE BASIS OF THE STORED LM AND CSM STATE VECTORS.
- (2) THE ISS IS ON AND ALIGNED.
- (3) THE ROUTINE IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY.

PRG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
			.CREW .ROUTINE .SELECTION . . .			#10
	----- START BACKUP RENDEZVOUS PARAMETER DISPLAY ROUTINE (R31) ----- . . .	.....	----- KEY IN V--E -----			#20
..... HOLD .	----- FLASH VERB-NOUN TO REQUEST RESPONSE AND DISPLAY RENDEZVOUS PARAMETERS: V06 N-- R1-RANGE R2-RANGE RATE R3-THETA RANGE-CALCULATED RANGE TO LM. IN NAUTICAL MILES TO NEAREST .01 NM.	.....	----- MONITOR DSKY: OBSERVE VERB-NOUN FLASH TO REQUEST RESPONSE AND DISPLAY OF RENDEZVOUS PARAMETERS. (NOTE: THESE PARA- METERS ARE ONLY COMPUTED ONCE AND ARE NOT CONTINUALLY UPDATED.) -----			#30

RANGE RATE-
 CALCULATED RANGE
 RATE BETWEEN CSM AND
 LM. NEGATIVE SIGN
 INDICATES CLOSING
 IN FPS TO NEAREST
 .1 FPS

#40

THETA-ANGLE BETWEEN
 CSM +X AXIS AND THE
 LOCAL HORIZONTAL
 PLANE AT THE PRESENT
 TIME. PLUS SIGN
 INDICATES +X AXIS
 ABOVE PLANE. IN
 DEGREES TO NEAREST
 .01 DEGREE

#50

 .
 .
 .

 RELEASE USKY
 FOR LGC PROGRAM USE
 WHEN KEY RELEASE IS
 RECEIVED.

EXIT R31

 .
 .
 .

 OBSERVE PARAMETERS
 AS DESIRED WHEN
 FINISHED PUSH KEY
 RELEASE

EXIT R31

#60

#70

END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

TARGET DELTA V ROUTINE (R32)

REV 4

10/06/66

- PURPOSE:
- (1) TO PROVIDE A MEANS OF NOTIFYING THE CMC THAT THE LM HAS CHANGED ITS ORBITAL PARAMETERS BY THE EXECUTION OF A THRUSTING MANEUVER.
 - (2) TO PROVIDE TO THE CMC THE DELTA V APPLIED TO THE LM TO ENABLE AN UPDATING OF THE LM STATE VECTOR.
- ASSUMPTIONS:
- (1) THE CSM CREW HAS THE DELTA V TO BE APPLIED BY THE LM IN LOCAL VERTICAL AXES AT A SPECIFIED TIG. THESE VALUES ARE DISPLAYED PRIOR TO TIG BY THE THRUSTING PROGRAM (P40, P41, AND P42 IN THE LGC). NO PROVISION IS MADE IN THESE THRUSTING PROGRAMS TO DISPLAY THE RESULTS OF THE MANEUVER IN A FORM USABLE BY THIS ROUTINE. IF THE BURN IS NOT NOMINAL AND THIS DELTA V IS NOT AS SPECIFIED OR IF TIG IS NOT AS ORIGINALLY SPECIFIED CONSULT BACKUP PROCEDURES.
 - (2) IF THIS ROUTINE IS SELECTED DURING STATE VECTOR UPDATING BY THE RENDEZVOUS NAVIGATION PROGRAM (P20.) THE VECTOR UPDATING PROCESS WILL BE TEMPORARILY TERMINATED UNTIL THE LM DELTA V HAS BEEN INCORPORATED INTO THE LM STATE VECTOR BY THE CMC.
 - (3) IF THE RENDEZVOUS NAVIGATION PROGRAM (P20) IS IN PROCESS THIS ROUTINE MUST BE SELECTED PRIOR TO THE APPLICATION OF DELTA V TO THE LM. THIS CAN BE ASSURED BY VOICE COMMUNICATION BETWEEN THE LM AND CSM.
 - (4) THE ROUTINE IS SELECTED BY THE ASTRONAUT BY DSKY ENTRY

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
			.CREW .ROUTINE .SELECTION ...			#10
	----- START TARGET DELTA V ROUTINE (R32) -----	.....	----- KEY IN V--E -----			
	..... ..... .....		..... ..... .....			#20
	----- RESET UPDATE FLAG (SEE P20) -----		..... ..... .....		
	..... ..... .....		..... ..... .....			#30

FLASH VERB-NOUN
TO REQUEST RESPONSE
AND DISPLAY THREE
STORED COMPONENTS OF
DELTA V(LV).

V06N--
R1-DELTA VX(LV)
R2-DELTA VY(LV)
R3-DELTA VZ(LV)

DELTA VX(LV)-
COMPONENT OF DELTA V
APPLIED AT TIGN
ALONG (RXV)XR. IN
FPS TO NEAREST .1
FPS.

DELTA VY(LV)-
COMPONENT OF DELTA V
APPLIED AT TIGN
ALONG VXR. IN FPS TO
NEAREST .1 FPS.

DELTA VZ(LV)-
COMPONENT OF DELTA V
APPLIED AT TIGN
ALONG -R. IN FPS TO
NEAREST .1 FPS.

WAIT FOR KEYBOARD
ENTRY

MONITOR DSKY
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF THREE STORED
COMPONENTS OF DELTA
V APPLIED ALONG
LOCAL VERTICAL AXES
AT TIG.

WAIT UNTIL THE LM
CREW HAS TRANSMITTED
THE VALUES OF THE
DELTA V TO BE APP-
PLIED AND THE TIME OF
IGNITION AND THE
THRUSTING MANEUVER
HAS BEEN SUCCESSFUL-
LY COMPLETED.

ARE THE VALUES
DISPLAYED THE
CORRECT ONES
EXECUTED BY THE LM?

.Y .N

KEY IN
PROCEED
V33E

#40

#50

#60

#70

#80

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW DATA

KEY IN V25
AND LOAD THE
CORRECT DELTA
V.

#90

PROCEED NEW
DATA

STORE DATA

#100

FLASH VERB-NOUN
TO REQUEST RESPONSE
AND DISPLAY STORED
TIGN

MONITOR DSKY
OBSERVE VERB-NOUN
FLASH TO REQUEST
RESPONSE AND DISPLAY
OF STORED TIG.

#110

V06N34
R1-TIG-HRS
R2-TIG-MINS
R3-TIG-SECS

TIG-TIME OF IGNITION
(GET). IN HRS,MINS,
SEC TO NEAREST .01
SEC.

#120

WAIT FOR KEYBOARD
ENTRY.

IS THE VALUE
DISPLAYED THE
CORRECT TIME AT
WHICH THE LM EXECUT-
ED THE MANEUVER

#130

.Y .N

KEY IN PROCEED
V33E

#140

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW DATA

P NEW
R DATA
O
C STORE DATA
E
E
D
.
.
.
.

UPDATE LM STATE
VECTOR TO REFLECT
THE DELTA V ADDED.

SET UPDATE FLAG (SEE
P20)

EXIT R32

KEY IN V25
AND LOAD THE
CORRECT TIG

EXIT R32

#150

#160

#170

334 END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

COARSE ALIGN ROUTINE (R50)

REV 3

10/06/66

PURPOSE: (1) TO COARSE ALIGN THE IMU TO A DESIRED INERTIAL ORIENTATION.

ASSUMPTIONS: (1) THE DESIRED IMU INERTIAL ORIENTATION HAS BEEN SPECIFIED BY THE CALLING PROGRAM.

(2) THE ROUTINE IS AUTOMATICALLY SELECTED BY THE INFLIGHT ALIGNMENT PROGRAMS: IMU REALIGN PROGRAM (P52) OR CSM/IMU REALIGN PROGRAM (P53).

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
	•CMC •ROUTINE •SELECTION					#10
	• ••• •					
	----- START COARSE ALIGN ROUTINE (R50) -----					
	• • •					#20
	----- READ PRESENT IMU ORIENTATION W.R.T. THE VEHICLE. (GIMBAL ANGLES) -----					
	• • •					#30
	----- SELECT PRESENT IMU INERTIAL ORIENTATION FROM STORAGE -----					
	• • • • • • • • • • •					

.....

TERMINATE COARSE
ALIGN MODE IN ISS.
RESUME ATTITUDE
HOLD OF VEHICLE

#100

.....
EXIT R50

538

END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

FINE ALIGNMENT ROUTINE (R51)

REV 8

10/20/66

PURPOSE: (1) TO OBTAIN THE NECESSARY STAR SIGHTINGS AND THEN TO FINE ALIGN THE IMU TO A DESIRED INERTIAL ORIENTATION.

ASSUMPTIONS: (1) THE DESIRED IMU INERTIAL ORIENTATION HAS BEEN SPECIFIED BY THE CALLING PROGRAM.

(2) THE ROUTINE IS NORMALLY AUTOMATICALLY SELECTED BY THE INFLIGHT ALIGNMENT PROGRAMS: THE IMU REALIGN PROGRAM (P52) OR THE CSM/IMU REALIGN PROGRAM (P53).

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
	.CMC ROUTINE .SELECTION . . .					#10
	----- START FINE ALIGNMENT ROUTINE (R51) ----- . . .					#20
	..... . . ----- . SELECT STAR #1 FOR USE BY AUTO OPTICS POSI- TIONING ROUTINE (R52) ----- . . .					#30
	----- . SET TARGET FLAG TO STAR FOR USE BY SIGHTING MARK ROUTINE (R53) -----					#40

340

SET MARK INDEX TO 1
FOR USE BY THE
SIGHTING MARK
ROUTINE (R53).

DO AUTO OPTICS
POSITIONING
ROUTINE (R52)
FOR STAR #1

SELECT STAR #2
FOR AUTO OPTICS
POSITIONING
ROUTINE (R52)

DO AUTO OPTICS
POSITIONING
ROUTINE (R53)
FOR STAR #2

DO STAR DATA TEST
ROUTINE (R54)

DO GYRO TORQUING
ROUTINE (R55)

OPTIONAL.

DO AUTO OPTICS
POSITIONING
ROUTINE (R52)
FOR STAR #1

DO AUTO OPTICS
POSITIONING
ROUTINE (R52) FOR
STAR #2

DO STAR DATA TEST
ROUTINE (R54)

DO GYRO TORQUING
ROUTINE (R55)

OPTIONAL.

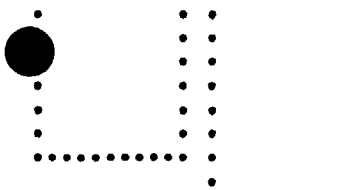
#50

#60

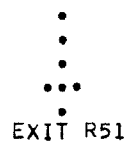
#70

#80

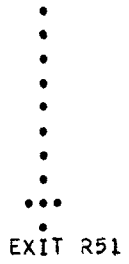
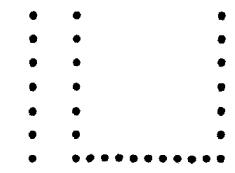
#90



RESET PREFERRED
ORIENTATION FLAG



EXIT R51



EXIT R51

#100

342- END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

AUTOMATIC OPTICS POSITIONING ROUTINE (R52)

REV 7

10/29/66

PURPOSE: (1) TO POINT THE STAR LOS OF THE OPTICS AT A STAR OR LANDMARK DEFINED BY THE PROGRAM OR BY DSKY INPUT (ASTRONAUT).
 (2) TO POINT THE STAR LOS OF THE OPTICS AT THE LM DURING RENDEZVOUS TRACKING OPERATIONS.

ASSUMPTIONS: (1) THE ROUTINE IS AUTOMATICALLY SELECTED BY THE FINE ALIGNMENT ROUTINE (R51) DURING THE INFLIGHT ALIGNMENT PROGRAMS: IMU REALIGN PROGRAM (P52), OR CSM/IMU REALIGN PROGRAM (P53) AND ALSO BY THE RENDEZVOUS NAVIGATION PROGRAM (P20) OR BY THE ORBITAL NAVIGATION PROGRAM (P22).

(2) THIS ROUTINE IS SELF PERPETUATING AND IS TERMINATED BY THE SIGHTING MARK ROUTINE (R53) AND V--E, OR P00 AS APPLICABLE.

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
	.CMC ROUTINE .SELECTION • • • • •					#10
	----- START AUTO OPTICS POSITIONING ROUTINE (R 52) -----					
	• • •					
	----- RESET TERMINATE FLAG -----					#20
	• • •					
	----- SET TRUNNION DRIVE FLAG -----					#30
	• • • • • • • • • • •					

343

IS THE TARGET FLAG
LM, STAR OR LANDMARK

.LM .STAR.LMK

IS THE TARGET THE LM
A STAR OR A LAND-
MARK?

.LMK .STAR LMK

#40

POSS
HOLD

FLASH VERB-NOUN TO
REQUEST RESPONSE
AND DISPLAY STORED
LANDMARK IDENTITY:

V06 N44
R1 - LAT
R2 - LONG
R3 - ALT

LAT-LATITUDE OF
LANDMARK. IN
DEGREES TO NEAR-
EST .01 DEGREES.
+ IS NORTH

LONG-LONGITUDE OF
LANDMARK. IN
DEGREES TO NEAR-
EST .01 DEGREES.
+ IS EAST

ALT-ALTITUDE OF
LANDMARK ABOVE
PAD RADIUS. IN
NAUTICAL MILES
TO NEAREST .1 NM.

MONITOR DSKY:
OBSERVE FLASHING
VERB-NOUN TO RE-
QUEST RESPONSE AND
DISPLAY OF STORED
LANDMARK IDENTITY

#50

AM I SATISFIED
WITH THESE VALUES

.Y .N

#60

DO I WISH TO
POINT THE OP-
TICS MANUALLY?

.N .Y

#70

PUT OP-PUT OP-
TICS TICS
SWITCH SWITCH
TO TO
AUTO MANUAL

#80

WAIT FOR KEYBOARD
ENTRY

KEY IN PROCEED
V 33 E

TERMINATE FLASH
UPON RECEIPT OF
PROCEED OR NEW DATA

KEY IN V25 AND
LOAD DESIRED
PARAMETERS

V33E NEW
 DATA

STORE DATA

#90

#100

#110

#120

POSS .
HOLD .

FLASH VERB-NOUN TO
REQUEST RESPONSE
AND DISPLAY STORED
STAR CODE
V06 N30
R1-STAR CODE
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE FLASHING
VERB-NOUN TO REQUEST
RESPONSE AND DISPLAY
OF STORED STAR CODE

#130

STAR CODE - STAR
DESIGNATION FROM
STAR CODE LIST

Am I SATISFIED WITH
THIS STAR CODE?

 .Y .N

#140

DO I WISH TO
POINT THE OP-
TICS MANUALLY?

 .N .Y

345

POSS .
.....
HOLD .

FLASH VERB-NOUN
TO REQUEST
PLEASE PERFORM
OSS SWITCH TO
CMC MODE:
V50 N25
R1-00013
R2-BLANK
R3-BLANK

MONITOR DSKY:
DOES VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM OSS
SWITCH TO CMC MODE?

.Y N.

#200

IS OSS
ALREADY IN
CMC MODE?

.N .Y

#210

#220

WAIT FOR KEY-
BOARD ENTRY

SWITCH OPTICS
TO CMC MODE AND
KEY IN ENTER

#230

TERMINATE FLASH
UPON RECEIPT OF
ENTER OR PROCEED

KEY IN PRO-
CEED

V33E

.P .E
.R .N
.O .T
.C .E
.E .R
.E .
.D

#240

GET PRESENT IMU
ORIENTATION FROM
STORAGE (REFSMAT)

#250

CHECK OPTICS MODE
DISCRETE. IS THE
OSS IN THE CMC MODE?

.Y .N

CALL SIGHTING
MARK ROUTINE
(R53)

IS THE OPTICS IN THE
MANUAL OR AUTO MODE?

.MAN .AUTO

MONITOR DSKY:
OBSERVE V51
FLASH TO RE-
QUEST PLEASE
PERFORM MARK.

DO I WISH TO
HAVE OPTICS
AUTOMATICALLY
POINTED?

.N .Y

PUT OP-
TICS IN
CMC MODE

DO SIGHTING
MARK ROUTINE
(R53)

#260

#270

#280

#290

#300

#310

READ PRESENT VEHI-
CLE ATTITUDE FROM
ICDUS

IS THE TARGET FLAG
LM ?

Y N
• (LM) •
• •

IS THE TARGET
FLAG STAR OR
LANDMARK

• (STAR) • (LMK)
• •

COMPUTE
TARGET
VECTOR
FROM CSM
TO DESIG-
NATED
LANDMARK.

COMPUTE TAR-
GET VECTOR
FROM CSM TO
DESIGNATED
STAR.

#320

#330

#340

#350

IS THE OP-
TICS ENABLE
FLAG SET
(SEE P20)?

#360

.Y .N

WAIT -
SEC.

#370

COMPUTE
TARGET VEC-
TOR FROM
CSM TO LM

#380

CALCULATE THE RE-
QUIRED OPTICS ANGLES
TO POINT THE STAR
LOS OF THE OPTICS
ALONG THE TARGET
VECTOR.

#390

IS A TRUNNION ANGLE
GREATER THAN 90 DEG
REQUIRED TO POINT
THE STAR LOS OF THE
OPTICS AT THE
TARGET?

#400

.N .Y

FLASH VERB-NOUN
TO REQUEST RESP-
ONSE AND DISPLAY
ALARM CODE:

V05N31
R1-
R2-
R3-

MONITOR DSKY:
DOES ALARM CODE
DISPLAY INDICATE
THAT THE TARGET IS
NOT WITHIN THE
HEMISPHERE OF
OPTICS VISIBILITY?

.Y N.

#410

FOR STAR/LANDMARK
SIGHTINGS THERE
ARE THREE OPTIONS,
FOR LM SIGHTINGS
THERE ARE TWO
(OMIT B):

#420

(A) MANUALLY MA-
NEUVER VEHICLE
UNTIL OPTICS CAN
ACQUIRE THE DES-
IRED TARGET.

#430

(B) RESELECTION
OF THE TARGET.

(C) TERMINATION
OF AUTO OPTICS
POSITIONING AND
SUBSEQUENT MANU-
AL OPTICS POINT-
ING.

#440

.A B. C.

MANUALLY
MANEUVER VEH-
ICLE UNTIL IT
IS ESTIMATED
THAT OPTICS
CAN ACQUIRE
THE TARGET.
MONITOR FDAI
TO AVOID
GIMBAL LOCK.

#450

#460

352

WAIT FOR KEY-
BOARD ENTRY.

KEY IN
PROCEED
V33E

#470

KEY IN RECYCLE
V32E

TERMINATE FLASH
UPON RECEIPT OF
PROCEED, RECYCLE
OR TERMINATE.

KEY IN TERMIN-
ATE.
V34E

#480

.T .R .P
.E .E .R
.R .C .O
.M .Y .C
.I .C .E
.N .L .E
.A .E .D
.T
.E

GO TO SIGHTING
MARK ROUTINE
(R53)

#490

EXIT
R 52

RETURN TO
START OF
THIS ROUTINE

RETURN TO
START OF
THIS ROUTINE

#500

GO TO SIGHTING
MARK ROUTINE
(R53)

#510

EXIT R52

IS THE TRUNNION
ANGLE REQUIRED TO
POINT THE STAR LOS
OF THE OPTICS AT THE
TARGET GREATER THAN
40 DEGREES?

.N .Y

SET TRUNNION:
DRIVE FLAG

RESET TRUNNION
DRIVE FLAG.

FLASH VERB-NOUN
TO REQUEST RESPON-
SE AND DISPLAY DE-
SIRED OPTICS

ANGLES:
V06N57
R1-SHAFT
R2-TRUNNION
R3-BLANK

SHAFT-DESIRED
SHAFT ANGLE, IN
DEGREES TO NEAREST
.01 DEGREE.

TRUNNION-DESIRED
TRUNNION ANGLE.
IN DEGREES TO
NEAREST .001
DEGREE.

MONITOR DSKY:
DOES VERB-NOUN
FLASH TO REQUEST RE-
SPONSE AND DISPLAY
OF DESIRED OPTICS
ANGLES.

.Y N.

FOR STAR/LANDMARK
SIGHTINGS THERE
ARE THREE OPTIONS,
FOR LM SIGHTINGS
THERE ARE TWO
(OMIT B):

(A) MANUALLY MA-
NEUVER VEHICLE
UNTIL OPTICS CAN
ACQUIRE THE DES-
IRED TARGET.

(B) RESELECTION
OF THE TARGET.

#520

#530

#540

#550

#560

#570

(C) TERMINATION
 OF AUTO OPTICS
 POSITIONING AND
 SUBSEQUENT MANU-
 AL OPTICS
 POINTING

#580

•A •B •C

 MANUALLY MA-
 NEUVER VEHI-
 CLE UNTILL
 IT IS ESTIM-
 ATED THAT
 OPTICS CAN
 ACQUIRE THE
 TARGET. MON-
 ITOR DSKY
 DISPLAY OF
 OPTICS ANGL-
 ES FOR ASSI-
 STANCE. MON-
 ITOR FDAI TO
 AVOID GIMBAL
 LOCK.

#590

#600

 WAIT FOR KEY-
 BOARD ENTRY

 WHEN DESIRED
 TRUNNION AN-
 GLE IS LESS
 THAN 40 DEG-
 REES KEY IN
 PROCEED V33E

#610

 KEY IN RE-
 CYCLE

#620

RETURN
TO START
OF THIS
ROUTINE

#630

TERMINATE FLASH
UPON RECEIPT OF
PROCEED, RECYCLE,
OR TERMINATE.

KEY IN
TERMINATE
V34

#640

.T .R .P
.E .E .R
.R .C .O
.M .Y .C
.I .C .E
.N .L .E
.A .E .D
.T
.E

GO TO
SIGHTING
MARK
ROUTINE
(R53)

#650

RETURN TO
START OF
THIS
ROUTINE

EXIT
R52

#660

GO TO SIGHTING
MARK ROUTINE
(R53)

EXIT
R52

#670

IS THE PRESENT STAR
LOS OF THE OPTICS
WITHIN 5 DEGREES OF
THE TARGET VECTOR?

.N .Y

#680

358

356

CALL SIGHTING
MARK ROUTINE
(R53)

MONITOR DSKY:
DOES V51 FLASH
INDICATE THAT CMC IS
READY TO RECEIVE
MARKS?

.Y .N

#690

DO SIGHTING MARK
ROUTINE (R53)

#700

DISPLAY ON DSKY:
V06N57
R1-SHAFT
R2-TRUNNION
R3-BLANK

MONITOR DSKY:
OBSERVE DISPLAY
OF DESIRED OPTICS
ANGLES.

#710

SHAFT-DESIRED SHAFT
ANGLE. IN DEGREES TO
NEAREST .01 DEGREE.

TRUNNION-DESIRED
TRUNNION ANGLE. IN
DEGREES TO NEAREST
.001 DEGREE.

#720

CHECK OPTICS MODE
DISCRETE. IS THE
OSS IN CMC MODE?

.Y .N

#730

IS TRUNNION
DRIVE FLAG SET?

.Y .N

DRIVE DRIVE
SEXTANT SEXTANT
AND CDU
TRUN- ONLY
NION

CDUS

#740

WAIT 2 SECONDS.

#750

HAS TERMINATE FLAG
BEEN SET BY THE
SIGHTING MARK ROU-
TINE (R53)?

#760

Y N

EXIT R52

#770

357
END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

SIGHTING MARK ROUTINE (R 53)

REV 8 10/24/66

PURPOSE: (1) TO PERFORM A SATISFACTORY NUMBER OF OPTICAL SIGHTING MARKS FOR THE REQUESTING PROGRAM (OR ROUTINE).

ASSUMPTIONS: (1) SIGHTINGS ARE MADE WITH EITHER SCT OR SXT AS REQUIRED.
 (2) SIGHTINGS MAY BE MADE ON A STAR OR EARTH LANDMARK.
 (3) WHEN THE CMC ACCEPTS A MARK IT RECORDS AND STORES 5 ANGLES (3 ICDUS AND 2 OCDUS) AND THE TIME OF THE MARK.
 (4) MAXIMUM UNREJECTED-MARK THRESHOLDS ARE ESTABLISHED UTILIZING A MARK COUNTER. THIS MARK COUNTER WILL INCREMENT EACH TIME A MARK IS MADE AND DECREMENT EACH TIME A MARK REJECT IS MADE. THE MARK COUNTER WILL BE COMPARED AGAINST A MARK INDEX. THE MAGNITUDE OF THIS INDEX WILL BE SELECTED BY THE PROGRAM (OR ROUTINES) SELECTING THE SIGHTING MARK AS FOLLOWS:

- (A) STAR - 1
- (B) LANDMARK - 5

IN ADDITION MINIMUM UNREJECTED-MARK THRESHOLDS ARE ESTABLISHED IN THE PROCESSING LOGIC AS FOLLOWS:

- (A) STAR - 1
- (B) LANDMARK (KNOWN) - 1
- (C) LANDMARK (UNKNOWN) - 2

(5) THE ROTATION OR MINIMUM IMPULSE CONTROLLER MAY BE USED AS REQUIRED TO REDUCE THE S/C DRIFT RATE.
 (6) THE ROUTINE IS AUTOMATICALLY SELECTED BY THE AUTO OPTICS POSITIONING ROUTINE (R52). IF ASTRONAUT DESIRES TO MARK BEFORE THIS ROUTINE HAS BEEN SELECTED HE MAY CALL THIS ROUTINE AT ANY TIME DURING THE AUTO OPTICS POSITIONING ROUTINE (R52) BY SELECTING MANUAL OPTICS MODE (SEE R52).

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
--------------	-----	--------	------	-----------	------	---------------

.CMC ROUTINE
 .SELECTION

•
 •••
 •

#10

 START SIGHTING MARK
 ROUTINE (R 53)

•
 •
 •
 •

ZERO MARK COUNTER

#20

IS SIGHTING FLAG
STAR?

#30

Y. N

FLASH VERB-NOUN
TO REQUEST PLEASE
MARK AND DISPLAY
LANDMARK DATA:
V51 N44
R1-LAT
R2=LONG
R3=ALT

PLEASE
MARK

MONITOR DSKY:
OBSERVE FLASHING
VERB TO REQUEST
PLEASE MARK

#40

HOLD

FLASH VERB-NOUN TO
REQUEST PLEASE MARK
AND DISPLAY STAR
CODE:
V 51 N30
R1-STAR CODE
R2-BLANK
R3-BLANK

PLEASE
MARK

#50

HOLD

SELECT MANUAL OPTICS
MODE

#60

WAIT FOR KEYBOARD
ENTRY

MARK

WHEN SIGHTING IS
SATISFACTORILY
ACCOMPLISHED PRESS
MARK BUTTON

#70

ENTER

WAS THE SIGHTING SATISFACTORY?

#80

Y N

TERMINATE FLASH OF V51 UPON RECEIPT OF MARK, MARK REJECT, OR ENTER

MARK REJECT ENTER

#90

MARK REJECT

PRESS MARK REJECT BUTTON

#100

IS MARK FLAG SET?

Y N

MARK REJECT WITH NO MARK

ERASE LAST SET OF MARK DATA AND DECREMENT MARK COUNTER BY ONE

#110

HAVE THE MINIMUM NUMBER OF UNREJECTED MARKS BEEN MADE FOR THIS TYPE OF TARGET?

STAR - 1 KN LMK - 1 UKN LMK - 2

RESET MARK FLAG

#120

IS THE TARGET A STAR OR LANDMARK?

STAR LMK

362

#130

SET MARK
FLAG

DO I WISH TO
MAKE MORE
MARKS?

N. Y

#140

STORE FIVE ANGLES
AND TIME AND
INCREMENT MARK
COUNTER BY ONE.

KEY IN
ENTER

#150

IS MARK COUNTER
STILL LESS THAN
MARK INDEX?

Y. N

#160

HOLD

FLASH VERB NOUN TO
REQUEST PLEASE
PERFORM TERMINATE
MARK SEQUENCE:
V50 N25
R1-00016
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE FLASHING
VERB-NOUN TO REQUEST
PLEASE PERFORM
TERMINATE MARK
SEQUENCE

#170

#180

WAIT FOR KEYBOARD
ENTRY.

WAS LAST MARK
SATISFACTORY?

.Y .N

ENTER

KEY IN
ENTER

MARK
REJECT

PRESS MARK
REJECT
BUTTON

TERMINATE FLASH
UPON RECEIPT OF
ENTER, MARK, OR
MARK REJECT

SURPLUS
MARK

SURPLUS
MARK

.SUR .MK .E
.....MK .REJ .N

.T
.E
.R

SET TERMINATE
FLAG FOR USE
BY R52.

RESET MARK FLAG

IS MARK COUNTER ZERO

.Y .N

#190

#200

#210

#220

#230

364

•
•
•
•
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•

IS SIGHTING FLAG
STAR OR LANDMARK?

• STAR • LMK
•
•
•
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•
•
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•
•
•

EXIT R53

#240

POSS
•
•••••
•
HOLD

FLASH VERB-NOUN
TO REQUEST LOAD
OF STAR CODE.
V21 N30
R1-BLANK
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE FLASHING
VERB-NOUN TO REQUEST
LOAD OF STAR CODE.

#250

#260

•
•
•

WAIT FOR KEYBOARD
ENTRY.

•
•
•

LOAD STAR CODE:
R1-STAR CODE

TERMINATE FLASH UPON
RECEIPT OF ENTER.

•
•••••
•

STAR CODE - STAR
DESIGNATION FROM
CARRY ON DATA.

#270

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•
EXIT R53

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•
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•
•
•
•
EXIT R53



END OF RUN



366

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

STAR DATA TEST ROUTINE (R54)

REV 5

10/31/66

PURPOSE: (1) TO TEST THE ACCURACY OF A PAIR OF STAR SIGHTINGS

ASSUMPTIONS: (1) THE ROUTINE IS NORMALLY AUTOMATICALLY SELECTED BY THE INFLIGHT ALIGNMENT-IMU ORIENTATION DETERMINATION PROGRAM (P24) OR THE FINE ALIGN ROUTINE (R51).

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
	•CMC •ROUTINE •SELECTION ••• •					#10
	----- START STAR DATA TEST ROUTINE (R 54) ----- • • •				00:00	
	----- CALCULATE ANGLE BE- TWEEN TWO STARS USING STORED EPHEM- ERIS DATA (ACTUAL) ----- • • •					#20
	----- CALCULATE ANGLE BE- TWEEN TWO STARS USING STAR VECTORS DERIVED FROM MARK ANGLES (INDICATED) ----- • • •					#30
	----- SET TEST TOLERANCE TO .05 DEG ----- • • • • • • •					#40

IS THE DIFFERENCE
BETWEEN ACTUAL AND
INDICATED ANGLES
GREATER THAN THE
TEST TOLERANCE?

#50

Y. .N

DISPLAY ON DSKY:
V06 N05
R1-STAR ANGLE
DIFF
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE VERB-NOUN
AND DISPLAY OF STAR
ANGLE DIFF

#60

STAR ANGLE DIFF-
DIFFERENCE BE-
TWEEN ACTUAL
AND INDICATED
ANGLES BETWEEN
STAR VECTOR
#1 AND STAR
VECTOR #2. IN
DEGREES TO
NEAREST .01
DEGREES.

#70

WAIT 10 SECONDS

#80

EXIT R 54

POSS.
HOLD
FLASH VERB-NOUN TO
REQUEST RESPONSE AND
DISPLAY STAR ANGLE
DIFF:

IS VERB-NOUN STATIC
OR FLASHING

#90

V06 N05
R1-STAR ANGLE DIFF
R2-BLANK
R3-BLANK

VERB- . VERB-NOUN
NOUN . STATIC
FLASH .

EXIT R 54

#100

WAIT FOR KEYBOARD
ENTRY

SHALL I PROCEED
WITH BAD DATA

.Y .N

KEY IN
PROCEED
V 33 E

EXIT R 54

#110

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR NEW PROGRAM

KEY IN DESIRED NEW
PROGRAM
V 37 E -- E

P. .NEW
R. .PROGRAM
O. .
C. -----
E. GO TO PROGRAM
E. SELECTED
D. -----

EXIT R54

#130

EXIT R 54 EXIT R 54

#140

END OF RUN

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

GYRO TORQUING ROUTINE (R55)

REV 4

10/06/66

PURPOSE: (1) TO CALCULATE GYRO TORQUING ANGLES FOR FINAL (FINE) ALIGNMENT OF THE INERTIAL PLATFORM DURING AN INFLIGHT ALIGNMENT, TO DISPLAY THESE ANGLES AND TO TORQUE THE GYROS.

ASSUMPTIONS: (1) THE ROUTINE IS NORMALLY AUTOMATICALLY SELECTED BY THE FINE ALIGN ROUTINE (R51).

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
	.CMC .ROUTINE .SELECTION					#10
	----- START GYRO TORQUING ROUTINE (R55) ----- . . .					
	----- CALCULATE REQUIRED TORQUING ANGLES FOR EACH GYRO ----- . . .					#20
	----- IS ANY ANGLE GREATER THAN 5 DEGREES? ----- .Y .N . . .					#30
	. DISPLAY ON DSKY: . GYRO TORQUING . ANGLES . V06 N67 . R1-X GYRO . R2-Y GYRO . R3-Z GYRO . . . . . . . .		. MONITOR DSKY: . OBSERVE VERB-NOUN . AND DISPLAY OF GYRO . TORQUING ANGLES			#40

GYRO TORQUING
ANGLES-THE ANGLE
THRU WHICH EACH
GYRO MUST BE
TORQUED TO COM-
PLETE THE FINE
ALIGNMENT. ALL
ANGLES IN DEGREES
TO NEAREST .001
DEGREE.

#50

POSS
.....
HOLD
FLASH VERB-NOUN
TO REQUEST RESPO-
NSE AND DISPLAY
V06 N67
R1-X GYRO
R2-Y GYRO
R3-Z GYRO

#60

IS VERB-NOUN STATIC
OR FLASHING?

FLASHING STATIC
VERB-NOUN VERB-
NOUN

#70

SHALL I PERMIT
TORQUING

N. Y.

#80

WAIT FOR KEYBOARD
ENTRY

KEY IN
TERMINATE
V 34 E

EXIT R55
AND P--

#90

TERMINATE FLASH
UPON RECEIPT OF
PROCEED OR TERMIN-
ATE

KEY IN PROCEED
V 33 E

T.
E.
R.
M.
.
.

P.
R.
O.
C.
E.
E.
D.

TERMINATE
PROGRAM
GO TO P00

EXIT.R55
AND P--

PULSE IRIGS THROUGH
DESIRED ANGLES

FLASH VERB-NOUN TO
REQUEST PLEASE
PERFORM FINE ALIGN
CHECK:
V50 N25
R1-00014
R2-BLANK
R3-BLANK

HOLD

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM FINE
ALIGN CHECK

DO I WANT TO CHECK
THE FINE ALIGNMENT?

N. Y.

#100

#110

#120

#130

#140

.....

WAIT FOR KEYBOARD
ENTRY

.....

KEY IN PROCEED
V33 E

#150

.....
EXIT R55

.....

TERMINATE FLASH UPON
RECEIPT OF ENTER
OR PROCEED

.....

KEY IN ENTER

#160

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.....
.....
.....
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.....
.....
.....
.....

.....
.....
.....
.....
.....
.....
.....

RETURN TO START
OF FINE ALIGN
ROUTINE (R51)

RETURN TO START
OF FINE ALIGN
ROUTINE (R51)

#170

.....
.....
.....
.....
.....
EXIT R55

.....
.....
.....
.....
.....
EXIT R55

#180

END OF RUN

374

APOLLO COMPUTER LOGIC CHECKLIST INTERFACE

ATTITUDE MANEUVER ROUTINE (R60)

REV 7 10/31/66

- PURPOSE: (1) TO MANEUVER THE LM/CSM, CSM, OR CM ALONE TO AN ATTITUDE SPECIFIED BY THE PROGRAM IN PROGRESS.
- ASSUMPTIONS: (1) THE FINAL ATTITUDE DESIRED HAS BEEN STORED BY THE CALLING PROGRAM. THE ATTITUDE IS USUALLY DEFINED AS FOLLOWS:
- (1) A SPECIFIC BODY FIXED VECTOR
 - (2) A DIRECTION IN SPACE IN WHICH THIS VECTOR IS TO BE ALIGNED.
- THIS ROUTINE IS ALSO APPLICABLE TO ATTITUDES DEFINED BY A COMPLETE THREE AXIS BODY ORIENTATION.
- (2) THE MANEUVER MAY BE PERFORMED AUTOMATICALLY BY THE GNCS OR PERFORMED MANUALLY WITH AN OPTIONAL FINAL AUTOMATIC GNCS CONTROLLED TRIM MANEUVER. THIS OPTIONAL TRIM MANEUVER SHOULD BE CONSIDERED ESSENTIAL FOR MANEUVERS TO SPS THRUSTING ATTITUDES.
- (3) THE DOCKED CONFIGURATION OF THE VEHICLE(S) HAS BEEN MADE KNOWN TO THE CMC BY THE APPLICABLE DISCRETE:
- (A) CM ALONE - BY CM/SM SEP DISCRETE
 - (B) CSM - BY NO CM/SM SEP DISCRETE OR LM DOCKED DISCRETE (BACKED UP BY V--E)
 - (C) LM/CSM - BY LM DOCKED DISCRETE. (BACKED UP BY V--E)
- (4) THE ATTITUDE MANEUVER RATE DESIRED FOR DAP CONTROLLED MANEUVERS HAS BEEN DEFINED TO THE CMC BY DSKY ENTRY.
- (5) THE ROUTINE IS AUTOMATICALLY SELECTED BY THE PROGRAM OR ROUTINE REQUIRING THE ATTITUDE MANEUVER.

PROG CONT	CMC	GROUND	CREW	CHECKLIST	TIME	TOTAL TIME
	•CMC •ROUTINE •SELECTION • • ••• •					#10
	----- START ATTITUDE MANEUVER ROUTINE (R60) ----- • • • • • • • • • •					#20

 OBTAIN DESIRED
 ATTITUDE FROM THE
 CALLING PROGRAM

 RESET MANUAL FLAG

 IS THE TRACK FLAG
 (SEE P20)?

.Y .N

 IS THIS MANEJVER
 UNDER THE CONTROL OF
 THE PREFERRED TRACK-
 ING ATTITUDE ROUTINE
 FOR RENDEZVOJS NAVI-
 GATION?

.Y .N

 FLASH VERB-NOUN TO
 REQUEST PLEASE
 PERFORM GNCS A/P
 AND AUTO MODE
 SELECTION:
 V50 N25
 R1-000--
 R2-BLANK
 R3-BLANK

HOLD.

 MONITOR DSKY:
 OBSERVE VERB-NOJN
 FLASH TO REQUEST
 PLEASE PERFORM GNCS
 A/P AND AUTO MODE
 SELECTION:

 SHALL I PROCEED WITH
 THE MANEUVER AT THIS
 TIME?

.Y .N

#30

#40

#50

#60

#70

SHALL I PROVIDE THE
GNCS WITH THE
CAPABILITY TO
PERFORM THE MANEUVER
AUTOMATICALLY?

.Y .N
:
:

#80

SELECT SELECT
GNCS CON- A/P AND
TROL AND GNCS
PLACE MODE CON-
MODE TROL AS
SWITCH IN DESIRED.
AUTO

#90

WAIT FOR KEYBOARD
ENTRY

KEY IN PRO-
CEED
V33E

#100

TERMINATE FLASH UPON
RECEIPT OF ENTER
OR PROCEED

KEY IN ENTER

#110

.E .P
.N .R
.T .O
.E .C
.R .E
. .E
. .D

IS GNCS AUTO
MODE SELECTED?

.N .Y

#120

SET MAN-
UAL FLAG

READ PRESENT VEHICLE
ATTITUDE FROM ICDUS

3 AXIS FLAG SET?

.N .Y

CALCULATE FINAL
VEHICLE ATTITUDE TO
MEET THE DESIRED
ATTITUDE SPECIFICA-
TION. THIS FINAL VE-
HICLE ATTITUDE WILL
BE CALCULATED TO
MEET THE ATTITUDE
SPECIFICATION IN
SUCH A WAY AS TO
CONSERVE RCS FUEL
AND NOT CONSTRAIN
ANY UNSPECIFIED DE-
GREE OF FREEDOM.
NOTE:GNCS CAPABILI-
TY TO PERFORM
MANEUVER AUTOMATICA-
LLY WILL BE COMPROMI-
SED IF THE VEHICLE
ATTITUDE IS CHANGED
BY MANUAL INPUTS
AFTER THIS TIME

#130

#140

#150

#160

#170

#180

```

-----
SELECT GIMBAL
ANGLES CORRES-
PONDING TO
PREFERRED
VEHICLE ATTIT-
UDE AND PRES-
ENT IMU ORIEN-
TATION
-----

```

#190

```

-----
IS TRACK FLAG SET
(SEE P20)?
-----

```

```

.Y       .N

```

```

-----
DISPLAY FINAL
GIMBAL ANGLES
V06 N17
R1-OG ROLL
R2-IG PITCH
R3-MG YAW

```

```

ALL ANGLES IN
DEGREES TO NEAR-
EST .01 DEGREE
-----

```

```

-----
IS THE MANUAL
FLAG SET?
-----

```

```

.N       .Y

```

```

-----
DO MANEUVER CAL-
CULATION (KALCMA
NU) AND IC DU
DRIVE TO ACHIEVE
FINAL GIMBAL
ANGLES WITHOUT
PASSING THROUGH
GIMBAL LOCK. IN
PROGRAM 61 THE
MANEUVER RATE
-----

```

```

-----
MONITOR DSKY:
OBSERVE DISPLAY OF
FINAL GIMBAL ANGLES
CORRESPONDING TO AN
AUTOMATIC MANEUVER
TO THE FINAL ATTIT-
UDE STARTING FROM
THE PRESENT ATTITUDE
-----

```

#200

```

-----
DID I DIRECT THE CMC
TO PERFORM THE MANE-
UVER AUTOMATICALLY?
-----

```

```

.Y       .N

```

#210

```

-----
MONITOR ATTITUDE
MANEUVER BY
REFERENCE TO FDI
BALL AND ERROR
NEEDLES
-----

```

#220

#230

WILL BE 4 DEG/
 SEC. IN ALL OTHER
 CASES THE MANEU-
 VER RATE WILL BE
 THAT LAST DEFINED
 TO THE CMC BY
 DSKY ENTRY. THIS
 PROCESS WILL IN-
 CLUDE A MONITOR
 OF THE RHC INPUTS
 TO THE CMC. ANY
 INPUT FROM THE
 RHC WILL BE IN-
 TERPRETED AS A
 MANUAL OVERRIDE
 AND WILL CAUSE
 IMMEDIATE TERMI-
 NATION OF THIS
 MANEUVER CALCULA-
 TION AND ICPU
 DRIVE ROUTINE.

IS THE TRACK FLAG
 SET (SEE P20)?

.Y .N

DID AN
 RHC IN-
 PUT OC-
 CUR?

.N .Y

EXIT
 R60

SHALL I OVERRIDE
 THE PGNC AND
 COMPLETE THE
 MANEUVER MANUALLY?

.N .Y

IS THIS MAN-
 EUVER UN-
 DER THE CON-
 TROL OF THE
 PREFERRED
 TRACKING AT-
 TITUDE ROU-
 TINE FOR
 RENDEZVOUS
 NAVIGATION?

.N .Y

EXIT R60

PREFORM ATTITUDE
 MANEUVER MANUALLY
 USING RHC AND BY
 REFERENCE TO THE
 OUT-THE-WINDOW-
 VIEW AND/OR THE
 FDAI BALL. THIS
 OPERATION MAY
 INCLUDE ESTABLISH-

#240

#250

#260

#270

#280

#290

MENT OF A PREFERR-
ED ORIENTATION
ABOUT THE DIRECTED
BODY-FIXED VECTOR

FLASH VERB-NOUN TO
REQUEST PLEASE
PERFORM ATTITUDE
TRIM MANEUVER
ENABLE:
V50 N25
R1-0007
R2-BLANK
R3-BLANK

HOLD.

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH AND DISPLAY TO
REQUEST PLEASE
PERFORM ATTITUDE
TRIM MANEUVER ENABLE

#300

#310

DO I WISH TO FURTHER
ADJUST THE VEHICLE
ATTITUDE MANUALLY?

.Y .N

SELECT A/P AND
GNCS MODE
CONTROL AS
DESIRED

#320

PERFORM ATTITUDE
MANEUVER
MANUALLY USING
RHC AND BY
REFERENCE TO
THE OUT - THE
- WINDOW VIEW
AND/OR THE
FDAI BALL.
THIS OPERATION
MAY INCLUDE
ESTABLISHMENT
OF A PREFERRED
ORIENTATION
ABOUT THE DIR-
ECTED BODY-
FIXED VECTOR.

#330

#340

SHALL I PROVIDE THE
GNCS WITH THE CAPA-
BILITY TO TRIM THE
ATTITUDE AUTOMATI-
CALLY?

#350

.N .Y
.
.

SELECT A/P SELECT
AND GNCS GNCS
MODE CON- CONTROL
TROL AS AND PLACE
DESIRED. MODE
SWITCH IN
AUTO.

#360

WAIT FOR KEYBOARD
ENTRY

KEY IN PRO-
CEED
V33E

#370

EXIT R60

#380

TERMINATE FLASH UPON
RECEIPT OF PROCEED
OR ENTER.

KEY IN
ENTER

#390

.E .P
.N .R
.T .O
.E .C
.R .E
.
.

•
•
•
•
•

RESET THREE
AXIS FLAG

•
•
•
•
EXIT R60

384
END OF RUN

 IS RENDEZVOUS
 FLAG SET?
 (SEE P20)

.N .Y

 WAIT-SEC

 EXIT R61
 AND P20

#40

#50

 EXTRAPOLATE LM AND
 CSM STATE VECTORS TO
 PRESENT TIME
 USING CONIC
 EQUATIONS

.
 .
 .

#60

 CALCULATE LOS
 FROM CSM TO LM

.
 .
 .

 DEFINE THE DESIRED
 VEHICLE ATTITUDE TO
 BE THE TRACK AXIS
 (I) ALONG THE LOS TO
 THE LM FOR USE BY
 THE ATTITUDE
 MANEUVER ROUTINE
 (R60).

#70

.
 .
 .
 .
 .
 .
 .
 .

#80

 IS GNCS AUTO MODE
 SELECTED?

.Y .N

.
 .
 .
 .
 .
 .
 .
 .

```

-----
FLASH VERB-NOUN
TO REQUEST
PLEASE PERFORM
GNCS AUTO MODE
SELECTION:
V50N25
R1-000--
R2-BLANK
R3-BLANK
-----

```

```

-----
MONITOR DSKY:
DOES VERB-NOUN
FLASH TO REQUEST
PLEASE PERFORM GNCS
AUTO MODE SELECTION?
-----

```

#90

```

.Y .N

```

#100

```

-----
HAS GNCS AUTO
MODE BEEN
SELECTED?
-----

```

#110

```

.Y .N

```

```

-----
WAIT FOR KEY-
BOARD ENTRY
-----

```

```

-----
KEY IN
PROCEED
V33E
-----

```

#120

```

-----
SELECT
GNCS CON-
TROL AND
PLACE MODE
SWITCH IN
AUTO.
-----

```

```

-----
TERMINATE FLASH
UPON RECEIPT OF
ENTER OR PROCEED
-----

```

#130

```

-----
KEY IN
ENTER
-----

```

```

.P .E
.R .N
.O .T
.C .E
.E .R
.E .....
.D

```

```

-----
DO ATTITUDE MANEUVER
ROUTINE (R60)
-----

```

#140

```

-----
DO ATTITUDE MANEUVER
ROUTINE (R60)
-----

```

.....
.....
EXIT R61

.....
.....
EXIT R61

END OF RUN

TERMINATE ENGINE
ON COMMAND

IS SPS ROUGH ECO
ILLUMINATED?

#40

Y. N.

PERFORM
ALTERNATE
PROCEDURE

#50

TURN OFF TVC
DAP

PUT FCSM POWER
SWITCH IN RESET
POSITION MOMENTARILY
THEN TO ON

#60

TURN ON RCS
DAP

CHECK THAT THE ROUGH
ECO LIGHT GOES OUT

Y N

#70

DO I WISH TO
CONTINUE RESTART
ATTEMPT?

WAIT 0.5 SEC

Y. N.

COMMAND +X
TRANSLATION
(2 JET)

PUT FCSM OVER-
RIDE SWITCH IN
OVERRIDE POSI-
TION

#80

#90

#150

TURN ON TVC DAP

TURN OFF RCS DAP

WAIT UNTIL DELTA V
MONITOR DETECTS SPS
ON

TERMINATE +X
TRANSLATION

TERMINATE V50 N11
AND DISPLAY ORIGINAL
V06 N--

RETURN TO TVC IN
PROGRAM IN PROGRESS

EXIT R70

#160

#170

HAS ENGINE
IGNITED ?

.Y

.N

GO TO BACKUP
PROCEDURES

#180

#190

RETURN TO TVC
MONITORING IN
PROGRAM IN PROCESS

#200

EXIT R70

394

IS RENDEZVOUS
FLAG SET?

.N .Y

SET TRACK
FLAG (SEE P20)

SET UPDATE
FLAG (SEE P20)

DISPLAY P20

EXIT P

IS RENDEZVOUS
NAVIGATION PROGRAM
(P20) IN PROCESS?

.Y .N

MONITOR DSKY:
OBSERVE DIS-
PLAY OF P20 UPON
COMPLETION
OF

EXIT P

POSS .
.....
HOLD .
FLASH VERB-NOUN TO
REQUEST PLEASE
PERFORM SELECTION OF
AGC IDLING PROGRAM
(P00)

V50 N07
R1-00000
R2-BLANK
R3-BLANK

MONITOR DSKY:
OBSERVE VERB-NOUN
FLASH TO REQUEST
PERFORM SELECTION OF
P00

#210

#220

#230

#240

#250

#260

```

-----
SELECT CMC IDLING
PROGRAM (P00)
V37E 00E
-----

```

```

-----
WAIT FOR KEYBOARD
ENTRY
TERMINATE FLASH UPON
RECEIPT OF P00
-----

```

#270

```

-----
MONITOR DSKY:
OBSERVE TERMINATION
OF P40 AND DISPLAY
P00
-----

```

```

-----
TERMINATE P40 AND GO
TO P00
-----

```

EXIT P40

EXIT P40

376

END OF RUN

378

P00/CSM CMC IDLING PROGRAM

- 1 KEY V37 00E
- 2 IF DESIRED, PERFORM DSKY TESTS (P07)

END OF RUN

400

P05/CSM GNCS STARTUP PROGRAM

1 POSS STBY LT-ON (IF NOT, GO TO 2)

PRESS STBY PB: STBY LT-OUT
PRESS R SET:

2 KEY V37E 05E

3 FL V50 N25

R1-00060 (ISS TURN ON)

ACCEPT: G/N PWR SW - AC1 OR AC2

IMU/OFF SW - IMU
NO ATT LT-ON
AFTER 90 SEC NO ATT LT-OFF
ENTER

REJECT: V33E

4 POO

END OF RUN

402

P06/CSM GNCS POWER DOWN PROGRAM

1 KEY V37E 06E

POSS FL V05 N25

R1-00061 (IMU POWER DOWN)

ACCEPT: IMU/OFF SW - OFF
ENTER

REJECT: V33E

2 FL V50 N25

R1-00062 (CMC POWER DOWN)

ACCEPT: ENTER
PRESS STBY PB.
STBY LT - ON

REJECT: V33E

3 P00

END OF RUN

4104

P11/CSM EARTH ORBIT INSERTION
MONITOR PROGRAM

- 1 CMC DISPLAYS P11
- 2 CHECK AUTO START OF DET
IF NO AUTO START, DET START/STOP SW -
START
- 3 MONITOR FDAI:
ATT ERRORS<--DEG.
ATT RATES<--DEG/SEC
BALL INDICATES ROLLOUT, THEN PITCHOVER
- 4 V06 N40
GAMMA XXX.XX DEG
VI XXXXX. FPS
H PAD XXXX.X NM
- 5 SATURN SHUTDOWN
KEY: V37E 00E

END OF RUN

406

P20/CSM - RENDEZVOUS NAVIGATION
PROGRAM

1 KEY V37E 20E

(R02 - IMU STATUS CHECK)

2 POSS FL V50 N07

R1 00005 (GNCS START UP)
V37E 05E

3 POSS FL V50 N07

R1 00051 (IMU ORIENTATION
DETERMINATION)
V37E 51E

4 FL V06 NXX

000XX (ASSUMED STATE VECTOR SELECTION
CODE)
0000X (STATE VECTOR OPTION CODE)

ACCEPT: V33E
REJECT: V22E

LOAD CODE FOR DESIRED STATE VECTOR

5 TO TERMINATE PROGRAM

A. IF ANOTHER PROGRAM BESIDES P20
IS IN PROCESS:
V XX E (SELECTING OTHER
PROGRAM.)

OR

B. IF NO OTHER PROGRAM IS IN
PROCESS:

V XX E

OR

V37E 00E

END OF RUN

P21/CSM - GROUND TRACK
DETERMINATER PROGRAM

1 KEY V37E 21E

2 FL V25 N34 (LOAD T LAT LONG)

T LAT LONG

00XXX. HRS
000XX. MIN
0XX.XX SEC

3 FL V06 N44

LAT

0XX.XX DEG

LONG
ALTXXX.XX DEG
XXXX.X NMRECYCLE: V32E (TO OBTAIN PARAMETERS
FOR A TIME TEN MIN. LATER THAN PRESENT
DISPLAY)
TERMINATE: V34E

4 POO

END OF RUN

410

P23/CSM CISLUNAR MIDCOURSE
NAVIGATION MEASUREMENT PROGRAM

1 KEY V37E 23E

2 FL V51 (PLEASE MARK)

PERFORM STAR-LANDMARK ACQUISITION
MARK

3 FL V06 N57

SHAFT XXX.XX DEG
TRUN XX.XXX DEG

RECORD ANGLES
V33E

4 FL V06 N34

T MARK 00XXX. HRS
 000XX. MIN
 0XX.XX SEC

RECORD TIME
V33E

5 POO

END OF RUN

P27/CSM-AGC UPDATE PROGRAM

AUTO UPDATE:

1 UP TLM SW - ACCEPT

UPDATE COMPLETE
UP TLM SW - BLOCK

VOICE TRANSMISSION UPDATE:

1 KEY: V70E - LM RVT
V72E - EXTERNAL DELTA V
V76E - CSM RVT
V77E - TIME

2 FL V21 N01

BLANK
UNCHANGED
UPADR

V34E TO TERMINATE P27 WHEN DESIRED

3 KEY IN UPDATE DATA

(DISPLAYED IN R1)

4 FL V21 N02 (LOAD COMPLETE)

BLANK
UNCHANGED
UPADR

ACCEPT: V33E
REVIEW DATA: V01 N01E

KEY OCTAL ADDRESS OF
FIRST WORD
R1 DISPLAYS FIRST WORD
KEY N15E TO SEE NEXT WORD
KEY ENTER FOR EACH
SUCCEEDING WORD

CHANGE DATA: KEY IN OCTAL IDENTIFIER
OF REGISTER TO BE
CHANGED (DATA LOADED
DISPLAYED IN R1)
LOAD NEW DATA
V33E

5 POO

END OF RUN

414

P30/CSM EXTERNAL DELTA V
PROGRAM

1 KEY V37E 30E

2 FL V06 N34

GET1 00XXX. HRS
 000XX. MIN
 0XX.XX SEC

ACCEPT: RECORD VALUES
 V33E

REJECT: LOAD NEW DATA

3 FL V06 N

DELTA VX (LV) XXXX.X FPS
DELTA VY (LV) XXXX.X FPS
DELTA VZ (LV) XXXX.X FPS

(STORED COMPONENTS OF IMPULSIVE DELTA V
ALONG CSM LOCAL VERTICAL AXES AT GET1)

ACCEPT: V33E

REJECT: LOAD NEW DATA

4 FL V06 N45 (THRUSTING PARAMETERS)

APOGEE ALT XXXX.X NM
PERIGEE ALT XXXX.X NM
DELTA V XXXX.X FPS

ACCEPT: V33E

REJECT: RESELECT P/30 OR P/27
 LOAD NEW PARAMETERS

5 FL V06 N35 (TIME TO GO TO IGNITION - TTI)

TTI 00XXX. HRS
 000XX. MIN
 0XX.XX SEC

SET: LEB CLOCK TO TTI (OPTIONAL)
TO CONTINUE P30: V33E
TO TERMINATE P30: V37E XXE
(ENTER NEW PROG.)
 (R2 - IMU STATUS CHECK)

6 POSS FL V50 N07

R1-00005 (GNCS START UP)

V37E 05E

7 POSS FL V50 N07

R1-00051 (IMU ORIENTATION
DETERMINATION)

V37E 51E

8 FL V06 N

--

BLANK
TTI
MGA

XXBXX MIN-SEC
XXX.XX DEG

V33E

9 FL V50 N07

BLANK
BLANK
BLANK

SELECT PROPULSION SYSTEM

SELECT SPS: V37E 40E
OR SELECT RCS: V37E 41E

END OF RUN

P34-CSM TRANSFER PHASE
INITIATION PROGRAM

1 KEY V37E 34E

2 FL V06 N

--
OPTION CODE 000XX OCTAL
OPTION 0000X OCTAL
BLANK

ACCEPT: V33E
REJECT: V22E
LOAD DESIRED OPTION IN R2
(1E OR 2E)

3 IF OPTION CODE 00001:

FL V06 N34

GETI(TPI) 00XXX. HRS
 000XX. MIN
 0XX.XX SEC

ACCEPT: RECORD VALUES
 V33E
 (GO TO STEP 5)
REJECT: V25E
 LOAD DESIRED GETI(TPI)

OR IF OPTION CODE 00002:

FL V06 N

--
BLANK
E XXX.XX DEG
BLANK

ACCEPT: RECORD VALUE
 V33E
REJECT: V22E
 LOAD DESIRED E

4 POSS FL V05 N31

R1 000XX (COMPUTATION DIFFICULTY)
V32E TO RECYCLE TO STEP 3
LOAD ADJUSTED E

5 FL V06 N

--
DELTA T TRANS 00XXX. MIN
 000XX. MIN
 0XX.XX SEC

ACCEPT: RECORD VALUES
 V33E
 REJECT: V25E
 LOAD DESIRED DELTA T TRANS.

6 POSS FL V05 N31
 R1 000XX (COMPUTATION DIFFICULTY)

V32E TO RECYCLE TO STEP 2
 ADJUST INPUT PARAMETERS

7 IF OPTION CODE 0001:

FL V06 N

BLANK

E

BLANK

XXX.XX DEG

RECORD VALUE

V33E (GO TO STEP 9)

OR IF OPTION CODE 00002:

FL V06 N34

GETI(TPI)

000XX. HRS

000XX. MIN

0XX.XX SEC

RECORD VALUES

V33E

8 FL V06 N (TERMINAL PHASE PARAMETERS)

DELTA V (TPI)

XXXX.X FPS

PERIGEE ALT (TPI)

XXXX.X NM

DELTA V (TPF)

XXXX.X FPS

RECORD VALUES

V33E

9 FL V06 N35 (TIME TO GO TO IGNITION)

TTI

00XXX. MIN

000XX. MIN

0XX.XX SEC

SET: LEB CLOCK TO TTI

SET: MDC CLOCK TO TTI (OPTIONAL)

V33E

10 POSS FL V06 N

N-(SINCE LAST BURN OR P20) 000XX. MARKS
 TTI XXBXX MIN-SEC
 BLANK

ACCEPT: V33E (IF TTI < 8 MIN OR NO
 MORE MARKS DESIRED
 (IN P20))

REJECT: 1. TO ADJUST GETI OR DATA:
 V37E 34E
 2. MORE MARKS DESIRED: V--E
 3. FINAL COMPUTATION NOT
 DESIRED: V32E

11 POSS FL V50 N07
 R1 00005 (GNCS START UP)

V37E 05E

12 POSS FL V50 N07
 R1 00051 (IMU ORIENTATION DETER-
 MINATION)

V37E

13 FL V06 N

--

N(SINCE LAST BURN OR P20)000XX. MARKS

TTI XXBXX MIN-SEC
 MGA AT GETI XXX.XX DEG

RECORD NUMBER OF MARKS AND MGA

V33E

14 FL V50 N07

BLANK
 BLANK
 BLANK

SELECT PROPULSION SYSTEM

SELECT SPS: V37E 40E
 SELECT RCS: V37E 41E

420

END OF RUN

P35/CSM - TRANSFER PHASE
MIDCOURSE PROGRAM

- 1 KEY V37E 35E
- 2 FL V06 N35 (TIME TO INTERCEPT - TT INT)
TT INT 00XXX. HRS
 000XX. MIN
 0XX.XX SEC

SET: LEB CLOCK TO TT INT
SET: MDC CLOCK TO TT INT (OPTIONAL)
V33E
- 3 FL V06 N
 --
N (SINCE LAST BURN OR P20) 000XX.MARKS
TT INT XXBXX MIN-SEC
BLANK

ACCEPT: V33E (IF TT INT > 20 MIN AND
 MORE MARKS ARE DESIRED
 (P20))

REJECT: V37E 36E (IF TT INT < 20 MIN)
 OR
 V E (IF TT INT > 20 MIN, AND
 --
 MORE MARKS ARE DESIRED (P20))
- 4 FL V06 N
 --
N (SINCE LAST BURN OR P20) 000XX.MARKS
TTI XXBXX MIN-SEC
MGA XXX.XX DEG

RECORD VALUES
SET: LEB CLOCK TO TTI
SET: MDC CLOCK TO TTI (OPTIONAL)
V33E
- 5 FL V06 N (TERMINAL PHASE PARAMETERS)
 --
DELTA V (MID) XXXX.X FPS
TTI XXBXX MIN-SEC
DELTA V (TPF) XXXX.X FPS

RECORD VALUES

ACCEPT: V33E (NO MIDCOURSE BURN
 REQUIRED)
REJECT: V32E (MIDCOURSE BURN REQUIRED)
- 6 FL V50 N07

BLANK
BLANK
BLANK

SELECT PROPULSION SYSTEM

SELECT SPS: V37E 40E

SELECT RCS: V37E 41E

END OF RUN

424

P36/CSM-TRANSFER PHASE FINAL
PROGRAM

```
1 KEY V37E 36E
2 FL V06 N  --
  RANGE RATE      XXX.XX NM
  RANGE RATE      XXXX.X FPS
  THETA           XXX.XX DEG
  PERFORM RENDEZVOUS MANEJVER
3 FL V50 N07
  00000
  V37E 00E
4 P00
```

END OF RUN

426

P41/CSM - RCS PROGRAM

1 KEY V37E 41E

(R2-IMU STATUS CHECK)

2 POSS FL V50 N07

R1-00005 (GNCS STARTUP)

V37E 05E

SELECT P51 AFTER COMPLETION OF
P05

3 POSS FL V50 N07

R1-00051

V37E 51E

RESELECT P41 AFTER COMPLETION OF
P51

4 FL V06 N-- (MASS PARAMETERS)

IX	XXX00 SLUG-FT SQ
IY/IZ	XXX00 SLUG-FT SQ
W	XXXXX LBS

ACCEPT: V33E
REJECT: V25E
RELOAD DATA

5 FL V06 N--

ASSUMED TRANS. AXIS CODE 000--
CMC ASSUMED AXIS OPTION CODE 0000X
BLANK

ACCEPT: V33E
REJECT: V22E
RELOAD AXIS OPTION CODE IN R2

6 FL V06 N-- (VG AT IGNITION)

VGX (CSM)	XXXX.X FPS
VGY (CSM)	XXXX.X FPS
VGZ (CSM)	XXXX.X FPS

ACCEPT: V33E
REJECT: V32E
RECYCLE TO STEP 5

7 FL V06 N17 (RESULTING GIMBAL ANGLES)

ROLL, PITCH, YAW XXX.XX

RECORD VALUES

ACCEPT: V33E
 REJECT: V32E
 (RECYCLE TO STEP 5)
 OR
 V37E 53E (OR 52E)
 RESELECT P41 AT COMPLETION OF
 P53 (OR P52)

8 FL V06 N-- (INITIAL VG)

VGX (LV) XXXX.X FPS
 VGY (LV) XXXX.X FPS
 VGZ (LV) XXXX.X FPS

RECORD VALUES
 V33E

(R60 - ATTITUDE MANEUVER)

9 POSS FL V50 N25

R1-000-- (SC CONT AND CMC MODE SELECT)

ACCEPT: SC CONT SW - CMC
 CMC MODE SW - AUTO
 ENTR

REJECT: SELECT SC CONT AND CMC MODE
 DESIRED
 V33E

10 V06 N17 (FINAL GIMBAL ANGLES)

ROLL, PITCH, YAW XXX.XX DEG

11 MONITOR MANEUVER ON FDAI

12 POSS FL V50 N25

R1-00007 (ATTITUDE TRIM ENABLE)

ACCEPT: SC CONT SW - CMC
 CMC MODE SW - AUTO
 ENTR

REJECT: SELECT SC CONT AND CMC MODE
 DESIRED
 V33E

13 FL V50 N25

R-000-- (SC CONT AND CMC MODE SELECT)

ACCEPT: SC CONT SW - CMC
 CMC MODE SW - AUTO
 ENTR
 REJECT: SC CONT SW - CMC
 CMC MODE SW - HOLD
 V33E (GO TO STEP 18)

14 IF AUTO, V06 N51

TTI XXBXX MIN-SEC
 VG XXXX.X FPS
 DELTA VM XXXX.X FPS

UPDATE TTE CLOCKS (OPTIONAL)

00:05

15 FL V50 N11

TTI XXBXX MIN-SEC
 VG XXXX.X FPS
 DELTA VM XXXX.X FPS

ACCEPT: ENTR
 REJECT: V34E
 FL V50 N07
 R1-00000

V37E 00E

00:00

16 V50 N11

TG XXBXX MIN-SEC (DECREASING)
 VG XXXX.X FPS (DECREASING)
 DELTA VM XXXX.X FPS (INCREASING)

FDAI: ATT ERR < -- DEG
 ATT RATES < -- DEG/SEC

17 FL V06 N51

TG XXBXX MIN-SEC
 VG XXXX.X FPS
 DELTA VM XXXX.X FPS

ACCEPT: V33E (NO TRIM)
 GO TO STEP 19
 REJECT: V32E (FINAL TRIM)
 RECYCLE TO STEP 13

18 IF MANUAL, FL V06 N--

VGX (CSM) XXXX.X FPS
 VGY (CSM) XXXX.X FPS
 VGZ (CSM) XXXX.S FPS

MANUALLY MANEUVER TO NULL VG
V33E

(R30 - ORBITAL PARAMETER DISPLAY)

19 FL V06 N43

APOGEE ALT	XXXX.X NM
PERIGEE ALT	XXXX.X NM
TFF	XXBXX MIN-SEC

V33E

20 POSS FL V06 N35 - IF PERIGEE ALT <
300,00 FT.

T PERIGEE	00XXX. HRS
	000XX. MIN
	0XX.XX SEC

V33E

21 P20

OR

FL V50 N07

R1-00000

V37E 00E

430

END OF RUN

P47/CSM THRUST MONITOR PROGRAM

- 1 KEY V37E 47E
(R2 - IMU STATUS CHECK)
- 2 POSS FL V50 N07
R1-00005 (GNCS START JP)
V37E 05E
- 3 POSS FL V50 N07
R1-00051 (IMU ORIENTATION
DETERMINATION)
V37E 51E
- 4 V16 N
--
DELTA VX(IMU) XXXX.X FPS
DELTA VY(IMU) XXXX.X FPS
DELTA VZ(IMU) XXXX.X FPS

MONITOR MANEUVER ON FDAI
- 5 WHEN MANEUVERS ARE COMPLETED:
V37E 00E
- 6 PCO

432-

END OF RUN

P51/CSM IMU ORIENTATION
DETERMINATION PROGRAM

1 KEY V37E 51E

2 POSS FL V50 N07
R1-00005 (GNCS START UP)

V37E 05E

3 FL V50 N25

R1-00015 (STAR ACQUISITION)

MANEUVER CSM TO POSITION IG AXIS IN
PREFERRED DIRECTION (OPTIONAL)
MANEUVER CSM, IF NECESSARY, TO ACQUIRE
TWO NAV. STARS IN SCT
MONITOR FDAI FOR GIMBAL LOCK
ENTER

XX

IF GIMBAL LOCK IMPENDING: V33E

DISPLAY: V41 N20

ROLL,PITCH,YAW * 000.00 DEG

NO ATT LIGHT - ON, THEN OFF

XX

(R53 - SIGHTING MARK)

4 FL V51 N30

STAR CODE 000XX. (FOR STAR
#1)

SET: OPTICS MODE Sw - MAN
CENTER STAR IN SXT
MARK

NOTE: UNSATISFACTORY MARKS MAY BE
REJECTED BY MARK REJECT PB.
PRIOR TO ENTER IN STEP 5.

5 FL V50 N25

R1-00016 (TERMINATE MARK SEQUENCE)

ENTER

6 FL V21 N30 (LOAD STAR CODE)

V21E
LOAD STAR CODE IN R1.
(R53-SIGHTING MARK)

7 FL V51 N30

STAR CODE 000XX. (FOR STAR
 #2)
CENTER STAR IN SXT
MARK

NOTE: UNSATISFACTORY MARKS MAY BE
REJECTED BY MARK REJECT PB.
PRIOR TO ENTER IN STEP 8.

8 FL V50 N25

R1-00016 (TERMINATE MARK SEQUENCE)

KEY: ENTER

9 FL V21 N30 (LOAD STAR CODE)

V21E
LOAD STAR CODE IN R1.

(R54 - STAR DATA TEST)

10 V06 N05 (10 SECONDS)

STAR ANGLE DIFF XXX.XX DEG
(DATA GOOD, ANGLE < 0.05 DEG)

OR FL V06 N05

STAR ANGLE DIFF XXX.XX DEG
(DATA BAD, ANGLE > 0.05 DEG)

ACCEPT: V33E
REJECT: V37E 00E

11 P00

END OF RUN

- 1 KEY V37E 52E
- 2 POSS FL V50 N07
R1-00005 (GNCS STARTUP)
V37E 05E
- 3 FL V06 N--
R1-000-- OPTION CODE FOR ASSUMED IMU
ORIENTATION
R2-0000X CMC ASSUMED OPTION:
00001 PREFERRED
00002 NOMINAL
00003 REFSMMAT
- ACCEPT: V33E
REJECT: LOAD DESIRED OPTION
NOTE:
POSS FL V05 N31
R1-000-- (PREFERRED IMU NOT
SPECIFIED)
- SELECT: NOMINAL V32E
OR
PREFERRED V37E --E (PROGRAM
TO DEFINE
IMU ORIEN-
TATION)
- 4 POSS FL V06 N-- (NOMINAL SELECTED)
- | | |
|-----------|------------|
| T (ALIGN) | 00XXX. HRS |
| | 000XX. MIN |
| | 0XX.XX SEC |
- ACCEPT: V33E
REJECT: LOAD DESIRED T (ALIGN)
- 5 FL V06 N17 (GIMBAL ANGLES)
- | | |
|------------------|------------|
| ROLL, PITCH, YAW | XXX.XX DEG |
|------------------|------------|
- CHECK MGA
- ACCEPT: V33E
REJECT: MANEUVER USING ROTATION
CONTROLLER
OR
SELECT NEW PROGRAM
- (R50 - COARSE ALIGN)
- 6 WAIT -- SECONDS FOR COMPLETION OF COARSE
ALIGNMENT

(R56 - STAR SELECTION)

POSS FL V05 N31 (TWO STARS NOT AVAILABLE
IN SCT)

R1-000--

NOTE: AME - ATTITUDE
ATT-IMP - ENABLEBYPASS R56 - MANEUVER TO ACQUIRE
STARS V33E

OR

REPEAT R56 - MANEUVER TO POSSI-
BLE STAR ACQUI-
SION V32E

XX

NOTE: NAVIGATOR SHOULD MONITOR FDAI BALL TO
AVOID GIMBAL LOCK

XX

(R51 - FINE ALIGN)
(R52 - AUTO OPTICS POSITIONING - STAR
NO. 1)

7 FL V06 N30

R1-STAR CODE

ACCEPT: SET AUTO/MAN OPTICS SWITCH TO
DESIRED SETTING
V33E

REJECT: LOAD NEW STAR CODE

IF OPTICS IN MANUAL MODE, GO TO STEP 10
IF OPTICS IN AUTO MODE, CONTINUE

NOTE:

POSS FL V05 N31

R1-000-- (STAR NOT IN HEMISPHERE
OF VISIBILITY)
AME - ATTITUDE

ATT IMP - ENABLE
 MANEUVER VEHICLE TO
 ENABLE ACQUISITION
 (MONITOR FDAI BALL)
 V33E

OR

V32E (RETURN TO STEP 7 FOR
 NEW STAR)

OR

SET OPTICS SWITCH TO MANUAL
 V34E (GO TO STEP 10)

8 POSS FL V06 N57 (TRUNNION ANGLE > 40 DEG)

SHAFT	XXX.XX DEG
TRUNNION	XX.XXX DEG

AME - ATTITUDE
 ATT-IMP - ENABLE
 MANEUVER VEHICLE TO PRODUCE
 TRUNNION ANGLE < 40 DEG.

MONITOR FDAI BALL

V33E

OR

V32 (RETURN TO STEP 7 FOR
 NEW STAR)

OR

SET OPTICS SWITCH TO MANUAL
 V34E (GO TO STEP 10)

9 POSS V06 N57 (STAR LOS NOT WITHIN 5 DEG.
 OF TARGET VECTOR)

DESIRED SHAFT	XXX.XX DEG
DESIRED TRUNNION	XX.XXX DEG

(R53 - SIGHTING MARK - STAR NO. 1)

10 FL V51 (PLEASE MARK)

AME - ATTITUDE
 ATT IMP - ENABLE

SELECT MANUAL OPTICS MODE MARK

11 FL V50 N25

R1-00016 (TERMINATE MARKS)

ACCEPT: ENTER
 REJECT: MARK REJECT

NOTE: AN UNSATISFACTORY MARK MAY BE REJECTED BY PRESSING MARK REJECT ANY TIME PRIOR TO TERMINATING THE MARKING SEQUENCE. POSSIBLE PROGRAM ALARM IF MARK REJECT WITHOUT PRIOR MARK OR IF SURPLUS MARK IS ENTERED.

12 FL V21 N20 (LOAD STAR CODE)

LOAD STAR CODE +000XX.

(R52 - AUTO OPTICS POSITIONING - STAR NO. 2.

13 FL V06 N30

R1-STAR CODE

ACCEPT: SET OPTICS MODE SWITCH TO DESIRED SETTING V33E

REJECT: LOAD STAR CODE

IF OPTICS IN MANUAL MODE, GO TO STEP 16
IF OPTICS IN AUTO MODE, CONTINUE

NOTE:

POSS FL V05 N31

R1-000-- (STAR NOT IN HEMISPHERE OF VISIBILITY)

AME - ATTITUDE
ATT IMP - ENABLE

MANEUVER VEHICLE TO ENABLE ACQUISITION (MONITOR FDAI BALL)
V33E

OR

V32E (RETURN TO STEP 13 FOR NEW STAR)

OR

SET OPTICS MODE TO MANUAL V34E
(GO TO STEP 16)

14 POSS FL V06 N57 (TRUNNION ANGLE > 40 DEG)

SHAFT XXX.XX DEG
TRUNNION XX.XXX DEG

AME - ATTITUDE
ATT IMP - ENABLE

MANEUVER VEHICLE TO PRODUCE
TRUNNION ANGLE < 40 DEG.

(MONITOR FDAI BALL)

V33E

OR

V32E (RETURN TO STEP 13 FOR NEW
STAR)

OR

SET OPTICS MODE TO MANUAL V34E
(GO TO STEP 16)

15 POSS V06 N57 (STAR LOS NOT WITHIN 5 DEG.
OF TARGET VECTOR)

R1 - DESIRED SHAFT XXX.XX DEG
R2 - DESIRED TRUNNION XX.XXX DEG

(R53 - SIGHTING MARK - STAR NO. 2)

16 FL V51 (PLEASE MARK)

AME - ATTITUDE
ATT IMP - ENABLE

SELECT MANUAL OPTICS MODE MARK

17 FL V50 N25

R1-00016 (TERMINATE MARKS)

ACCEPT: ENTER
REJECT: MARK REJECT

NOTE: AN UNSATISFACTORY MARK MAY BE
REJECTED BY PRESSING MARK REJECT
ANY TIME PRIOR TO TERMINATING
THE MARKING SEQUENCE.
POSSIBLE PROGRAM ALARM IF MARK
REJECT WITHOUT PRIOR MARK OR IF
SURPLUS MARK IS ENTERED.

18 FL V21 N20 (LOAD STAR CODE)

LOAD STAR CODE +000XX.

(R54 - STAR DATA TEST)

19 V06 N05 (10 SECS)

R1 - STAR ANGLE DIFFERENCE 000.0X DEG
(GOOD DATA, ANGLE < 0.05 DEG.)

OR

FL V06 N05

R1- STAR ANGLE DIFFERENCE XXX.XX DEG
(BAD DATA, ANGLE > 0.05 DEG.)

ACCEPT: V33E
REJECT: V37E --E (SELECT NEW PROGRAM)
(R55 - GYRO TORQUING) (OPTIONAL)

20 V06 N67

DELTA GYRO ANGLES X,Y,Z XX.XXX DEG
ALL ANGLES < 5 DEG. (GYRO ARE TORQUED)

OR

FL V06 N67

DELTA GYRO ANGLES X,Y,Z XX.XXX DEG
IF ANY ANGLE > 5 DEG.

ACCEPT: V33E (GYROS ARE TORQUED)
REJECT: V34E (CMC DISPLAYS P00)

21 FL V50 N25

R1-00014 (FINE ALIGN CHECK)

ACCEPT: ENTER (RETURN TO STEP 7)
REJECT: V33E

22 P00

23 SET CONTROLS:

LIMIT CYCLE - OFF
G & N/SCS - SCS
AME - MONITOR
SCS CHANNELS - OFF
CB OPTICS MNA & B - OPEN

442

END OF RUN

P53/CSM - CSM/IMU ALIGN PROGRAM

1 SET CONTROLS TO BASIC POSITIONS, EXCEPT:

2 KEY V37E 53E

(R02 - IMU STATUS CHECK)

3 POSS FL V05 N07
R1 00005 (GNCS START UP)

V37E 05E

4 POSS FL V05 N07
R1 00051 (IMU ORIENTATION DETER-
MINATION)

V37E 51E

5 FL V06 N

--
000XX (ASSUMED IMU ORIENTATION SELEC-
TION CODE)
0000X (IMU ORIENTATION OPTION CODE)

ACCEPT OPTION: V33E
REJECT OPTION: V22E
LOAD NEW OPTION CODE
IN R2

NOTE:

POSS FL V05 N31
000XX IF PREFERRED IMU ORIEN-
TATION HAS BEEN SELECTED
BUT HAS NOT BEEN SPECI-
FIED.

CHOOSE NOMINAL ORIENTATION:
V32E

OR

SELECT NEW PROGRAM: V37E XXE

IF PREFERRED IMU ORIENTATION IS
SELECTED, PROCEED TO STEP 9.

6 FL V06 N

--
T ALIGN 00XXX. HRS
 000XX. MIN
 0XX.XX SEC

ACCEPT: V33E
REJECT: V25
LOAD NEW T (ALIGN)

7 FL V06 N

--
000XX (ASSUMED CSM ATTITUDE SELECTION
CODE)

0000X (CSM ATTITUDE OPTION CODE)

ACCEPT OPTION CODE: V33E
REJECT OPTION CODE: V22
LOAD NEW OPTION
CODE IN R2

NOTE:

POSS FL V05 N31
000XX IF PREFERRED CSM ATTITUDE HAS BEEN SELECTED,
BUT HAS NOT BEEN SPECIFIED.

CHOOSE NOMINAL ATTITUDE: V32E
OR
SELECT NEW PROGRAM: V37E XXE

IF PREFERRED CSM ATTITUDE IS
SELECTED, PROCEED TO STEP 9.

- 8 FL V06 N17
ROLL,PITCH,YAW XXX.XX DEG
IF MG < 45 DEG: V33E
IF MG > 45 DEG: V32E (CMC WILL RETURN
TO START OF THIS
PROGRAM)
- 9 V01 M25
R1-0005X
(R60 - ATTITUDE MANEUVER)
- 10 POSS FL V50 N25
000XX (SC CONT AND CMC MODE SELECTION)
ACCEPT: CMC MODE SW - AUTO
ENTER
REJECT: SELECT SC CONT AND CMC MODE
DESIRED
V33E
- 11 V06 N17 (FINAL GIMBAL ANGLES)
ROLL, PITCH, YAW XXX.XX DEG
MONITOR MANEUVER ON FDAI
- 12 POSS FL V50 N25
000XX (ATT TRIM ENABLE)

ACCEPT: CMC MODE SW - AUTO
ENTER
REJECT: SELECT SC CONT AND CMC MODE
DESIRED
V33E

(R51 - FINE ALIGN-STAR #1)

13 FL V06 N30

000XX (STAR CODE FOR STAR #1)

ACCEPT: V33E
REJECT: V21
LOAD NEW STAR CODE

14 IF AUTO-OPTICS POSITIONING SELECTED:

POSS FL V50 N25

R1-00013 (OPTICS MODE SW TO CMC)

ACCEPT: OPTICS MODE - CMC
ENTER
REJECT: V33E
POSITION OPTICS MANUALLY

15 IDENTIFY STAR IN SCT

(R53 - SIGHTING MARK, STAR #1)

16 FL V51 (PLEASE MARK)

OPTICS MODE - MAN
ATT IMP ENABLE - ON (OPTIONAL)
MARK
ENTER

17 FL V50 N25

R1-00016 (TERMINATE MARK SEQUENCE)

MARK SATISFACTORY: ENTER
MARK UNSATISFACTORY: MARK REJECT

18 FL V21 N30 (LOAD STAR CODE)

LOAD STAR CODE IN R1
ATT IMP ENABLE - OFF
(R51 - FINE ALIGN-STAR #2)

19 FL V06 N30

ACCEPT: V33E
REJECT: V21
LOAD NEW STAR CODE

20 IF AUTO OPTICS POSITIONING SELECTED:

POSS FL V50 N25

00013 (OPTICS MODE SW TO CMC)

ACCEPT: OPTICS MODE - CMC
ENTER

REJECT: V33E
POSITION OPTICS MANUALLY

21 IDENTIFY STAR IN SCT

(R53 - SIGHTING MARK, STAR #2)

22 FL V51 (PLEASE MARK)

OPTICS MODE - MAN
ATT IMP ENABLE - ON (OPTIONAL)
MARK
ENTER

23 FL V50 N25

00016 (TERMINATE MARK SEQUENCE)

MARK UNSATISFACTORY: ENTER
MARK UNSATISFACTORY: MARK REJECT

24 FL V21 N30 (LOAD STAR CODE)

LOAD STAR CODE IN R1
ATT IMP ENABLE - OFF

(R54 - STAR DATA TEST)

25 FL V06 N05 (10 SEC)

XXX.XX DEG (STAR ANGLE DIFF)

(DATA GOOD, ANGLE < 0.05 DEG)

OR

FL V06 N05

XXX.XX DEG (STAR ANGLE DIFF)

(DATA BAD, ANGLE > 0.05 DEG)

ACCEPT: V33E
REJECT: V37E XXE (SELECT NEW PROGRAM)

(R55 - GYRO TORQUING)

26 FL V06 N67

(GYRO TORQUING ANGLES, IF ANY ANGLE >
5 DEG)

X, Y, Z XX.XXX DEG

ACCEPT: V33E (GYROS ARE TORQUED)
REJECT: V34E
(CMC DISPLAYS P00)

OR

V06 N67 (90 SEC)

(GYRO TORQUING ANGLES, ALL < 5 DEG)
X, Y, Z XX.XXX DEG
(GYROS ARE TORQUED)

27 FL V50 N25

R1-00014 (FINE ALIGN CHECK)

ACCEPT: ENTER
RETURN TO STEP 13
REJECT: V33E

28 IF CODE 00052 OR 00054

(R60 - ATTITUDE MANEUVER)

29 POSS FL V50 N25

R1-000XX (SC CONT AND CMC MODE
SELECTION)

AUTO: SELECT CMC
MODE SW - AUTO
ENTER

MANUAL: SELECT SC CONT AND CMC MODE
DESIRED
V33E

30 V06 N17 (FINAL GIMBAL ANGLES)

ROLL, PITCH, YAW XXX.XX DEG

MONITOR MANEUVER ON FDAI

31 POSS FL V50 N25

000XX (ATTITUDE TRIM MANEUVER ENABLE)

AUTO: SELECT CMC
MODE SW - AUTO
ENTER

MANUAL: SELECT SC CONT AND CMC MODE
V33E

448

32. FL V50 N07

000XX

V37E XXE

(SELECT INDICATED PROGRAM
P40, P41, OR P42)

END OF RUN

450

P61/CSM - MANEUVER TO CM/SM
SEPARATION ATTITUDE PROGRAM

1 KEY: V37E 61E

NOTE: IF FL V05 N31
R1-01427
IMU REVERSED, ZERO ROLL ON
FDAI
IS LIFT DOWN

IF FL V05 N31
R1-01426
IMU UNSATISFACTORY, V X R
NOT WITHIN 30 DEG OF Y
-SM

2 FL V06 N53

G MAX XXX.X G
V PRED XXXXX.FPS
GAMMA EI XXX.XX DEG

RECORD DATA
V33E

3 FL V06 N

RTGO XXXX.X NM
V 10 XXXXX.FPS
TTE XXBXX MIN-SEC

RECORD DATA
V33E

(R60 - ATTITUDE MANEUVER)

4 POSS FL V50 N25

R1-000XX (SC CONT AND CMC MODE SELECT)

ACCEPT: SC CONT SW - CMC
CMC MODE SW - AUTO
ENTR

REJECT: SELECT SC CONT AND CMC MODE
S1RED
V33E

5 V06 N17 (FINAL GIMBAL ANGLES)

ROLL,PITCH,YAW XXX.XX DEG

6 MONITOR MANEUVER ON FDAI

7 POSS FL V50 N25

R1-00007 (ATT TRIM ENABLE)

ACCEPT: SC CONT SW - CMC
CMC MODE SW - AUTO

REJECT: ENTR
SELECT SC CONT AND CMC MODE
DESIRED
V33E

8 P62

452

END OF RUN

P62/CSM - CM/SM SEPARATION AND
PRE-ENTRY MANEUVER PROGRAM

1 CMC DISPLAYS P62

OR

KEY: V37E 62E

NOTE: IF FL V05 N31
R1-01427
IMU REVERSED, ZERO ROLL ON
FDAI IS LIFT DOWN

IF FL V05 N31
R1-01426
IMU UNSATISFACTORY, V X R
- - -
WITHIN 30 DEG OF Y
-SM

2 FL V50 N25

R1-00041

CM/SM NOT SEPARATED: CM/SM SEP SW -UP
ENTER

CS/SM SEPARATED: V33E

3 FL V06 N62

IMPACT LAT XXX.XX DEG
IMPACT LONG XXX.XX DEG
HEADS UP/DOWN + OR - 00001

ACCEPT: V33E
REJECT: V25E
RELOAD PARAMETERS

4 V06 N17 (DESIRED FINAL GIMBAL ANGLES)

ROLL, PITCH, YAW, XXX.XX DEG

5 P63

END OF RUN

484

P63/CSM - ENTRY INITIALIZATION
PROGRAM

1 CMC DISPLAYS P63

2 V06 N54

BETA XXX.XX DEG
VI XXXXX.FPS
R TO TARG XXXX.X (DECREASING)
FDAI: ATT RATES<-- DEG/SEC
 ATT ERRORS<-- DEG

FDAI BALL: ROLL = BETA
 PITCH = -- DEG AT--
 YAW = 0 DEG

3 P64

END OF RUN

456

1 CMC DISPLAYS P64

SET 0.05 G ENTRY SW TO ON

2 V06 N054

BETA XXX.XX DEG (VARIES)
VI XXXXX. FPS (DECREASING)
H XXXXX. FPS (NOMINAL)
FDAI: ATT ERRORS<--DEG
 ATT RATES<--DEG/SEC
 BALL INDICATES LIFT VECTOR
 DIRECTION

3 P67

P67/CSM - ENTRY FINAL PHASE
PROGRAM

1 CMC DISPLAYS P67

2 V06 N71

BETA XXX.XX DEG (VARIES)
CROSS RANGE ERR XXXX.X NM (NOMINAL)
DOWN RANGE ERR XXXX.X NM (DECREASING)

FDAI: ATT. ERR<-- DEG
 ATT RATES<-- DEG
 BALL INDICATES DIRECTION OF
 LIFT VECTOR

3 FL V06 N-- V = 1000 FT/SEC (65000 FT)
 REL

RANGE TO GO XXXX.X NM
LAT. XXX.XX DEG
LONG. XXX.XX DEG

MONITOR ALTIMETER

4 CHUTES DEPLOY

V33E

5 P00

460

END OF RUN



P74/CSM - LM TRANSFER PHASE
INITIATION TARGETING PROGRAM

1 KEY V37E 74E

2 FL V06 N

CODE FOR ASSUMED TPI DATA LOAD 000XX
CMC ASSUMED OPTION CODE 0000X
BLANK

ACCEPT: V33E
REJECT: V22E
RELOAD OPTION CODE

3 IF 00001 SELECTED,
FL V06 N34 (TIME OF IGNITION)

GETI(TPI) 00XXX. HRS
000XX. MIN
0XX.XX SEC

ACCEPT: RECORD VALUES
V33E (GO TO STEP 4)
REJECT: V25E
RELOAD DATA

OR IF 00002 SELECTED,
FL V06 N

BLANK
E (ELEVATION ANGLE) XXX.XX DEG
BLANK

ACCEPT: RECORD VALUE
V33E
REJECT: V22E
RELOAD DATA

NOTE: IF FL V05 N31
R1-000-- (NO GETI FOR
GIVEN E)

V32E
ADJUST E

4 FL V06 N (TRANSFER TIME FROM GETI TO
INTERCEPT)

DELTA T TRANS 00XXX. HRS
000XX. MIN
0XX.XX SEC

ACCEPT: RECORD VALUES
 V33E
 REJECT: V25E
 RELOAD DATA

NOTE: IF FL V05 N31
 R1-000--(DELTA T TRANS
 GIVES HYPERBOLIC
 CSM VELOCITY)

V32E
 READJUST INPJT PARAMETERS

5 FL V06 N (DELTA V ALONG LM LOCAL
 VERTICAL AXES)

DELTA VX (LV) XXXX.X FPS
 DELTA VY (LV) XXXX.X FPS
 DELTA VZ (LV) XXXX.X FPS

RECORD VALUES
 V33E

6 IF OPTION CODE 00001

FL V06 N
 --

BLANK
 E (ELEVATION) XXX.XX DEG
 BLANK

RECORD VALUE
 V33E (GO TO STEP 7)

OR IF OPTION CODE 00002

FL V06 N34

GETI (TPI) 00XXX. HRS
 000XX. MIN
 0XX.XX SEC

RECORD VALUE
 V33E

7 FL V06 N
 --

DELTA V (TPI) XXXX.X FPS
 PERIGEE ALT (TPI) XXXX.X NM
 DELTA V (TPF) XXXX.X FPS

RECORD VALUES
 V33E

8 FL 16 N35 (TIME TO IGNITION)

TTI 00XXX. HRS
 000XX. MIN
 0XX.XX SEC

RECORD VALUES

SET: LEB CLOCK TO TTI
 SET: MDC CLOCK TO TTI (OPTIONAL)
 V33E

9 POSS FL V06 N

N (SINCE LAST BURN ON P20) 000XX.
 TTI XXBXX MIN-SEC
 BLANK

ACCEPT: (IF TTI > 16 MIN AND MANEUVER
 PARAMETERS ARE SATISFACTORY
 AND (A) TTI < 17 MIN, OR (B)
 P20 IS NOT IN PROCESS, OR
 (C) NO MORE MARKS ARE
 DESIRED AND DESIRE TO INCOR-
 PORATE PRESENT STATE VECTOR
 IN COMPUTATION)

REJECT: A. RESELECT P74 AND SLIP
 GETI (IF TTI < 16 MIN OR IF
 PARAMETERS ARE UNSATIS-
 FACTORY AND TTI < 18 MIN)
 OR B. RESELECT P74, DO NOT SLIP
 GETI (IF PARAMETERS ARE
 UNSATISFACTORY AND TTI >
 18 MIN)
 OR C. V E (IF PARAMETERS ARE
 SATISFACTORY, TTI > 17 MIN,
 P20 IS IN PROCESS, AND
 MORE MARKS ARE DESIRED)
 OR D. V32E (IF PARAMETERS ARE
 SATISFACTORY, TTI > 17 MIN,
 P20 IS IN PROCESS, NO
 MARKS ARE DESIRED, BUT
 NOT DESIRED TO INCORPOR-
 ATE PRESENT STARE VECTOR
 INTO COMPUTATION)

10 P20
 OR

FL V50 N07

R1-00000 (CMC IDLING)

V37E 00E

464

END OF RUN

P75/CSM LM TRANSFER PHASE
(MIDCOURSE) TARGETING PROGRAM

1 KEY V37E 75E

2 FL V06 N35 (TIME OF INTERCEPT)

TT INT 00XXX. HRS
 000XX. MIN
 0XX.XX SEC

TRANSMIT VALUE TO LM
SET LEB CLOCK TO TT INT
SET MDC CLOCK TO TT INT (OPTIONAL)
V33E

3 FL V06 N

--
N (SINCE LAST BURN OR P20) 000XX. MARKS
TT INT XXBXX MIN-SEC
BLANK.

IF TT INT < 20 MIN: ADVISE LM TO
SELECT P36 AND COMPLETE RENDEZVOUS
MANUALLY IF TT INT > 20 MIN. P20 IS IN
PROCESS, AND MORE MARKS ARE DESIRED:
V E

--
IN ANY OTHER CASE: V33E

4 FL V06 N (DELTA V ALONG LM LOCAL
-- VERTICAL AXES)

DELTA VX(LV) XXXX.X FPS
DELTA VY(LV) XXXX.X FPS
DELTA VZ(LV) XXXX.X FPS

RECORD VALUES
V33E

5 FL V06 N34

GET1 (MID) 00XXX. HRS
 000XX. MIN
 0XX.XX SEC

RECORD VALUES
V33E

6 FL V06 N

--
DELTA V (MID) XXXX.X FPS
TTI XXBXX MIN-SEC
DELTA V (TPF) XXXX.X FPS

RECORD VALUES
SET LEB CLOCKS TO TTI
SET MDC CLOCK TO TTI (OPTIONAL)
ACCEPT: V33E
TRANSMIT MANEUVER PARAMETERS
TO LM
REJECT: V32E (MIDCOURSE BURN REQUIRED)

7 CMC DISPLAYS P20

OR

FL V50 N07

R1-0000 (CMC IDLING)

V37E 00E

END OF RUN



5. GUIDANCE EQUATIONS

5.1 General Comments

The CSM GNCS Computer (CMC) equations required for Mission 207/208A basically involve the following major navigation and guidance programs.

Coasting Flight

1. Orbital Integration Routine
2. Rendezvous Navigation Routine
3. Rendezvous Targeting Guidance - TPI and midcourse correction maneuvers
4. Orbital Navigation Routine

Accelerated Flight

1. Average G Routine
2. Rendezvous Intercept Maneuver Guidance
3. External ΔV Maneuver Guidance
4. Entry Guidance

These basic navigation and guidance routines are used to make up various programs listed in Section 4. The guidance routines proposed for Mission 207/208A are the same as those currently planned for some of the lunar landing mission phases unless specifically noted otherwise in the following sections.

The Basic Reference Coordinate system used for the CSM GNCS guidance computer in a lunar mission is an orthogonal inertial system centered at either the earth or the moon. The orientation of this coordinate system for the 207/208A mission is defined by the line of intersection of the mean earth equatorial plane and the mean orbit of the earth (the ecliptic) at the beginning of the Besselian year which starts January 1, 283, 1968. The X-axis is along the ascending node of the ecliptic on the equator (the equinox), the Z-axis is along the mean earth north pole, and the Y-axis completes the right-handed triad. In the 207/208A mission this Basic Reference Coordinate system will be earth-centered. The IMU stable member establishes another coordinate system. The stable member orientation for the various mission phases will nominally be established to minimize the possibility of gimbal lock. All computations in the guidance equations presented in the following sections are assumed to be referenced to one of these two inertial systems unless otherwise noted.

5.2 Coasting Flight Navigation

5.2.1 General Comments

The Coasting Flight Navigation program is used in all free-fall phases of the Apollo mission. The basic objective of this navigation program

is to estimate the vehicle state vector by an Orbital Integration Routine, and to update or modify this estimated state by optical tracking data. The Coasting Flight Navigation program is common to both CSM and LM with the major difference being in the type of input tracking data used. The CSM GNCS uses optical angle data from the scanning telescope (SCT) and sextant (SXT), while the LM PGNCs uses rendezvous radar (RR) tracking data. This navigation program involving state update by tracking data is normally used during the lunar orbit navigation phase, all LM-CSM rendezvous phases, and CSM return-to-earth aborts in the lunar landing mission.

During Mission 207/208A the CSM GNCS will use the Coasting Flight Navigation program to maintain estimates of the CSM and LM state vectors during all free-fall phases of this mission. During the rendezvous phases which constitute major flight objectives, SCT or SXT tracking angle data will be used to update one of the two vehicle state vectors in the CMC. The Orbital Navigation Routine used for orbital determination in the lunar landing mission is essentially the same as the Rendezvous Routine, and is included in the CMC 207/208A program. This orbital navigation concept involves tracking mapped surface landmarks and is presented in Section 5.2.7.

Coasting Flight Navigation is accomplished by maintaining in the computer an estimate of the six-dimensional state vector of the spacecraft. If \underline{r} and \underline{v} are the estimates of the position and velocity vectors of the spacecraft, then the state vector \underline{x} is partitioned as follows:

$$\underline{x} = \begin{pmatrix} \underline{r} \\ \underline{v} \end{pmatrix}$$

A simplified functional diagram of the rendezvous navigation program is presented in Fig. 5.2-1. The estimated active and passive vehicle state vectors are computed at required times by integrating the equations of motion with the Orbital Integration Routine which is presented in Section 5.2.2. After tracking acquisition (Section 5.2.4), individual tracking parameters are sequentially processed to determine trajectory deviations ($\delta \underline{r}$ and $\delta \underline{v}$), as described in Section 5.2.5, to update the estimated vehicle state vector. The rendezvous guidance modes for the various maneuvers outlined in Section 5.3 are then based upon the active and passive vehicle estimated state vectors.

The updating process indicated in Fig. 5.2-1 involves computing an estimated tracking measurement, \hat{Q} , based on the difference between the current state vector estimates. This estimated measurement is then compared with the actual tracking measurement Q (optical angles in the CMC) to form the measurement deviation δQ . A statistical weighting vector, $\underline{\omega}$, is generated

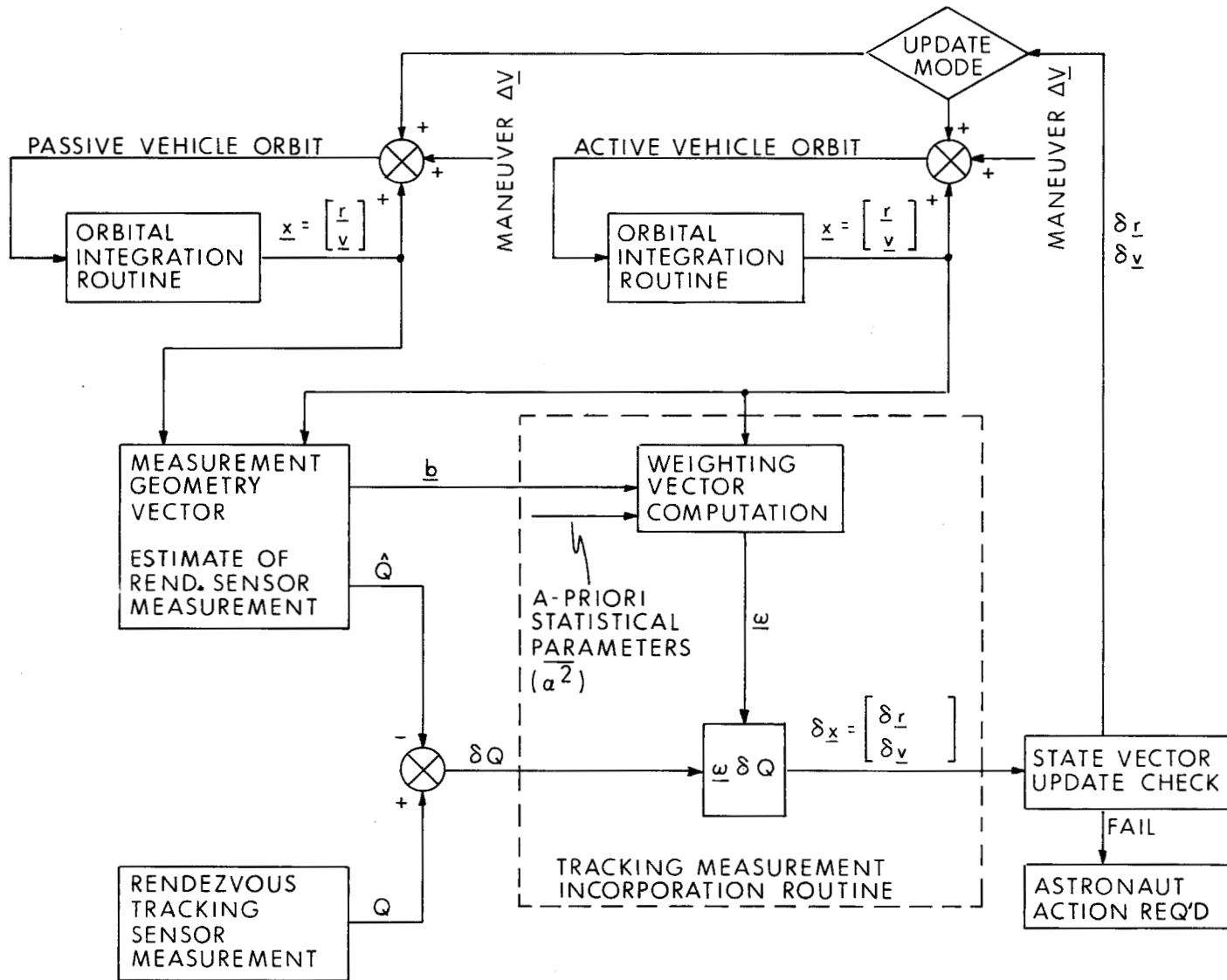


Fig. 5.2-1 Simplified CMC Rendezvous Navigational Functional Diagram

from a-priori statistical knowledge of nominal trajectory uncertainties and tracking performance, plus a geometry vector, \underline{b} , determined by the type of measurement being made. The weighting vector $\underline{\omega}$, is defined such that a statistical optimum linear estimate of the state deviation, $\delta \underline{x}$, from the estimated trajectory is obtained when the weighting vector is multiplied by the measurement deviation δQ .

A tracking alarm criterion is used during rendezvous navigation as a check on the magnitude of state vector corrections determined from line-of-sight tracking data. This alarm criterion is used in both the CMC and LGC. If the magnitude of both the estimated position and velocity deviations, $|\delta \underline{r}|$, and $|\delta \underline{v}|$, determined in the Measurement Incorporation Routine is less than a preset tracking alarm level, the vehicle state vector is automatically updated by the computed deviation $\delta \underline{x}$ and no special display is given the astronaut other than the tracking measurement counter, N , is increased by one. If the magnitude of either of the computed position or velocity deviation is larger than the tracking alarm levels, the state vector is not updated and the astronaut is alerted to this condition by a flashing verb noun combination with the δr and δv displayed. In this case the astronaut should recheck the optical tracking and make sure he is tracking the LM. Under certain conditions it is possible to mistake a star for LM reflected sunlight and it may take a period of a few minutes to determine the LM target by watching relative motion of the target and star background. After the line-of-sight has been verified, and tracked with another set of optical "MARK" data, the astronaut has the option of commanding a state vector update if the tracking alarm is again exceeded, or to repeat further optical checks before incorporating the tracking data. If the astronaut cannot determine the LM target due to no positive acquisition (bright background, etc) he can exit the routine and try to achieve tracking conditions at a latter time.

It might be noted that the tracking alarm criterion was incorporated in the Rendezvous Navigation Routine so that the astronaut would be alerted to the fact that the magnitude of one or both components of the state vector update is larger than normally expected, and to prevent the estimated state vector from automatically being updated in such cases unless specifically commanded to do so by the astronaut. The tracking alarm level beyond which updating is suspended is primarily chosen to avoid false acquisition and tracking conditions. As previously mentioned, this condition is possible in the CSM if a star is tracked by mistake instead of the LM reflected sun light, and it is therefore possible for the alarm level to be exceeded in such cases even though the estimated state vector is essentially correct. It is also possible for the state

vector update alarm level to be exceeded after correct initial acquisition and tracking in the case where a poor estimate of either the CSM or LM exists. In this case the astronaut would have to command the initial state vector update, after which the alarm level would seldom, be exceeded during the remainder of the rendezvous phase. It should be noted that this statement is only true if the powered maneuvers of the rendezvous phase are used to update the estimated state vector by the Average G Routine in the case of the CSM being the active vehicle, or by a DSKY entry of the maneuver ΔV if the LM is the active vehicle.

The actual state vector alarm levels used in Mission 207/208A depends upon the following factors:

- 1) Expected CSM and LM state vector uncertainties for the three rendezvous mission phases.
- 2) Initial W matrix values
- 3) Tracking performance factor α^2 of the Measurement Incorporation Routine

As indicated in Fig. 5.2-1 one of the two vehicle state vectors can be updated by the tracking measurements. This mode is an astronaut option and will be based primarily upon which vehicle has the most accurate initial state vector estimate, and which vehicle is controlling the rendezvous maneuvers. The vehicle state vectors are updated by a powered flight navigation routine (Average G Routine of Section 5.4.2) on the vehicle actively controlling and performing the rendezvous maneuvers. The passive vehicle estimate of the active vehicle state vector is updated by astronaut keyboard (DSKY) inputs of the active vehicle maneuvers received over the vehicle voice link. The passive vehicle then continues to process tracking data to update this state vector. This procedure is desired in order to maintain the most accurate estimate of vehicle state vectors at all times during a rendezvous phase.

The parameters required to initialize the rendezvous navigation program of Fig. 5.2-1 for the CMC are the initial LM and CSM state vectors with their respective initial covariance matrices. The initial covariance matrices are prestored as diagonal matrices and are modified in form to an error transition matrix, $W(t)$, as defined in Section 5.2.2. The basic input to the CMC rendezvous navigation program is SCT or SXT tracking angle data indicated by the astronaut by optics "Mark" inputs to the CMC when the optical reticle has been centered on the LM target. The primary output of the Rendezvous Navigation program is estimated LM and CSM state vectors.

The basic coordinate system in which the Coasting Flight Navigation program is referenced is the Basic Reference Coordinate System described in Section 5. 1.

The Coasting Flight Navigation programs consist of a Rendezvous Navigation Routine (Section 5. 2. 5) and an Orbital Navigation Routine (Section 5. 2. 7). These two routines both use the Orbital Integration Routine (Section 5. 2. 2) and Tracking Measurement Incorporation Routine (Section 5. 2. 3). All of these routines have been designed for both six and nine dimensional vector and matrix operation. The CMC Rendezvous Navigation Routine uses six dimensions, three for position and three for velocity, since no estimate of optical tracking biases is required. The nine-dimensional capability is required in the CMC for lunar orbit navigation since landmark bias uncertainties must be estimated to achieve desired landing CEP objectives, and to compensate for lunar coordinate and radius biases which affect lunar landing maneuver propellant requirements. Since nine-dimensional capability is currently required in both CMC and LGC, a common Orbital Integration Routine and Tracking Measurement Incorporation Routine are used which have six- and nine-dimensional modes.

The navigation program and subroutines presented in this section are the same as those planned for the lunar landing mission except for necessary rescaling and considerations of gravitational perturbations.

The CMC Orbital Navigation Routine of Section 5. 2. 7 is the nine-dimensional concept previously mentioned and differs from previous flights involving orbital navigation (204 and 205) in that landmark bias uncertainties are estimated along with the normal state vector deviations. The basic concept is the same as that of the Rendezvous Navigation Routine for Fig. 5. 2-1 except that optical measurements are made to a surface landmark rather than to an orbiting vehicle.

5. 2. 2 Orbital Integration Routine

During all coasting phase navigation procedures, an extrapolation of position and velocity by numerical integration of the equations of motion is required. The basic equation may be written in the form

$$\frac{d^2}{dt^2} \underline{r}(t) + \frac{\mu_e}{r^3} \underline{r}(t) = \underline{a}_d(t) \quad (5. 2. 1)$$

where μ_e is the gravitational constant of the earth and $\underline{a}_d(t)$ is the vector acceleration which prevents the motion of the vehicle (CSM or LM) from being precisely a conic with focus at the center of the earth. The Orbital Integration Routine has two modes. One is referred to as a conic integration mode

in which the disturbing acceleration, $\underline{a}_d(t)$ of Eq. (5.2.1), is set to zero. The second, and more common, mode is referred to as the precision integration mode in which the effects of the $\underline{a}_d(t)$ are included as indicated in the above equation.

Encke's Method

If \underline{a}_d is small compared with the central force field, direct integration of Eq. (5.2.1) is inefficient. Therefore, the extrapolation will be accomplished using the technique of differential accelerations attributed to Encke.

At time t_0 the position and velocity vectors \underline{r}_0 and \underline{v}_0 define an osculating conic orbit. Position and velocity in the conic orbit are calculated from

$$\begin{aligned} \underline{r}_{\text{con}}(t) &= \left(1 - \frac{F_1}{r_0}\right) \underline{r}_0 + \left(\tau - \frac{F_2}{\sqrt{\mu_e}}\right) \underline{v}_0 \\ \underline{v}_{\text{con}}(t) &= \frac{\sqrt{\mu_e}}{r_0 r_{\text{con}}(t)} (\alpha_0 F_2 - x) \underline{r}_0 + \left(1 - \frac{F_1}{r_{\text{con}}(t)}\right) \underline{v}_0 \end{aligned} \quad (5.2.2)$$

where

$$\begin{aligned} \alpha_0 &= \frac{2}{r_0} - \frac{v_0^2}{\mu_e} \\ \tau &= t - t_0 \\ F_1 &= x^2 C(\alpha_0 x^2) \\ F_2 &= x^3 S(\alpha_0 x^2) \\ S(x) &= \frac{1}{3!} - \frac{x}{5!} + \frac{x^2}{7!} - \dots \\ C(x) &= \frac{1}{2!} - \frac{x}{4!} + \frac{x^2}{6!} - \dots \end{aligned} \quad (5.2.3)$$

and x is determined as the root of Kepler's equation in the form

$$\sqrt{\mu_e} \tau = \frac{r_0 \cdot v_0}{\sqrt{\mu_e}} F_1 + (1 - r_0 \alpha_0) F_2 + r_0 x \quad (5.2.4)$$

In the CMC Orbital Integration Routine, the functions $S(x)$ and $C(x)$ represented by infinite series in Eq. (5.2.3) are approximated by functions of polynomials with an accuracy of 26 bits for the full range of x .

A Newton iteration technique is used to solve Eq. (5.2.4) for the variable x after the determination of an estimate accurate to third order in time.

Let τ_1 be the current value of τ (generally one-half time step less than τ). If \underline{r}_1 , \underline{v}_1 , and x_1 are the values of \underline{r}_{con} , \underline{v}_{con} , and x , respectively, at τ_1 , then a trial value of $x(\tau)$ is obtained from

$$x_t = x_1 + s \left[1 - F_3 s (1 - 2F_3 s) - \frac{1}{6} \left(\frac{1}{r_1} - \alpha_0 \right) s^2 \right] \quad (5.2.5)$$

where

$$s = \frac{\sqrt{\mu_e} (\tau - \tau_1)}{r_1} \quad (5.2.6)$$

$$F_3 = \frac{\underline{r}_1 \cdot \underline{v}_1}{2r_1 \sqrt{\mu_e}}$$

The iteration procedure is accomplished by using Eq. (5.2.4) to compute $\tau(x_t)$. The result is compared to the desired value of τ ; and, if required, a new trial value of x is given by

$$x_t = x_t + \frac{\sqrt{\mu_e} [\tau - \tau(x_t)]}{r[\tau(x_t)]} \quad (5.2.7)$$

where

$$r[\tau(x_t)] = r_0 + (1 - r_0 \alpha_0) F_1 + \frac{r_0 \cdot \underline{v}_0}{\sqrt{\mu_e}} (x_t - \alpha_0 F_2) \quad (5.2.8)$$

Because of the excellent initial approximation provided by Eq. (5.2.5), it has not been found necessary to compute Eq. (5.2.7) more than once (and frequently it is not necessary at all) in order to obtain a value of $\tau - \tau(x_t)$ which is less than the given tolerance level.

The true position and velocity vectors will deviate from the conic position and velocity since \underline{a}_d is not zero. Let

$$\underline{r}(t) = \underline{\delta}(t) + \underline{r}_{con}(t) \quad (5.2.9)$$

$$\underline{v}(t) = \underline{\nu}(t) + \underline{v}_{con}(t)$$

where $\underline{\delta}(t)$ and $\underline{v}(t)$ are the position and velocity deviations from the conic. The deviation vector $\underline{\delta}(t)$ satisfies the differential equation

$$\frac{d^2}{dt^2} \underline{\delta}(t) = - \frac{\mu_e}{r_{con}^3(t)} \left[f(q) \underline{r}(t) + \underline{\delta}(t) \right] + \underline{a}_d(t) \quad (5.2.10)$$

subject to the initial conditions

$$\underline{\delta}(t_0) = \underline{0}, \quad \underline{v}(t_0) = \underline{0} \quad (5.2.11)$$

where

$$q = \frac{(\underline{\delta} - 2\underline{r}) \cdot \underline{\delta}}{r^2} \quad (5.2.12)$$

$$f(q) = q \frac{3 + 3q + q^2}{1 + (1 + q)^{3/2}}$$

The first term on the right-hand side of Eq. (5.2.10) must remain small, i.e. of the same order as $\underline{a}_d(t)$, if the method is to be efficient. As the deviation vector $\underline{\delta}(t)$ grows in magnitude, this term will eventually increase in size. Therefore, in order to maintain the efficiency of the method, a new osculating conic orbit should be defined by the total position and velocity vectors $\underline{r}(t)$ and $\underline{v}(t)$. The process of selecting a new conic orbit from which to calculate deviations is called rectification. When rectification occurs, the initial conditions for the differential equation for $\underline{\delta}(t)$ are again zero.

Disturbing Acceleration

In earth orbit the form of the disturbing acceleration is

$$\underline{a}_d = \underline{a}_{obl} \quad (5.2.13)$$

where \underline{a}_{obl} is the gravitational anomaly arising from the non-spherical shape of the earth.*

The oblateness acceleration is given by

$$\underline{a}_{obl} = \frac{\mu_e}{r^2} \sum_{i=2}^4 J_i \left(\frac{r_{eq}}{r} \right)^i \left[P_{i+1}'(\cos \phi) \underline{u}_r - P_i'(\cos \phi) \underline{u}_z \right] \quad (5.2.14)$$

where

$$\begin{aligned} P_2'(\cos \phi) &= 3 \cos \phi \\ P_3'(\cos \phi) &= \frac{1}{2} (15 \cos^2 \phi - 3) \\ P_4'(\cos \phi) &= \frac{1}{3} (7 \cos \phi P_3' - 4 P_2') \\ P_5'(\cos \phi) &= \frac{1}{4} (9 \cos \phi P_4' - 5 P_3') \end{aligned} \quad (5.2.15)$$

*Atmospheric drag accelerations have been deleted from this program upon MSC request.

are the derivatives of Legendre polynomials,

$$\cos \phi = \underline{u}_r \cdot \underline{u}_z \quad (5.2.16)$$

and J_2, J_3, J_4 are the coefficients of the second, third, and fourth harmonics of the earth's potential function. The vectors \underline{u}_r and \underline{u}_z are unit vectors in the direction of \underline{r} and the polar axis of the earth, respectively.

Error Transition Matrix

The position and velocity vectors as maintained in the computer are only estimates of the true values. As part of the navigation technique, it is necessary also to maintain statistical data in the computer to aid in the processing of navigation measurements.

If $\underline{\epsilon}(t)$ and $\underline{\eta}(t)$ are the errors in the estimates of the position and velocity vectors, respectively, then the six-dimensional correlation matrix $E(t)$ is defined by

$$E_6(t) = \begin{pmatrix} \overline{\underline{\epsilon}(t) \underline{\epsilon}(t)^T} & \overline{\underline{\epsilon}(t) \underline{\eta}(t)^T} \\ \overline{\underline{\eta}(t) \underline{\epsilon}(t)^T} & \overline{\underline{\eta}(t) \underline{\eta}(t)^T} \end{pmatrix} \quad (5.2.17)$$

In certain applications it becomes necessary to expand the state vector and the correlation matrix to more than six dimensions so as to include estimation of biases in landmarks for the CMC during orbit navigation and rendezvous radar tracking biases in the LGC during the rendezvous navigation procedure. For this purpose a nine-dimensional correlation matrix is defined as follows

$$E(t) = \begin{pmatrix} & & \overline{\underline{\epsilon}(t) \underline{\beta}^T} \\ & E_6(t) & \overline{\underline{\eta}(t) \underline{\beta}^T} \\ \overline{\underline{\beta} \underline{\epsilon}(t)^T} & \overline{\underline{\beta} \underline{\eta}(t)^T} & \overline{\underline{\beta} \underline{\beta}^T} \end{pmatrix} \quad (5.2.18)$$

where the components of the three-dimensional vector $\underline{\beta}$ are the errors in the estimates of three biases.

In order to take full advantage of the operations provided by the interpreter in the computer, the correlation matrix will be restricted to either six or nine dimensions. If, in some navigation procedure, only one or two biases are to be estimated, then a sufficient number of dummy variables will be added to the desired seven- or eight-dimensional state vector to make it nine-dimensional.

Rather than use the correlation matrix in the navigation procedure, it is more convenient to utilize a matrix $W(t)$, called the error transition matrix, and defined by

$$E(t) = W(t) W(t)^T \quad (5.2.19)$$

Extrapolation of the nine-dimensional matrix $W(t)$ is made by direct numerical integration of the differential equation

$$\frac{d}{dt} W(t) = \begin{pmatrix} 0 & I & 0 \\ G(t) & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} W(t) \quad (5.2.20)$$

where $G(t)$ is the three-dimensional gravity gradient matrix and I and 0 are the three-dimensional identity and zero matrices, respectively. If the W matrix is partitioned as

$$W = \begin{pmatrix} \underline{w}_0 & \underline{w}_1 & \cdots & \underline{w}_8 \\ \underline{w}_9 & \underline{w}_{10} & \cdots & \underline{w}_{17} \\ \underline{w}_{18} & \underline{w}_{19} & \cdots & \underline{w}_{26} \\ \vdots & \vdots & \ddots & \vdots \end{pmatrix} \quad (5.2.21)$$

then,

$$\left. \begin{aligned} \frac{d}{dt} \underline{w}_i(t) &= \underline{w}_{i+9}(t) \\ \frac{d}{dt} \underline{w}_{i+9}(t) &= G(t) \underline{w}_i(t) \\ \frac{d}{dt} \underline{w}_{i+18}(t) &= \underline{0} \end{aligned} \right\} \quad i = 0, 1, \dots, 8 \quad (5.2.22)$$

The extrapolation may be accomplished by successively integrating the vector differential equations

$$\frac{d^2}{dt^2} \underline{w}_i(t) = G(t) \underline{w}_i(t) \quad i = 0, 1, \dots, 8 \quad (5.2.23)$$

The gravity gradient matrix $G(t)$ for earth orbit is given by

$$G(t) = \frac{\mu_e}{r^5(t)} \left[3 \underline{r}(t) \underline{r}(t)^T - r^2(t) I \right] \quad (5.2.24)$$

Thus, if D is the dimension of the matrix $W(t)$ for the given navigation procedure, the differential equations for the $w_i(t)$ vectors are

$$\frac{d^2}{dt^2} w_i(t) = \frac{\mu e}{r^3(t)} \left\{ 3 \left[\underline{u}_r(t) \cdot \underline{w}_i(t) \right] \underline{u}_r(t) - \underline{w}_i(t) \right\} \quad (5.2.25)$$

$i = 0, 1, \dots, D-1$

where $\underline{u}_r(t)$ is a unit vector in the direction of $\underline{r}(t)$.

Numerical Integration Method

The extrapolation of navigational data requires the solution of a number of second-order vector differential equations, specifically Eqs. (5.2.10) and (5.2.25). These are all special cases of the form

$$\frac{d^2}{dt^2} \underline{y} = \underline{f}(\underline{y}, t) \quad (5.2.26)$$

Nystrom's method is particularly well suited to this form and gives an integration method of fourth-order accuracy. The second-order system is written

$$\begin{aligned} \frac{d}{dt} \underline{y} &= \underline{z} \\ \frac{d}{dt} \underline{z} &= \underline{f}(\underline{y}, t) \end{aligned} \quad (5.2.27)$$

and the formulae are summarized below

$$\begin{aligned} \underline{y}_{n+1} &= \underline{y}_n + \underline{\phi}(\underline{y}_n) \Delta t \\ \underline{z}_{n+1} &= \underline{z}_n + \underline{\psi}(\underline{y}_n) \Delta t \\ \underline{\phi}(\underline{y}_n) &= \underline{z}_n + \frac{1}{6}(\underline{k}_1 + 2\underline{k}_2) \Delta t \\ \underline{\psi}(\underline{y}_n) &= \frac{1}{6}(\underline{k}_1 + 4\underline{k}_2 + \underline{k}_3) \\ \underline{k}_1 &= \underline{f}(\underline{y}_n, t_n) \\ \underline{k}_2 &= \underline{f}\left(\underline{y}_n + \frac{1}{2} \underline{z}_n \Delta t + \frac{1}{8} \underline{k}_1 (\Delta t)^2, t_n + \frac{1}{2} \Delta t\right) \\ \underline{k}_3 &= \underline{f}\left(\underline{y}_n + \underline{z}_n \Delta t + \frac{1}{2} \underline{k}_2 (\Delta t)^2, t_n + \Delta t\right) \end{aligned} \quad (5.2.28)$$

For efficient use of computer storage as well as computing time the computations are performed in the following order.

- a) Equation (5.2.10) is solved using the Nystrom formulae, Eq. (5.2.28). It is necessary to preserve the values of the vector \underline{r} at times t_n , $t_n + \Delta t/2$, $t_n + \Delta t$ for use in the solution of Eqs. (5.2.25).
- b) Equations (5.2.25) are solved one-at-a-time using Eqs. (5.2.28) together with the values of \underline{r} which resulted from the first step.

The variable Δt is the integration time step and should not be confused with τ , the time since rectification. The maximum value for Δt which can be used for precision integration in earth orbit and still retain sufficient accuracy is 270 seconds. If rectification does not occur for several time steps, then the value of τ will be several times 270 seconds. In the conic integration mode, τ and Δt are equal, and the integration is accomplished in one step using Eq. (5.2.2) through (5.2.8).

Estimates of the state vectors of two vehicles (CSM and LM) will be maintained in the computer. In various phases of the mission it will be required to extrapolate a state vector either alone or with an associated W matrix of dimension six or nine.

To accomplish all of these possible procedures, as well as to solve the computer restart problem, three state vectors will be maintained in the computer. Let \underline{x}_C and \underline{x}_L be the estimated CSM and LM state vectors, respectively, and let \underline{x} be a temporary state vector. Also, let the variable D indicate the dimension of the W matrix, and let

$$D = 0 \quad (5.2.29)$$

denote that the state vector only is to be extrapolated. Finally, let

$$V = \begin{cases} 1 & \text{for CSM} \\ 0 & \text{for LM} \end{cases} \quad (5.2.30)$$

indicate the appropriate vehicle.

The logic for the Orbital Integration Routine is shown in Figs. 5.2-2 and 5.2-3. In these figures the state vector is being integrated to time t_1 . The value of Δt for each time step is either Δt_{\max} (270 seconds) or the total time-to-go, whichever is smaller. The integration is terminated when the computed value of Δt is less than ϵ_t (3 cs.).

5.2.3 Tracking Measurement Incorporation Routine

Periodically it is necessary to update the position and velocity of the vehicle by means of navigational measurements as outlined in Fig. 5.2-1.

* Note: The diamond symbol used in all figures of this report represents a question or decision logic operation.

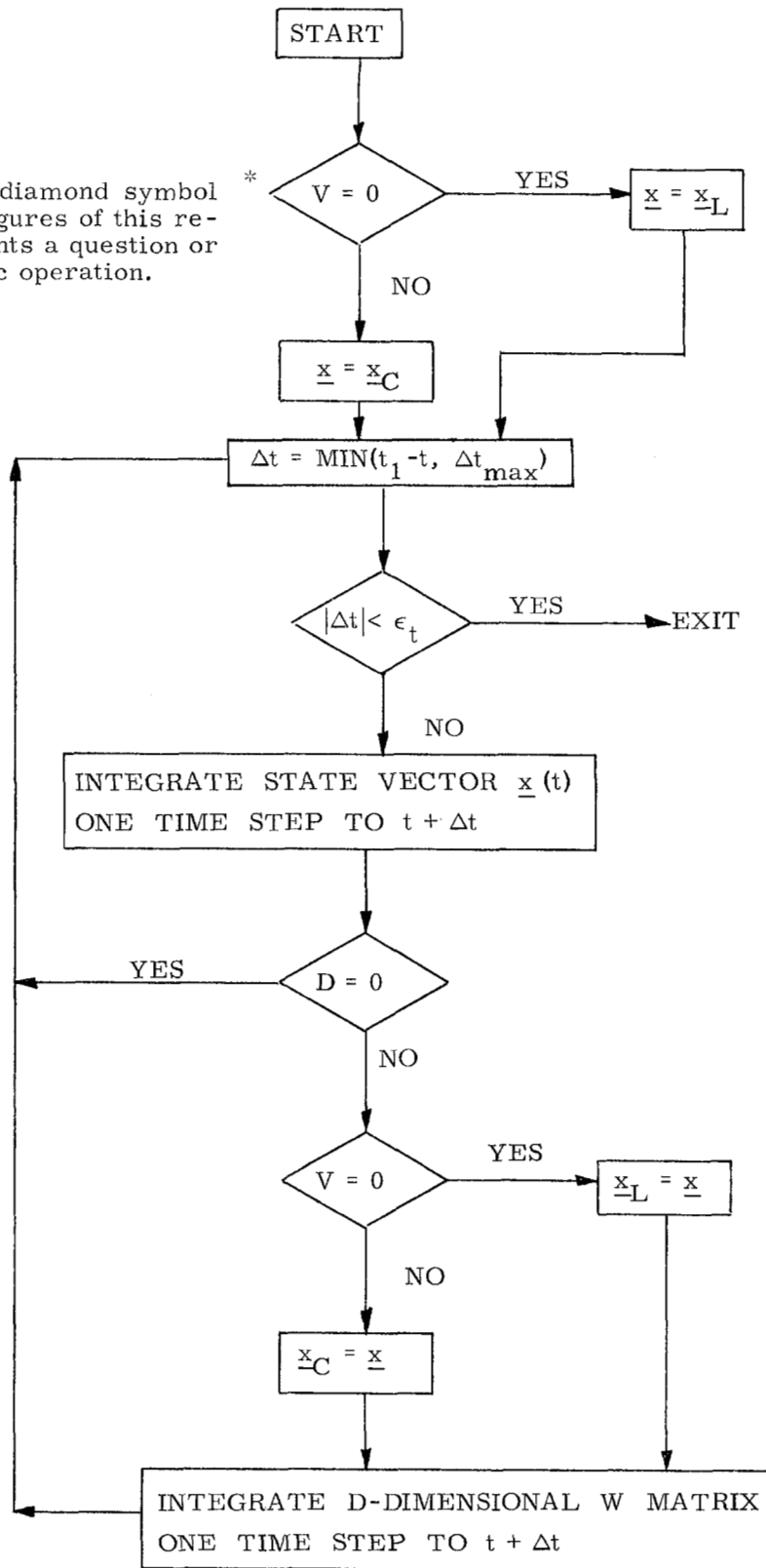


Fig. 5.2-2 Simplified Orbital Integration Routine Logic Diagram

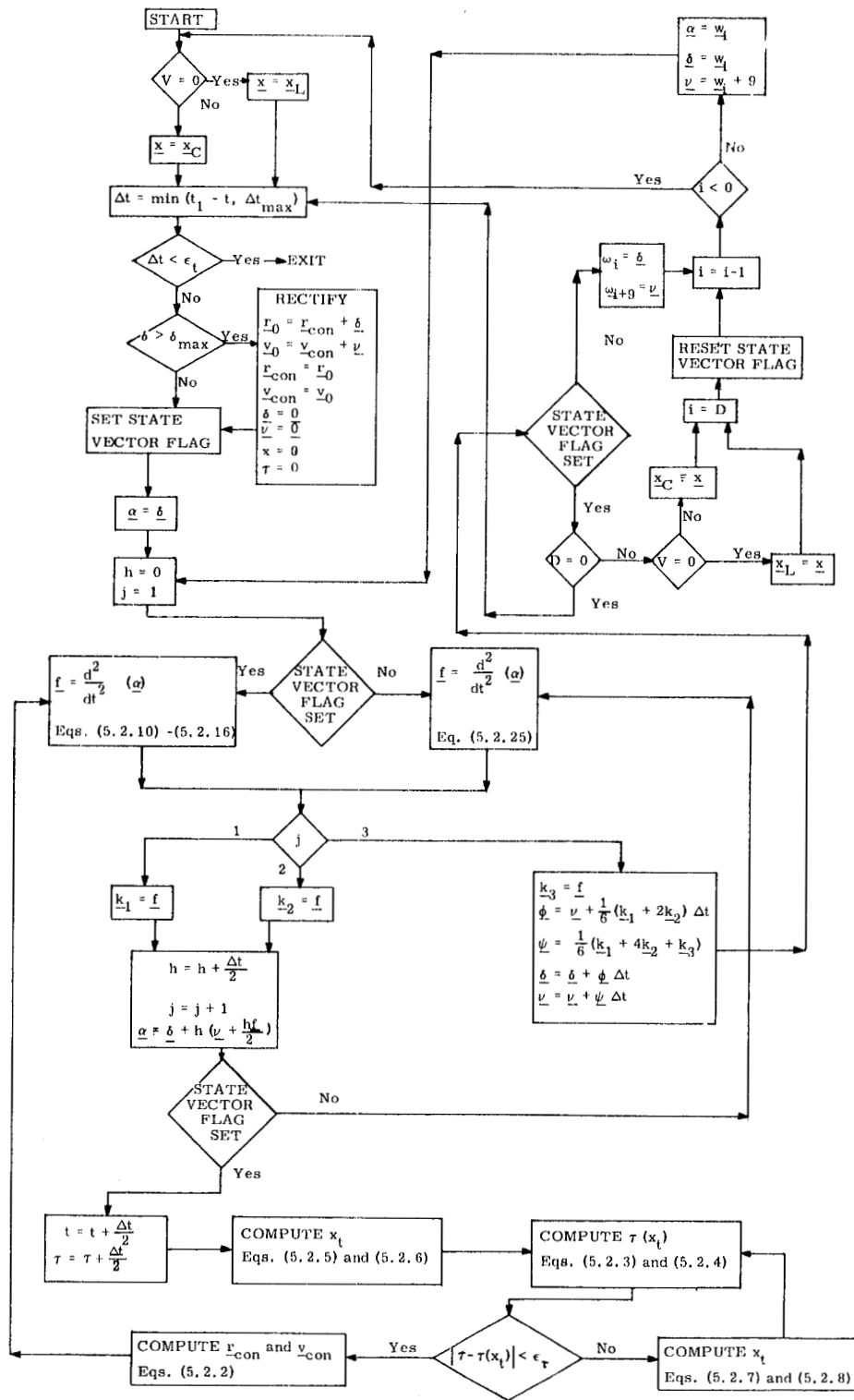


Fig. 5. 2-3 Orbital Integration Routine Logic Diagram

At the time a measurement is made, the best estimate of the state vector of the spacecraft is the extrapolated estimate maintained in the computer, denoted by \underline{x}' . The first six components of \underline{x}' are the components of the estimated position and velocity vectors. If biases are being estimated, then the state vector will be of nine dimensions and will have the bias estimates as its last three components. From this state vector estimate it is possible to determine an estimate of the quantity to be measured. When the predicted value of this measurement is compared with the actual measured quantity, the difference is used to update the indicated state vector as well as its associated W matrix in the computer.

Before the state vector and W matrix are updated, the components of the state vector deviation estimate $\delta\underline{x}$ is compared with present alarm levels as described in Section 5.2.1. In the CMC Rendezvous Navigation Routine, the astronaut is alerted to a larger than expected $\delta\underline{x}$ by a flashing verb-noun combination. In the case in which the state vector deviation exceeds the tracking alarm level the astronaut should repeat the optical measurement before incorporating the resulting $\delta\underline{x}$ as an update to the state vector. This particular program operation was incorporated to avoid false optical tracking since the LM target can appear as either a flashing or steady light depending upon the degree of reflected sunlight. In the case of the CMC Orbital Navigation Routine involving optical sightings against surface landmarks, the position and velocity components of the deviation $\delta\underline{x}$ are displayed to the astronaut and are not used to update the orbital state vector until approved by the astronaut by a keyboard entry to proceed.

Associated with each measurement is a geometry vector \underline{b} , which is of the same dimension as the W matrix, and also a mean-squared a-priori estimation error σ^2 based on the navigation measurement tracking performance. The procedure for incorporating a measurement into the estimate is as follows:

- a) Compute a D-dimensional \underline{z} vector from

$$\underline{z} = W'^T \underline{b} \quad (5.2.31)$$

where W' is the error transition matrix associated with \underline{x}' . The initial error transition matrix W used in this equation is prestored as a diagonal matrix as previously mentioned in Section 5.2.1. This initial error transition matrix is used the first time a measurement is to be incorporated at the start of a rendezvous phase, or for the first measurement after a state update has been received from the Mission Ground Control Center over the data uplink or communication link.

b) Compute the D-dimensional weighting vector $\underline{\omega}$ from

$$\underline{\omega}^T = \frac{1}{z^2 + \alpha^2} \underline{z}^T W'^T \quad (5.2.32)$$

c) Compute the state vector deviation estimates from

$$\delta \underline{x} = \underline{\omega} \delta Q \quad (5.2.33)$$

where δQ is the difference between the value of the quantity actually measured and the expected value based on the original value of the estimated state vector \underline{x}' .

d) If the data pass the validity test, update the state vector and the W matrix by

$$\underline{x} = \underline{x}' + \delta \underline{x} \quad (5.2.34)$$

$$W = W' - \frac{\underline{\omega} \underline{z}^T}{1 + \sqrt{\frac{\alpha^2}{z^2 + \alpha^2}}} \quad (5.2.35)$$

In order to take full advantage of the three-dimensional vector and matrix operations provided by the interpreter in the computer, the nine-dimensional W matrix will be stored sequentially in the computer as follows

$$\underline{w}_0, \underline{w}_1, \dots, \underline{w}_{26}$$

Now, define the three-dimensional matrices

$$W_0 = \begin{pmatrix} \underline{w}_0^T \\ \underline{w}_1^T \\ \underline{w}_2^T \end{pmatrix} \quad W_1 = \begin{pmatrix} \underline{w}_3^T \\ \underline{w}_4^T \\ \underline{w}_5^T \end{pmatrix} \quad \dots \quad W_8 = \begin{pmatrix} \underline{w}_{24}^T \\ \underline{w}_{25}^T \\ \underline{w}_{26}^T \end{pmatrix} \quad (5.2.36)$$

so that

$$W = \begin{pmatrix} W_0^T & W_1^T & W_2^T \\ W_3^T & W_4^T & W_5^T \\ W_6^T & W_7^T & W_8^T \end{pmatrix} \quad (5.2.37)$$

Let the nine-dimensional vectors $\delta \underline{x}$, \underline{b} , $\underline{\omega}$, and \underline{z} be partitioned as follows:

$$\delta \underline{x} = \begin{pmatrix} \delta x_0 \\ \delta x_1 \\ \delta x_2 \end{pmatrix} \quad \underline{b} = \begin{pmatrix} b_0 \\ b_1 \\ b_2 \end{pmatrix} \quad \underline{\omega} = \begin{pmatrix} \omega_0 \\ \omega_1 \\ \omega_2 \end{pmatrix} \quad \underline{z} = \begin{pmatrix} z_0 \\ z_1 \\ \vdots \\ z_8 \end{pmatrix} = \begin{pmatrix} z_0 \\ z_1 \\ z_2 \end{pmatrix} \quad (5.2.38)$$

Then, the computations shown in Eqs. (5.2.31) through (5.2.35) are performed as follows, using three-dimensional operations.

$$\underline{z}_i = \sum_{j=0}^{\frac{D}{3}-1} W'_{i+3j} b_j \quad i = 0, 1, \dots, \frac{D}{3} - 1$$

$$\beta = 1 / \left(\sum_{j=0}^{\frac{D}{3}-1} z_j \cdot z_j + \alpha^2 \right) \quad (5.2.39)$$

$$\underline{\omega}_i^T = \beta \sum_{j=0}^{\frac{D}{3}-1} z_j^T W'_{3i+j} \quad i = 0, 1, \dots, \frac{D}{3} - 1$$

$$\gamma = \frac{1}{1 + \sqrt{\beta \alpha^2}}$$

$$\delta \underline{x}_i = \delta Q \underline{\omega}_i \quad i = 0, 1, \dots, \frac{D}{3} - 1$$

$$\underline{W}_{i+9j} = \underline{W}'_{i+9j} - \gamma z_i \underline{\omega}_j \quad \begin{cases} i = 0, 1, \dots, D - 1 \\ j = 0, 1, \dots, \frac{D}{3} - 1 \end{cases}$$

The Tracking Measurement Incorporation Routine is divided into two parts, INCORP1 and INCORP2. The method of using these two subroutines is illustrated in Fig. 5.2-4.

5.2.4 CSM Preferred Tracking Attitude and Tracking Acquisition

During mission phases involving rendezvous, CSM SXT tracking data of the LM are used in the Rendezvous Navigation Routine (Section 5.2.5) and Tracking Measurement Incorporation Routine (Section 5.2.3) to update either the CSM or LM state vectors as outlined in Fig. 5.2-1. In order to initially acquire and maintain SXT tracking in the CSM, and RR tracking in LM, the

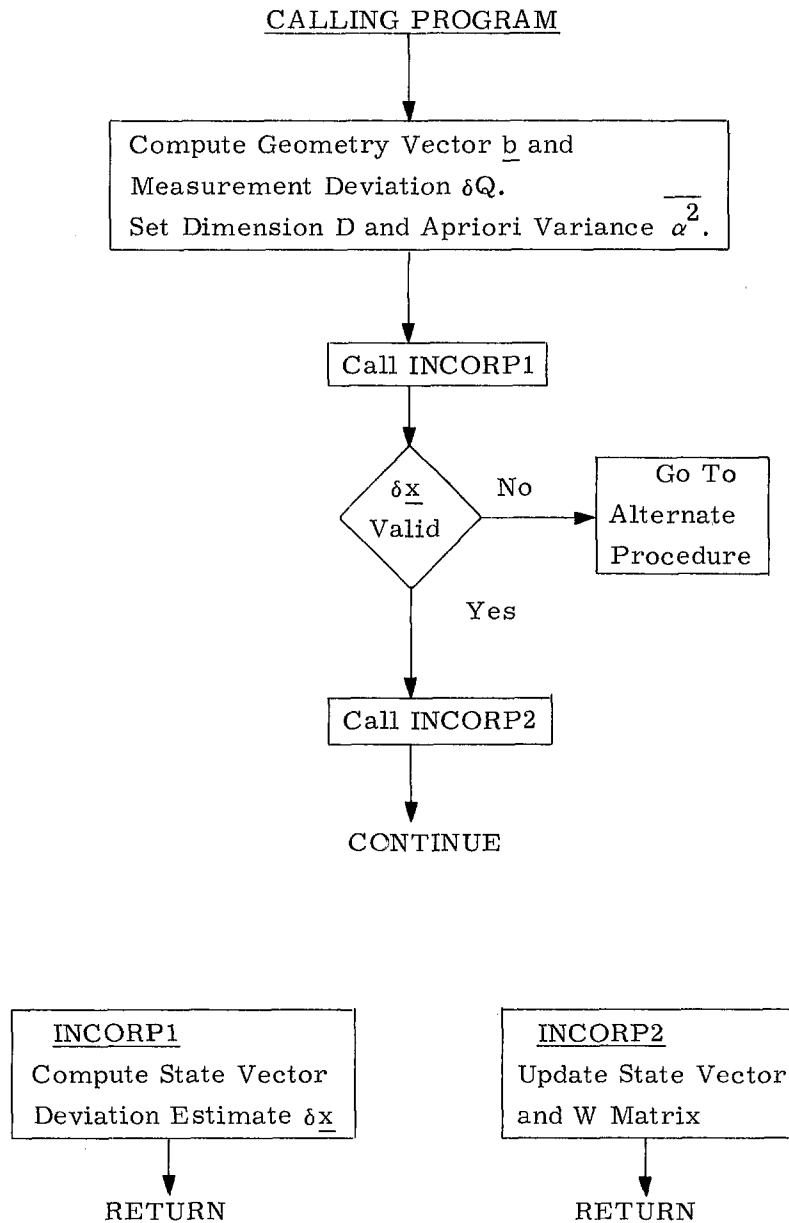


Fig. 5.2-4 Tracking Measurement Incorporation Procedure

CSM attitude must be oriented such that the tracking line of sight falls within the SXT and RR transponder coverage sectors.

The general routine used to achieve and maintain tracking conditions on the CSM is illustrated in Fig. 5.2-5. With reference to this figure, the estimated line of sight between the CSM and LM is first determined by advancing the two state vectors to the current time using the conic mode of the Orbital Integration Routine of Section 5.2.2. A preselected reference CSM vector (or axis) is then automatically controlled to coincide with the estimated line of sight. This reference CSM vector is chosen to be approximately in the center of the common coverage sector of the optics and RR transponder with allowance for the optics pole region. The reference vector currently considered for this function is illustrated in Fig. 5.2-6. The vehicle orientation about the reference axis is not controlled by the Preferred Tracking Attitude Routine and must be corrected manually by the astronaut if it is unsatisfactory. The Preferred Tracking Attitude Routine does maintain the CSM reference vector alignment to within $\pm 5^\circ$ of the estimated line of sight throughout free-fall rendezvous phases.

The Automatic Optics Designate routine of Fig. 5.2-5 drives the CSM optics to the estimated line-of-sight or pointing direction. The computations and positioning commands in this routine are repeated once every two seconds provided the optics mode switch is set to computer. The Automatic Optics Designate Routine also is used in other programs to align the optics to the following directions:

- a) A specified landmark during orbit navigation
- b) A specified star during IMU alignment procedures

After the astronaut has identified the target vehicle (a flashing optical beacon mounted on the LM or a steady light from LM reflected sunlight), he switches the optics mode to manual and centers the SXT reticle on the target. When accurate tracking is achieved, a "Mark" signal is entered by the astronaut upon which the CMC stores the measurement time and all SXT and IMU gimbale angles. These data are used in the Rendezvous Tracking Measurement Incorporation Routine at intervals of one minute.

If the astronaut is unable to visually acquire the LM after the SXT has been directed along the computed line of sight, he can call a SXT search pattern commanded by the CMC which will drive the SXT in a three degree box scan centered about the computed line of sight as indicated in Fig. 5.2-5. In the CMC controlled SXT search pattern, the SXT is initially positioned at one point on the 3 degree box scan pattern and this position is maintained until the astronaut commands a change with a DSKY proceed entry. The SXT is then

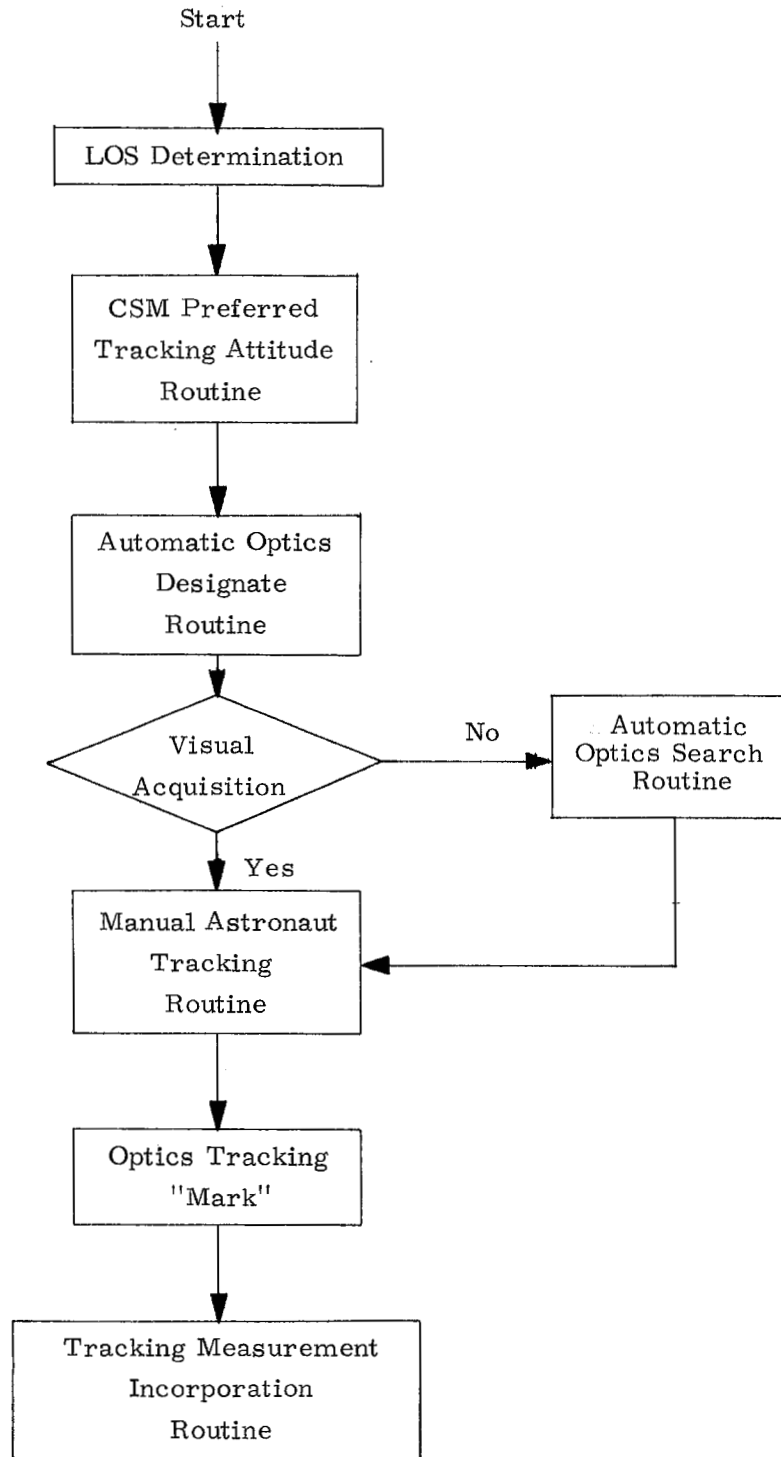


Fig. 5.2-5 CSM Preferred Tracking Attitude and Optics Designate Routine

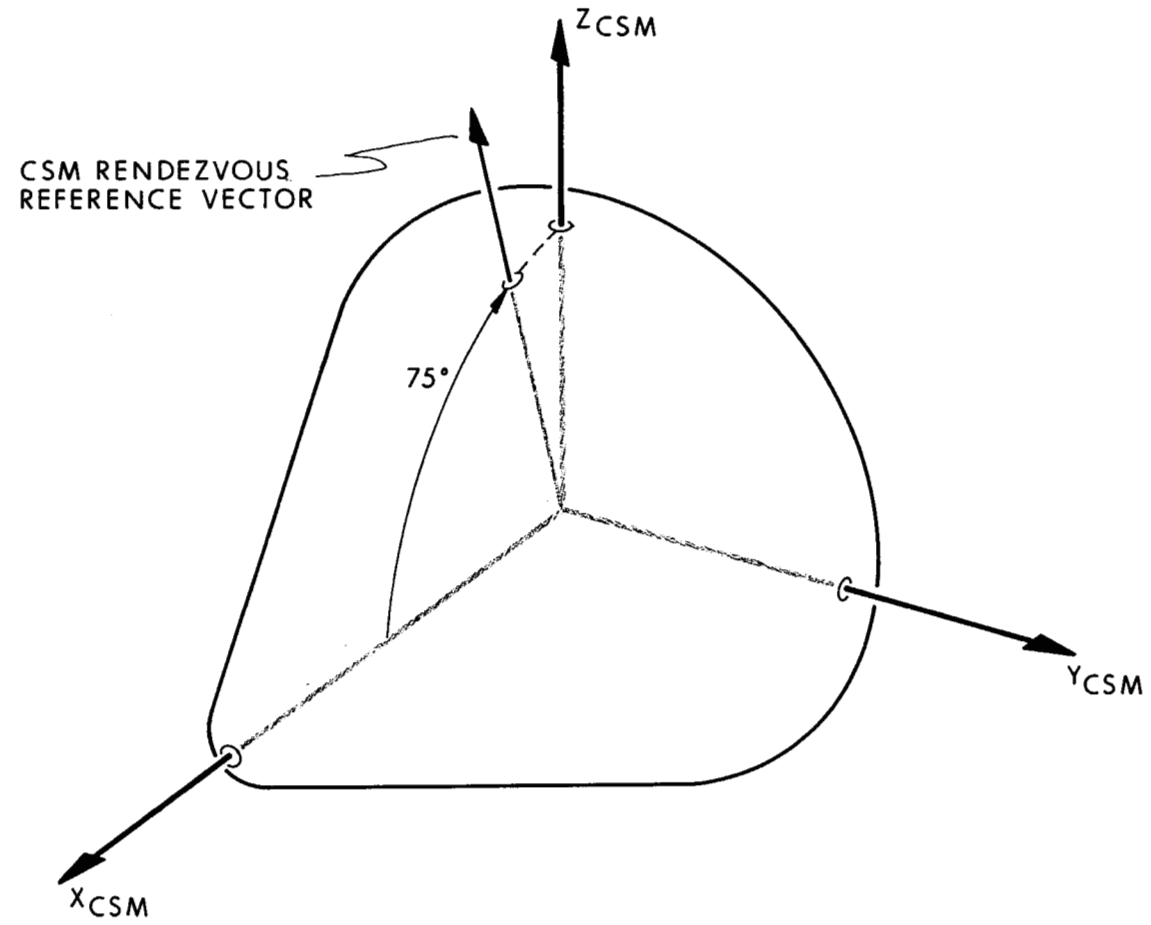


Fig. 5.2 -6 CSM Rendezvous Reference Vector

advanced by 0.75 degrees along the scan pattern and the operation repeated until the scan pattern is completed. At the end of each complete box scan cycle, the search pattern is recentered about the computed line of sight. It should be noted that the astronaut can also manually perform such a search procedure if he desires by placing the optics in the manual mode. In either case, final tracking and the optics mark procedure previously described is performed by the astronaut in the manual optics mode

In order to achieve desired accuracy levels of the vehicle state vector using optical measurements, it is important that optical tracking data used in the Rendezvous Navigation Routine of Section 5.2.5 be processed at essentially uniform intervals over the tracking period. Uniform tracking intervals are defined as once every minute throughout the phase, as opposed to all tracking data taken over a short period. The reason for this requirement is described in Section 5.2.5.

As previously mentioned in Section 5.2.1, CSM optical tracking is suspended during rendezvous maneuvers by either vehicle. If the CSM is the passive vehicle and is tracking the LM for monitoring and possible abort retrieval, LM rendezvous maneuvers are voice-linked to the CSM as an ignition time and three velocity components in a LM local vertical coordinate system, and then entered as updates to the LM state vector in the CMC. Upon receipt of these data, SXT tracking and data processing should be suspended until after the maneuver.

5.2.5 Rendezvous Navigation Routine

During rendezvous phases it is necessary to update either the LM or CSM state vectors by means of SXT sightings of the LM from the CSM. In this type of optical tracking, no tracking angle bias estimation is done in the navigation procedure since the SXT biases with respect to the IMU are small enough to be neglected.

After the preferred CSM attitude is achieved and optical tracking acquisition established (Section 5.2.4), the astronaut enters tracking data to the CMC by pressing the optics Mark button when he has centered the SXT reticle on the LM. As described in the preceding Section 5.2.4, the time of this tracking mark and the two SXT and three IMU gimbal angles are stored in the computer. From these angles the measurement unit vector, \underline{u}_m , along the CSM-LM line of sight is computed. The \underline{u}_m computation determines the line of sight unit vector in the Basic Reference Coordinate system from the optics shaft and trunnion angles and the IMU gimbal angles by

$$\underline{u}_m = [\text{REFSMMAT}]^T [\text{NBSM}] \underline{u}_{\text{NB}} \quad (5.2.40)$$

where [REFSMMAT] and [NBSM] are transformation matrices and \underline{u}_{NB} is the line of sight vector in navigation base coordinates. All terms of Eq. (5.2.40) are defined in Section 5.5.2., Eqs. (5.5.5) and (5.5.6).

This tracking measurement is mathematically equivalent to the simultaneous measurement of the angles between the LM and two stars. Thus, the data are incorporated by selecting two convenient unit vectors (fictitious star direction), converting the data to two star-LM measurements, and using the Tracking Measurement Incorporation Routine twice, once for each measurement. These two unit vectors are perpendicular to each other and to the line of sight so as to maximize the accuracy of the procedure.

The SXT tracking angle measurement processing procedure is then as follows:

- a) Use the Orbital Integration Routine to extrapolate the estimated CSM state vector, the estimated LM state vector, and the six-dimensional W matrix associated with the state vector being updated to the time of the mark, obtaining \underline{r}'_C , \underline{v}'_C , \underline{r}'_L , \underline{v}'_L and W' .
- b) Initialize the star vector \underline{u}_s to a convenient unit vector as described in Section 5.2.7.
- c) Compute the estimated CSM-LM line-of-sight vector from

$$\underline{r}'_{CL} = \underline{r}'_L - \underline{r}'_C \quad (5.2.41)$$

- d) Compute a fictitious star direction from

$$\underline{u}_s = \text{UNIT} (\underline{r}'_{CL} \times \underline{u}_s) \quad (5.2.42)$$

Note that this is a convenient vector since it makes the estimated angle equal to 90° .

- e) Then

$$\delta Q = \cos^{-1}(\underline{u}_s \cdot \underline{u}_m) - \frac{\pi}{2} \quad (5.2.43)$$

$$\underline{b} = \pm \frac{1}{r_{CL}} \begin{pmatrix} \underline{u}_s \\ 0 \end{pmatrix} \quad (5.2.44)$$

$$D = 6 \quad (5.2.45)$$

The upper or lower sign in Eq. (5.2.44) is selected depending on whether the CSM or LM state vector, respectively, is being updated.

- f) Incorporate the fictitious star-LM measurement using the Measurement Incorporation Routine

- g) Let

$$\underline{x}' = \underline{x} \quad (5.2.46)$$

h) Repeat steps c through f for the second angle to be processed.

The computational logic diagram for the Rendezvous Navigation Routine is illustrated in Fig. 5.2-7.

The tracking angle measurement procedure outlined above is repeated at one minute intervals throughout the rendezvous phase. As indicated in Section 5.2.4, it is important that the SXT tracking data be taken over as large an angular sector in inertial space swept out by the line of sight as possible to achieve desired state vector accuracy levels. This essentially uniform tracking operation is required since the SXT tracking angles provide information only in directions normal to the line of sight as indicated by Eq. (5.2.44), and the line of sight must be allowed to rotate in inertial space to achieve more complete update data.

The statistical measurement parameter $\overline{\alpha^2}$ for SXT rendezvous tracking performance used by the Tracking Measurement Incorporation Routine in Eq. (5.2.32) to determine the weighting vector, $\underline{\omega}$, has been assigned a value of 0.04 mr^2 for each SXT axis in GNCS rendezvous simulations.

The option of which state vector is to be updated by the SXT tracking data is controlled by the astronaut as described in Section 5.2.1 and illustrated in Fig. 5.2-1. This decision will be based upon which, if either, state vector is the most accurate and upon which vehicle is performing the rendezvous.

The only other astronaut operation required for the CMC Rendezvous Navigation Routine is for the case in which the LM is performing the rendezvous maneuvers. The LM ΔV maneuvers are voice-linked to the CSM and entered via the DSKY by the astronaut to maintain an accurate estimate of the LM state vector. SXT tracking measurements are not incorporated during LM maneuvers as described in Section 5.2.4. Also, the W matrix is reinitialized after each maneuver.

The two state vectors updated by the Rendezvous Navigation Routine are used to compute required rendezvous maneuvers as described in Section 5.3.

The Rendezvous Navigation Routine described in this section is similar to the orbital navigation concept with the exception that surface landmarks rather than the LM are tracked with the CSM optics. The Orbital Navigation Routine is described in the following Sections 5.2.6 and 5.2.7.

5.2.6 Latitude-Longitude Routine

This routine is used with the Orbital Navigation Routine of Section 5.2.7. For display and data load purposes, the latitude, longitude, and altitude of a point near the earth is more meaningful and more convenient to use than the components of the inertial position vector. The Latitude-Longitude Routine is

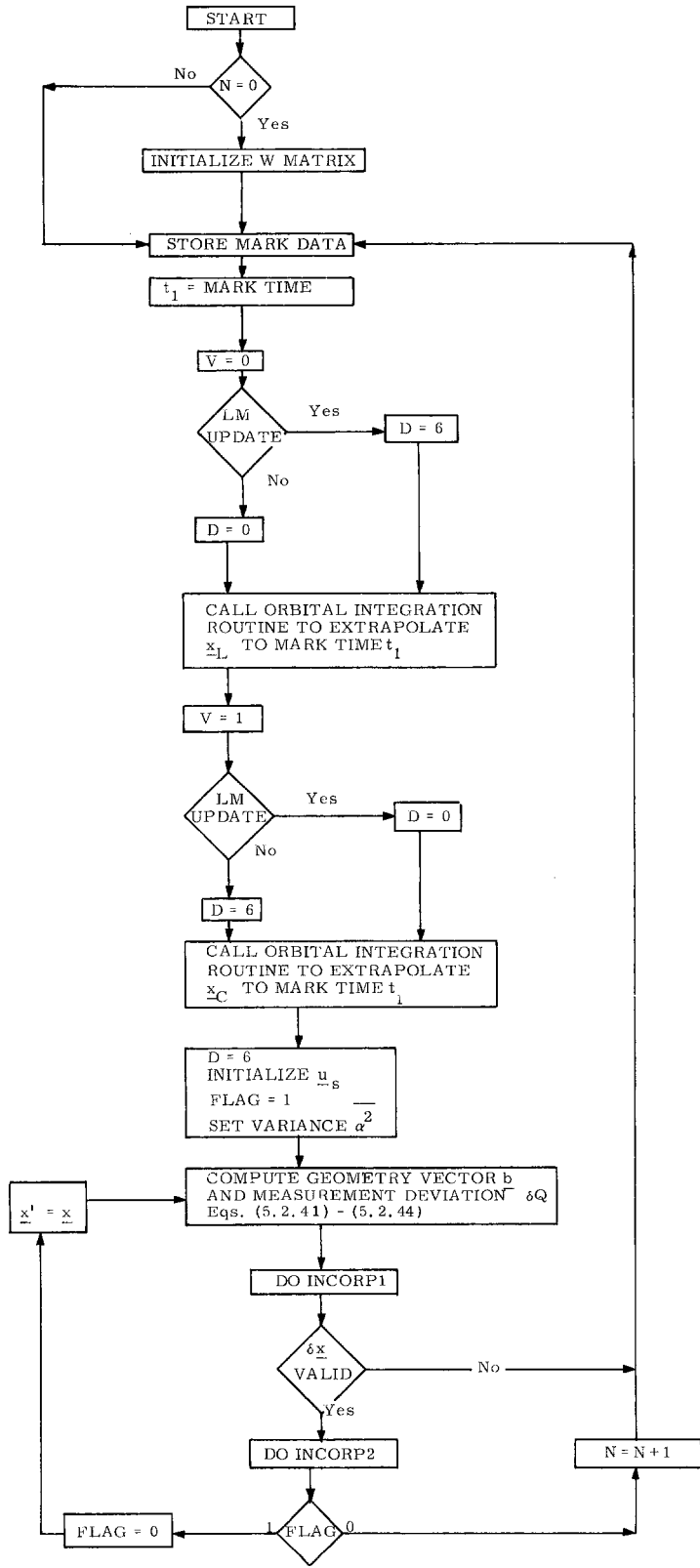


Fig. 5.2-7 Rendezvous Navigation Routine Logic Diagram

used to transform in either direction between an inertial position vector and the corresponding geodetic latitude, longitude, and altitude above the Fischer ellipsoid at a specified time.

Let \underline{r} be the inertial position vector and the specified time (GET) be t . Then, the angle about the Z-axis between the X-axis and the Greenwich meridian is given by

$$A_z = A_{z0} + \omega (t + t_{\text{ephem}}) \quad (5.2.47)$$

where A_{z0} is the angle between the X axis and the Greenwich meridian at midnight just prior to 1 July of the year preceding the reference Besselian year, t_{ephem} is the elapsed time between 1 July and the time that the CMC clock was zeroed, and ω is the angular velocity of the earth.

Let A_x and A_y be small angles about the X and Y axes, respectively, that describe the precession and nutation of the earth's pole. The vector

$$\underline{u} = \begin{pmatrix} u_0 \\ u_1 \\ u_2 \end{pmatrix} = \text{UNIT} \left[\begin{pmatrix} 1 & 0 & A_y \\ 0 & 1 & -A_x \\ -A_y & A_x & 1 \end{pmatrix} \underline{r} \right] \quad (5.2.48)$$

is a unit vector along \underline{r} in a coordinate system which has its Z-axis coincident with the true pole of the earth.

The geodetic latitude, longitude, and altitude are then computed from

$$\begin{aligned} \text{Lat} &= \tan^{-1} \left(\frac{u_2}{\sqrt{u_0^2 + u_1^2} (b^2/a^2)} \right) \\ \text{Long} &= \tan^{-1} \left(\frac{u_1}{u_0} \right) - A_z \\ \text{Alt} &= r - r_e \\ r_e^2 &= \frac{b^2}{1 - (1 - b^2/a^2) \cos^2 \text{Lat}} \end{aligned} \quad (5.2.49)$$

where a and b are the semi-major and semi-minor axes of the Fischer ellipsoid, respectively, and r_e is the radius of the ellipsoid at the given latitude.

The routine has an option in which a constant (the radius of the earth at the launch pad) is used for r_e instead of the computed value of the radius of the Fischer ellipsoid.

Conversely, let t , Lat, Long, and Alt be given. Then

$$\underline{u} = \text{UNIT} \begin{bmatrix} \cos (\text{Long} + A_z) \\ \sin (\text{Long} + A_z) \\ (b^2/a^2) \tan (\text{Lat}) \end{bmatrix} \quad (5.2.50)$$

is a unit vector in the direction of the given position in a coordinate system whose Z-axis coincides with the true pole of the earth. The vector \underline{u} is transformed to the reference coordinate system as follows:

$$\underline{r} = \text{UNIT} \begin{bmatrix} \begin{pmatrix} 1 & 0 & -A_y \\ 0 & 1 & A_x \\ A_y & -A_x & 1 \end{pmatrix} \underline{u} \end{bmatrix} \quad (5.2.51)$$

Finally,

$$\underline{r} = (r_e + \text{Alt}) \underline{r} \quad (5.2.52)$$

The above technique, although an approximation, is sufficiently accurate for low earth orbit and is exact at the surface of the Fischer ellipsoid. The angles A_x and A_y will be included in the pre-launch data load in erasable memory and are considered constant throughout the flight.

5.2.7 Orbital Navigation Routine

The orbital navigation concept implemented on Mission 207/208A is that planned for the lunar landing mission. As mentioned in Section 5.2.1 this concept involves a nine-dimensional matrix operation in which both the vehicle state vector and the landmark position are estimated and updated by optical measurements. The general orbital navigation procedure is similar to that of the Rendezvous Navigation Routine and is presented in simplified form in Fig. 5.2-8.

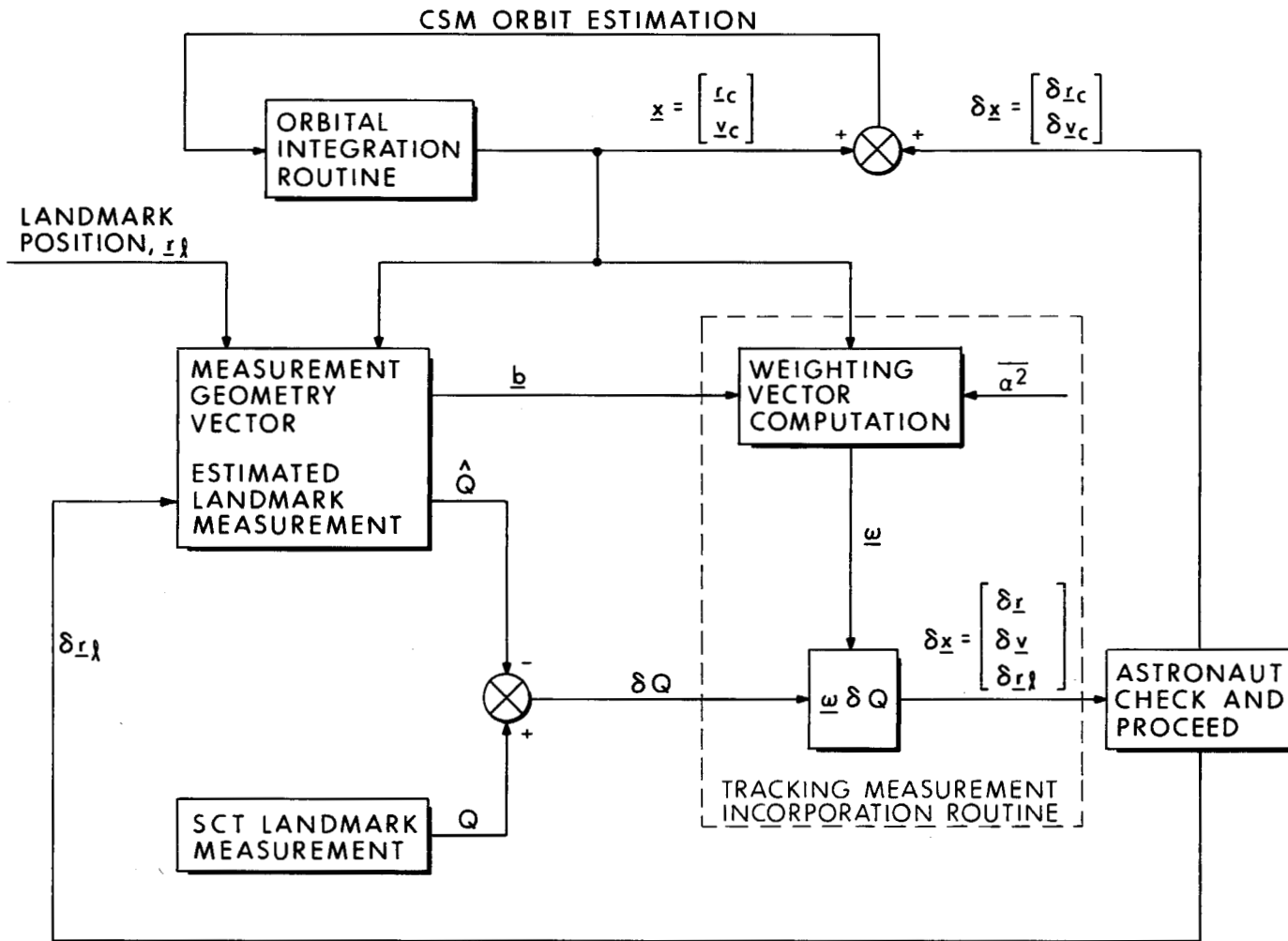


Fig. 5.2-8 Simplified Orbital Navigation Functional Diagram

Mapped Landmark Tracking

If the landmark positions are known within a given accuracy level, the scanning telescope is used for the tracking and marking procedure to determine the CSM orbit. As in the Rendezvous Navigation Routine, it is the CSM-landmark line-of-sight vector \underline{u}_m that is obtained from the measurement. The line-of-sight unit vector \underline{u}_m relative to the Basic Reference Coordinate system is determined by Eq. (5.2.40) in the same manner as in the Rendezvous Navigation Routine.

Let \underline{r}_ℓ be the inertial position vector of the landmark at the time of a mark obtained by means of the Latitude-Longitude Routine. The procedure for incorporating the landmark tracking data is as follows.

- a) Extrapolate the estimated CSM state vector and W matrix to the time of the mark by means of the Orbital Integration Routine.
- b) Assuming that it is required to include estimates of the biases in the knowledge of the landmark coordinates, the state vector is then defined as follows

$$\underline{x} = \begin{pmatrix} \underline{r}_C \\ \underline{v}_C \\ \underline{r}_\ell \end{pmatrix} \quad (5.2.53)$$

- c) Initialize the star vector \underline{u}_s to a convenient unit vector given by

$$\underline{u}_s = \text{UNIT} [(0, 0, 1) \times (\underline{r}_\ell' - \underline{r}_C')] \quad (5.2.54)$$

If the above equation results in computational difficulty the following vector is used

$$\underline{u}_s = (0, 1, 0) \quad (5.2.55)$$

- d) Compute the location of the landmark at the mark time t from the Latitude-Longitude Routine.

- e) Compute the estimated landmark line-of-sight vector from

$$\underline{r}_{C\ell} = \underline{r}_\ell' - \underline{r}_C' \quad (5.2.56)$$

- f) Compute a fictitious star direction from

$$\underline{u}_s = \text{UNIT} (\underline{r}_{C\ell} \times \underline{u}_s) \quad (5.2.57)$$

g) Finally

$$\delta Q = \cos^{-1}(\underline{u}_s \cdot \underline{u}_m) - \frac{\pi}{2} \quad (5.2.58)$$

$$\underline{b} = \frac{1}{r_{C\ell}} \begin{pmatrix} \underline{u}_s \\ 0 \\ -\underline{u}_s \end{pmatrix} \quad (5.2.59)$$

$$D = 9 \quad (5.2.60)$$

h) Incorporate the fictitious star-landmark measurement using the Measurement Incorporation Routine.

i) Let

$$\underline{x}' = \underline{x} \quad (5.2.61)$$

j) Repeat steps e through h.

Using this procedure, up to five accepted marks to the same landmark will be incorporated. At the beginning of the Orbit Navigation Routine a prestored nine-dimensional diagonal error transition matrix, $W(t)$, is used to initialize the Measurement Incorporation Routine. The statistical parameter $\overline{\alpha^2}$ used in Eq. (5.2.32) to determine the weighting vector $\underline{\omega}$ for the orbital navigation process is a function of the landmark position accuracy, the SCT tracking accuracy (including landmark size), and IMU alignment accuracy. In lunar orbit navigation simulations a value of $\overline{\alpha^2} = 1.0 \text{ mr}^2$ per SCT axis is presently being used. In the 207/208A case this parameter will have the same value for the earth orbital navigation simulations.

At the conclusion of the processing of each mark, an updated estimate of the landmark coordinates is obtained from the updated vector \underline{r}_ℓ by means of the Latitude-Longitude Routine.

The logic for the Orbital Navigation Routine is shown in Fig. 5.2-9.

During landmark tracking intervals of the Orbital Navigation phase, the vehicle attitude is under manual attitude-hold control. The SCT optics is automatically positioned along the predicted line of sight to the landmark selected by the astronaut by the Optics Designate Routine mentioned in Section 5.2.4. Final tracking is done by the astronaut with the optics in the manual mode and accurate landmark tracking identified by the optics "Mark" inputs as previously described.

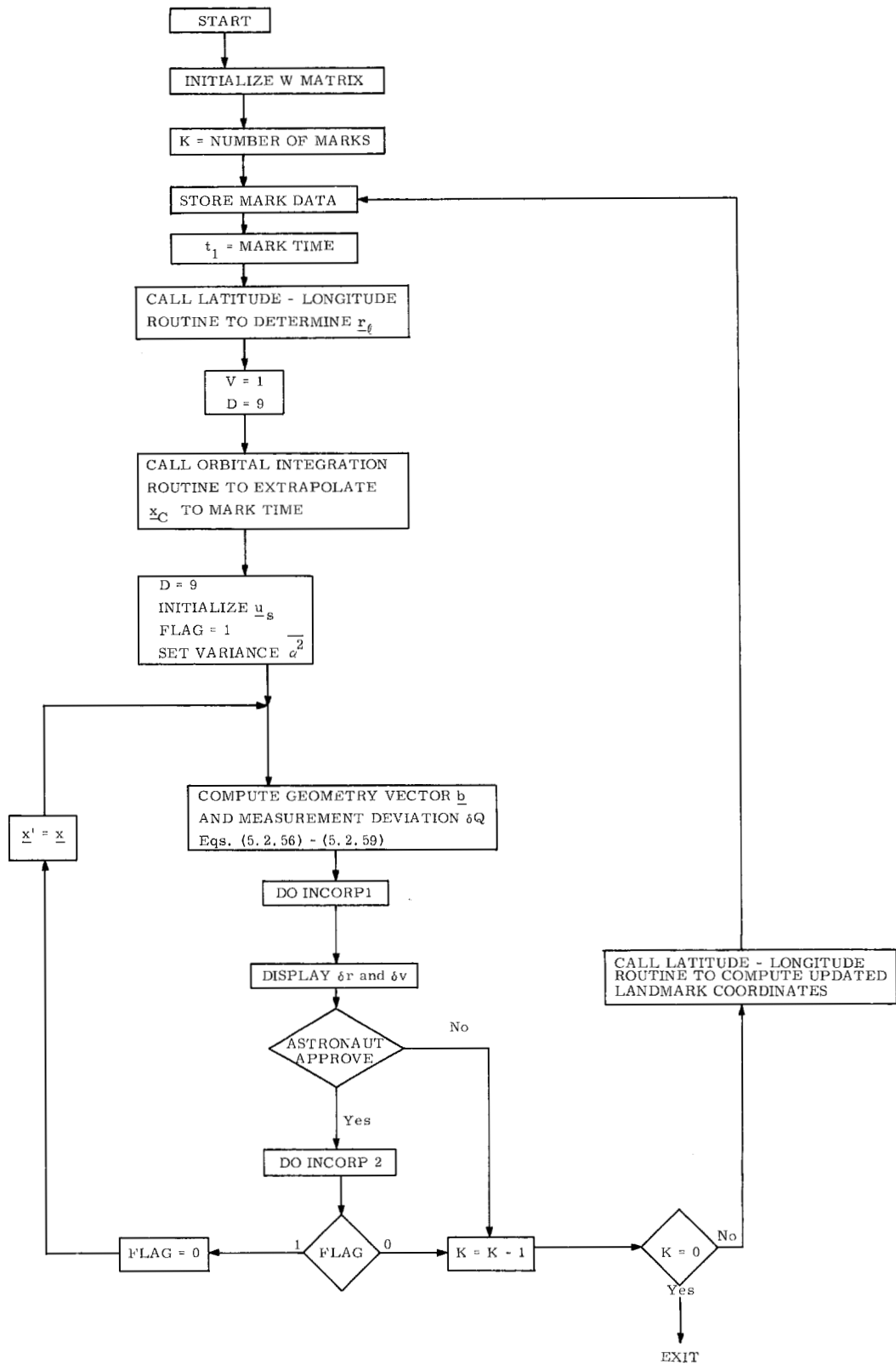


Fig. 5.2-9 Orbital Navigation Routine Logic Diagram

5.2.8 Landing Site Designation Routine

The nine-dimensional Orbital Navigation Routine described in Section 5.2.7 provides the means of mapping a point on the surface of the earth which is designated by a set of optical sightings. This procedure is that planned for lunar landing site designation during the lunar landing mission. The routine may also be used for orbital navigation since the method uses redundant data to improve the estimate of the vehicle state vector as well as the landmark position.

Assume that n optical sightings have been made against an unmapped landmark. Let t_{ref} be the time of the first sighting, and let \underline{u} be the CSM-landmark line of sight vector obtained from this measurement. An initial estimate of the landmark position is computed from

$$\underline{r}_{\ell 0} = \underline{r} + r \left[\cos A - \left(\frac{r_e^2}{r^2} - \sin^2 A \right)^{\frac{1}{2}} \right] \underline{u} \quad (5.2.62)$$

where

$$A = \cos^{-1} \left(\frac{\underline{u} \cdot \underline{r}}{r} \right) \quad (5.2.63)$$

\underline{r} is the estimated position of the spacecraft at time t_{ref} , and r_e is the radius of the earth.

The landmark position estimate after the first sighting is then improved by using the Orbital Navigation Routine and the data from the last $n-1$ sightings exactly as if the designated point were a mapped landmark, and $\underline{r}_{\ell 0}$ had been calculated by means of the Latitude-Longitude Routine.

The final result of this procedure is an accurate position vector estimate for the designated point at time t_{ref} ; and, in addition, an improvement in the vehicle state vector estimate.

5.3 Rendezvous Guidance Program

5.3.1 General

The Rendezvous Guidance Program in the CMC may be used in two modes which in combination provide the CSM with a direct intercept trajectory and the midcourse maneuvers required for rendezvous. These two modes designated pre-TPI mode (Terminal Phase Initiation) and Mid-Course mode are identical to the last two modes of the Concentric Rendezvous Program in the LM Guidance Computer (LGC). The automatic terminal rendezvous capability has been removed by MSC direction with the understanding that this phase of the rendezvous will be accomplished manually.

All computations performed in the Rendezvous Guidance Program use the Basic Reference Coordinate System defined in Section 5.1. The equations are the same as those used for the lunar mission except for necessary scaling differences, certain physical constants, and considerations of the gravitational anomalies.

The program has a basic dependence on the state vector estimates which are obtained from the navigation routines described in Sections 5.2 and 5.4.2.

In this section all references to particular program numbers (e. g. P 34) are based on the assumption that the CSM is the active vehicle. If the astronaut elects to make the LM active, via the first DSKY input, the only change is the program number selected. All equations and program operations in Section 5.3 are identical for these two active vehicle modes of operation.

5.3.2 Pre-TPI Maneuver (MODE 1)

This program mode corresponds to program P34 or P74 of Section 4.

5.3.2.1 Inputs

- 1) Choice of Maneuvering Vehicle (P34 if CSM, P74 if LM)
- 2) TPI time or Elevation angle
- 3) Δt of final transfer trajectory
(This time is the transfer trajectory time between TPI and intercept, (TPF), and does not include the effects of terminal rendezvous maneuvers.)

5.3.2.2 Program Operation

The computational sequence for this program is illustrated in Fig. 5.3-1. If the astronaut wishes to specify an elevation angle the following procedure is necessary.

MODE 1

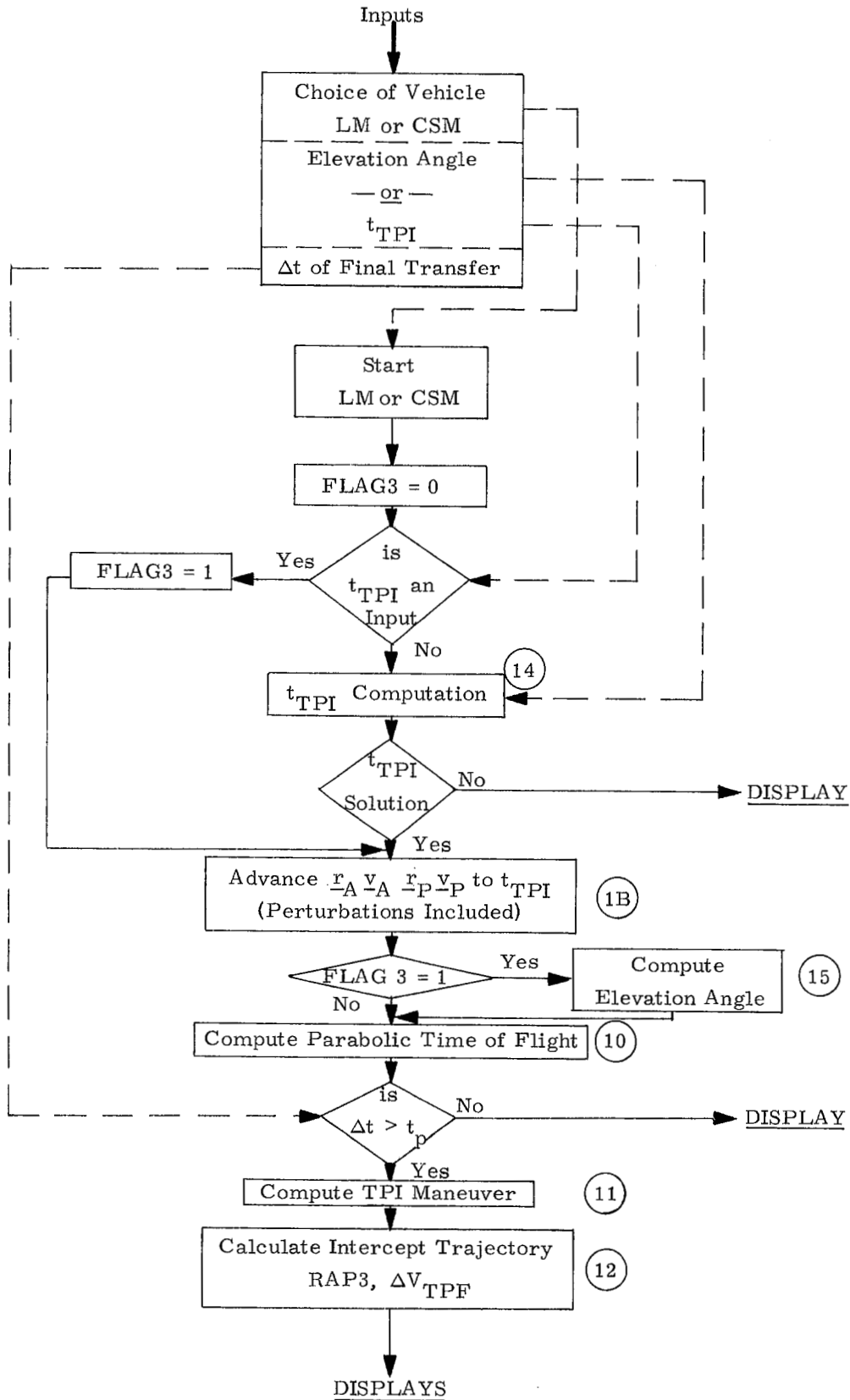


Fig. 5.3-1 Pre-TPI Maneuver Mode

- 1) Start P34 (or P74) with t_{TG} option
- 2) Input a nominal TPI time
- 3) Restart P34 (or P74) with the elevation angle option

The TPI time associated with the desired elevation angle will then be computed with the following iterative technique.

⑭* TPI Computation

Both vehicles are advanced to the stored TPI time using the precision orbit integration routine. If the difference between the true line of sight angle and the input TPI angle is greater than 0.1 degrees, the true TPI time is then calculated by making successive co-planar circular approximations to the current orbits (which are assumed to be no more than 5 degrees out of plane).

The time error to the true TPI for circular orbits is given by the equation:

$$TERR = \frac{ARCCOS [(RA/ RP) \cos \alpha] - \alpha - \lambda}{WP - WA} \quad (5.3.1)$$

where RA, RP = the magnitudes of current vehicle position vectors
 α = desired TPI angle
 λ = current central angle between vehicles
 WA, WP = the magnitudes of orbital angular velocities

It should be noted that the ARCCOS term in the above equation always gives rise to 2 solutions. If $RP > RA$ only one such solution is meaningful; however when $RA > RP$, both solutions are significant. In this case the solution corresponding to the shorter line of sight between vehicles is selected.

Both vehicles are then advanced to the time given by Eq. (5.3.3) and the true line of sight angle rechecked.

$$t_{TPI} = t_{TPI} + TERR \quad (5.3.3)$$

This process is repeated until the line of sight error becomes less than 0.1 deg. An iteration counter is used to protect against excessive iterations. When there is no TPI time associated with the elevation angle, the counter will serve as a means of initiating a program alarm which indicates that no solution can be found.

* Circled numbers in all of Section 5.3 refer to the logic flow diagrams of Fig. 5.3-1 and 5.3-3.

15 Elevation Angle Computation

If a TPI time is one of the inputs, both vehicles are advanced to that time using a precision orbit integration routine; and the elevation angle, defined in Fig. 5.3-2 which corresponds to the TPI time, is computed as follows:

$$\begin{aligned} \underline{H3} &= (\underline{r}_{A3} \times \underline{v}_{A3}) \times \underline{r}_{A3} \\ \underline{LOS} &= \text{UNIT} (\underline{r}_{P3} - \underline{r}_{A3}) \end{aligned} \quad (5.3.4)$$

$$\begin{aligned} \underline{UA3} &= \text{UNIT} (\underline{r}_{A3}) \\ E &= \pi/2 - \cos^{-1} (\underline{UA3} \cdot \underline{LOS}) \end{aligned}$$

$$\text{If } (\underline{LOS} \cdot \underline{H3}) < 0; \quad E = \pi - E \quad (5.3.5)$$

$$XE = |E| - \pi$$

$$\text{If } XE > 0; \quad E = XE - \pi \quad (5.3.6)$$

Computation of E is accomplished with the above equations and logic.

10 Computation of Parabolic Time of Flight

The estimate of both vehicle state vectors along with the Δt of the final transfer (an astronaut input) are used to compute an intercept aimpoint and the maneuver required to hit this aimpoint at the desired time. Gravitational anomalies are considered in calculating an offset target to be used by the Lambert Routine (See Section 5.3.5) for computing $\Delta \underline{V}_{\text{TPF}}$.

The position vector of the passive vehicle is advanced to the intercept time by the precision orbit integration routine, 1B using the input transfer trajectory Δt . The intercept time is given by Eq. (5.3.7).

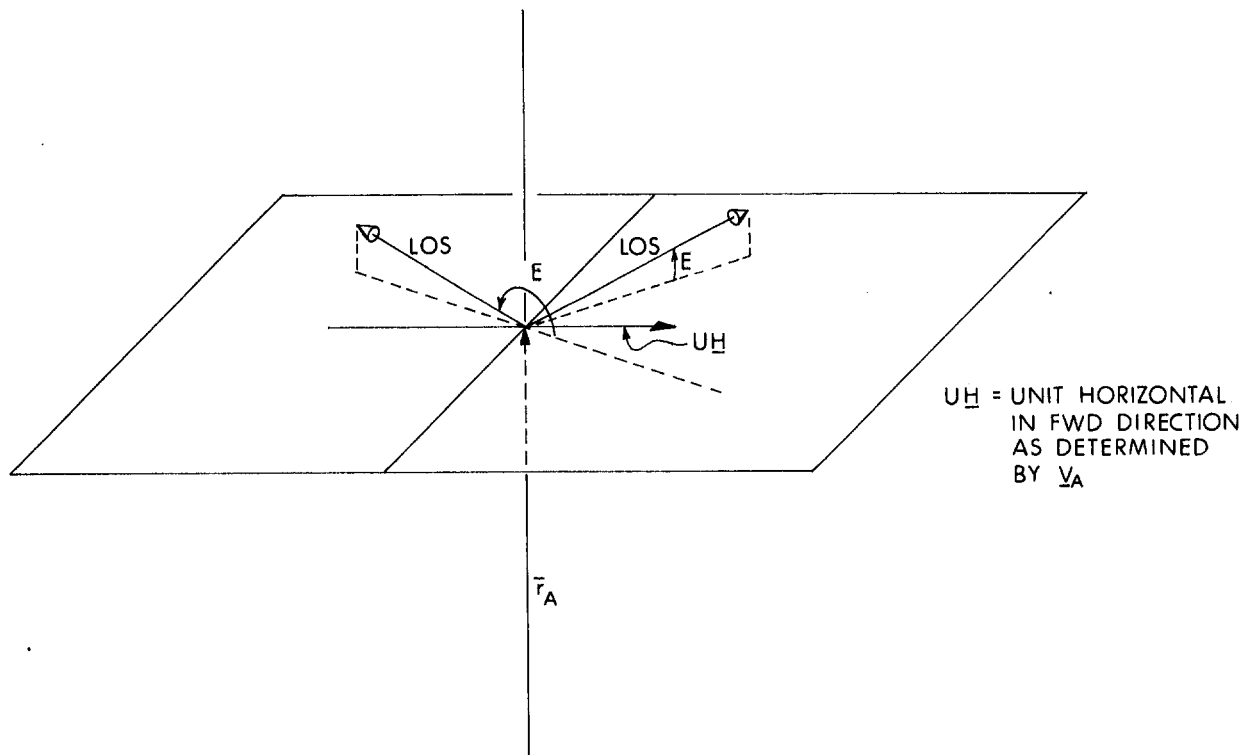
$$t_{\text{TPF}} = t_{\text{TPI}} + \Delta t \quad (5.3.7)$$

The aimpoint for the initial $\Delta \underline{V}$ calculation is the position vector of the passive vehicle at t_{TPF} , that is

$$\underline{r}_{\text{AIM}_0}(t_{\text{TPF}}) = \underline{r}_P(t_{\text{TPF}}) \quad (5.3.8)$$

The passive vehicle velocity vector at the intercept point, $\underline{v}_P(t_{\text{TPF}})$ is also obtained from the Precision Orbit Routine and stored.

Before the Lambert Routine is used, a check of the input transfer time is made to be sure that the velocity required is less than the parabolic velocity corresponding to the vehicle state. This check is included in the Lambert Routine (Section 5.3.5). If $\Delta t > t_P$ the program continues, using $\underline{r}_{\text{AIM}_0}$ and the Lambert Routine to calculate a $\Delta \underline{V}$ required to intercept the target.



- 1) IF THE LOS PROJECTION ON U_H IS POSITIVE:
 - a) WHEN THE LOS IS ABOVE THE HORIZONTAL PLANE $0 < E < \pi/2$
 - b) WHEN THE LOS IS BELOW THE HORIZONTAL PLANE $-\pi/2 < E < 0$

- 2) IF THE LOS PROJECTION ON U_H IS NEGATIVE
 - a) WHEN THE LOS IS ABOVE THE HORIZONTAL PLANE $\pi/2 < E < \pi$
 - b) WHEN THE LOS IS BELOW THE HORIZONTAL PLANE $-\pi < E < -\pi/2$

Fig. 5.3-2 Definition of Elevation Angle, E

⑪ Computation of TPI Maneuver

The state vector of the active vehicle is advanced to t_{TPI} using the Lambert solution, resulting in $\underline{r}_A(t_{\text{TPI}})$.

Due to gravitational anomalies, the active vehicle will not intercept the target. The position deviation from the desired position [$\underline{r}_P(t_{\text{TPI}})$] is given by

$$\delta \underline{r}_1(t_{\text{TPI}}) = \underline{r}_A(t_{\text{TPI}}) - \underline{r}_P(t_{\text{TPI}}) \quad (5.3.9)$$

A new aimpoint is computed for the second iteration, by the following equation:

$$\underline{r}_{\text{AIM}_1}(t_{\text{TPI}}) = \underline{r}_{\text{AIM}_0} - \delta \underline{r}_1(t_{\text{TPI}}) \quad (5.3.10)$$

A new $\Delta \underline{V}$ is then computed using $\underline{r}_{\text{AIM}_1}(t_{\text{TPI}})$, Δt , and $\underline{r}_A(t_{\text{TPI}})$ by the Lambert Routine of Section 5.3.5. Using the new $\Delta \underline{V}$, the state vector of the active vehicle is again advanced to t_{TPI} to obtain $\underline{r}_A(t_{\text{TPI}})$ and $\underline{v}_A(t_{\text{TPI}})$.

⑫ Intercept Trajectory Computation

Once a $\Delta \underline{V}_{\text{TPI}}$ has been computed the technique explained in Section 5.3.8 is used to determine the pericenter altitude of the trajectory established by the TPI maneuver. The relative velocity at intercept, $\Delta \underline{V}_{\text{TPI}}$ is

$$\Delta \underline{V}_{\text{TPI}} = \underline{v}_P(t_{\text{TPI}}) - \underline{v}_A(t_{\text{TPI}}) \quad (5.3.11)$$

where $\underline{v}_A(t_{\text{TPI}})$ and $\underline{v}_P(t_{\text{TPI}})$ are both determined as previously described.

5.3.2.3 Nominal Outputs (Pre-TPI Mode)

- 1) Elevation angle or TPI time
- 2) Magnitude of
 - a) $\Delta \underline{V}_{\text{TPI}}$
 - b) $\Delta \underline{V}_{\text{TPI}}$
- 3) Pericenter altitude after the TPI maneuver.

In addition to the above outputs there are two ways in which the pre-TPI mode of the Rendezvous Guidance Program may exit. If there is no solution to the TPI time for the input elevation angle or if Δt is less than t_P a program alarm, described in Section 4, will result.

5.3.3 Rendezvous Mid-Course Maneuvers (MODE 2)

This program mode corresponds to program P35 or P75 of Section 4. Normally midcourse maneuvers, and consequently this program, should not be used if the time-to-go to intercept is less than 10 minutes.

5.3.3.1 Inputs

- 1) Choice of maneuvering vehicle

5.3.3.2 Program Operation

The computational sequence for this program is illustrated in Fig. 5.3-3. The objective of this mode is to maintain an intercept trajectory with midcourse correction maneuvers so that the active vehicle would intercept the passive target vehicle at the time and aimpoint position established in the previous TPI mode.

The midcourse mode of the Rendezvous Guidance Program may be called up by the astronaut at any time after the TPI maneuver. When the program is initiated the number of navigation measurements since the last maneuver and the time to intercept are displayed. Based on this information and additional displays discussed in Section 5.3.4, the astronaut may elect to proceed with a midcourse correction maneuver at any point. When he does so the program computes the midcourse correction which would take place 5 minutes from the current time. The time delay is the period required to prepare for a thrusting maneuver. To compute the midcourse correction, both vehicles are advanced to a point 5 minutes from the present time using the precision orbit integration routine. The correction required to intercept the passive vehicle is then computed using the techniques described in (11) of Section 5.3.2.2.

5.3.3.3 Nominal Outputs

- 1) Midcourse Maneuver ΔV_{MC}
- 2) ΔV_{TPF} if midcourse maneuver is executed

5.3.4 Additional Rendezvous Displays

5.3.4.1 Pre-Thrust

The nominal outputs in Section 5.3 are only those which are a direct function of the Rendezvous Guidance Program. Additional displays which are presented in the pre-thrust programs are discussed in Chapter 4.

MODE 2

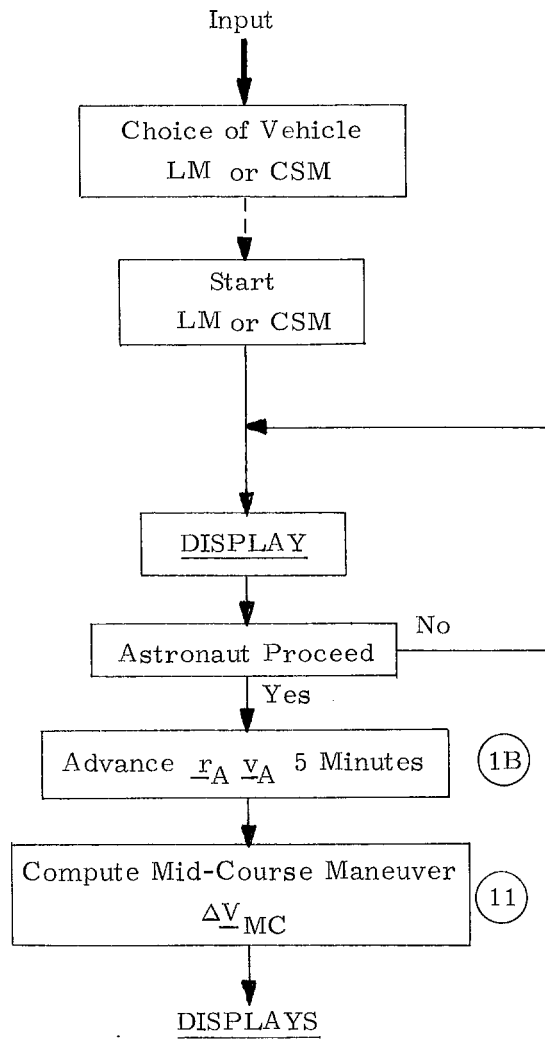


Fig. 5.3-3 Mid-course Correction Mode

5.3.4.2 Range, Range Rate, and θ

During any of the rendezvous phases of Mission 207/208A and upon astronaut request, three additional displays will be presented. The first two of these are the present values of the computed range and range rate between the two vehicles.

The third display, θ , is an angle measured from the positive vertical to the body X-axis and subtracted from $\pi/2$. (See Fig. 5.3-4)

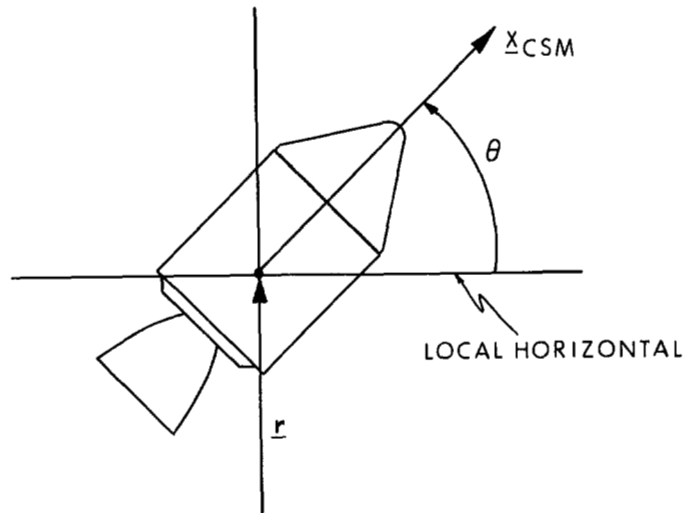


Fig. 5.3-4 Definition of θ

The angle, θ , computed is that which would be found by the vector dot product of a unit vector along \underline{r} and a unit vector along the body X-axis, and subtracting the angle found from $\pi/2$. Any ambiguity which therefore arises must be resolved by the astronaut.

5.3.5 Lambert Routine

Given a transfer trajectory time of flight between two position vectors the Lambert Routine computes the velocity required to travel from the first position to the second. The procedure shown in Fig. 5.3-5 is first used to properly define the plane of the transfer trajectory. Then the Lambert Routine is entered.

5.3.5.1 Required Input Parameters to the Lambert Routine

$\underline{r}_1(t)$ - Position vector of the active vehicle

$\underline{r}_2(t_A)$ - Position vector of the active vehicle at the final time t_A ,
where $t_A = t_F + t$.

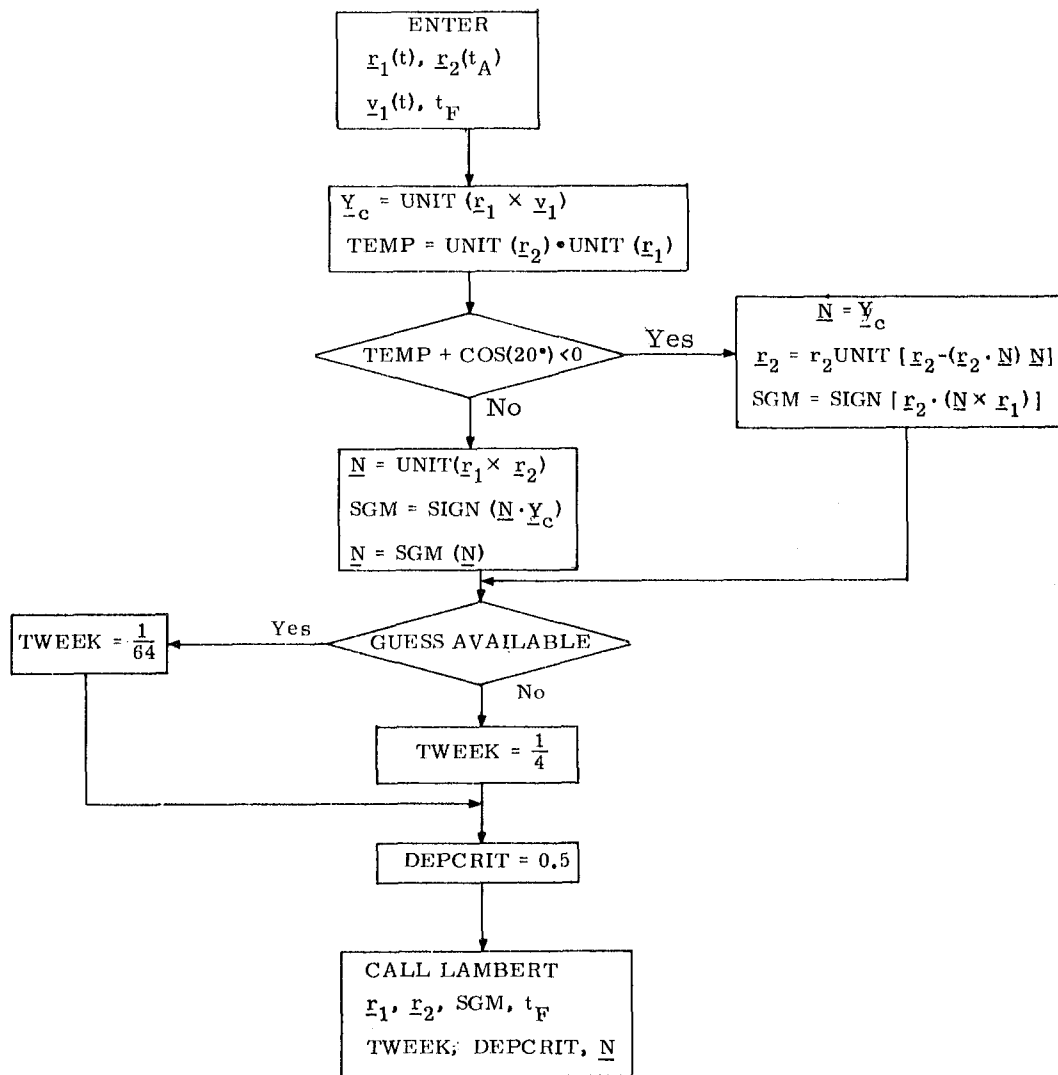


Fig. 5.3-5 Initialization for Lambert Routine

- \underline{U}_N - Unit vector normal to the desired transfer plane in the direction of the transfer angular momentum.
- t_F - desired time of flight from $\underline{r}_1(t)$ to $\underline{r}_2(t_A)$. ($t_F = \Delta t$ of Section 5.3.2.1)
- SGM - plus or minus depending on whether the transfer angle is less than or more than 180° respectively.

Some branches of the Lambert Routine shown in Figure 5.3-6 involve hyperbolic trajectory conditions which will not be encountered on Mission 207/208A and are therefore not discussed in detail.

5.3.5.2 Output Parameters

The result of the Lambert Routine is simply the total velocity vector required at the position $\underline{r}_1(t)$ to achieve the desired trajectory. The maneuver $\Delta \underline{V}$ is computed by subtracting the vehicle velocity vector at $\underline{r}_1(t)$ from this value.

5.3.6 Conic Subroutines

5.3.6.1 Time-True Anomaly Difference Routine (See Fig. 5.3-7)

Inputs

- \underline{r}_1 = the initial position vector
- \underline{v}_1 = the initial velocity vector
- COGTH = cotangent of TH/2 where TH is the true anomaly difference through which the state must be updated.
- μ = product of the universal gravitational constant and the mass of the attracting body.

NOTE: It is assumed that the paths leading to the dotted blocks in Fig. 5.3-7 will never be used for 207/208A. Therefore the logic and equations are not shown.

5.3.6.2 Orbital Parameter Routine

Using variables which are available from the Time-True Anomaly Difference Routine the apocenter and pericenter radii and altitudes are determined from the following

$$r_A = \frac{PR1}{1 + \sqrt{1 - PR1A}} \quad , \quad h_A = r_A - r_{PAD} \quad (5.3.12)$$

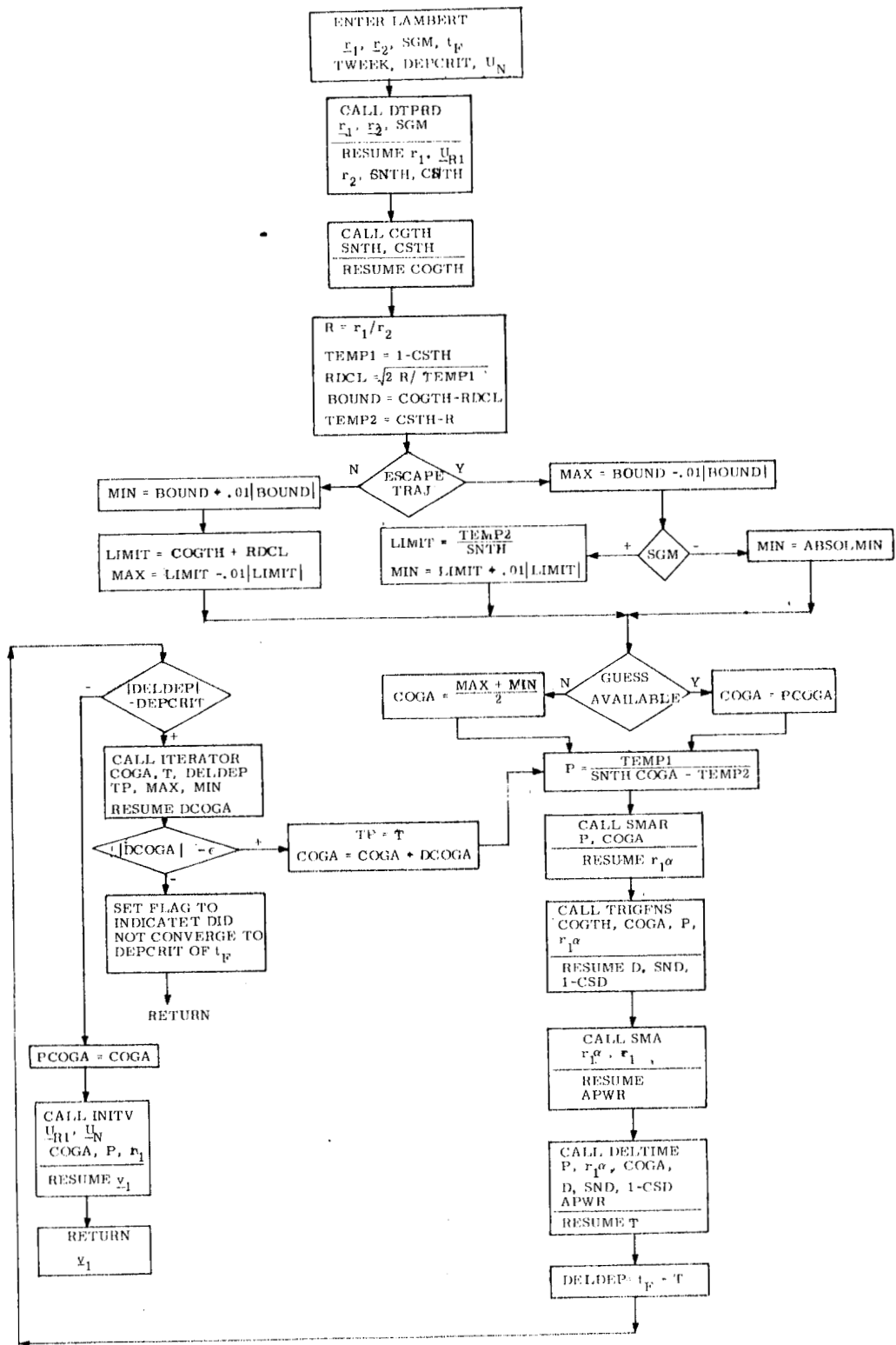


Fig. 5.3-6 Lambert Routine

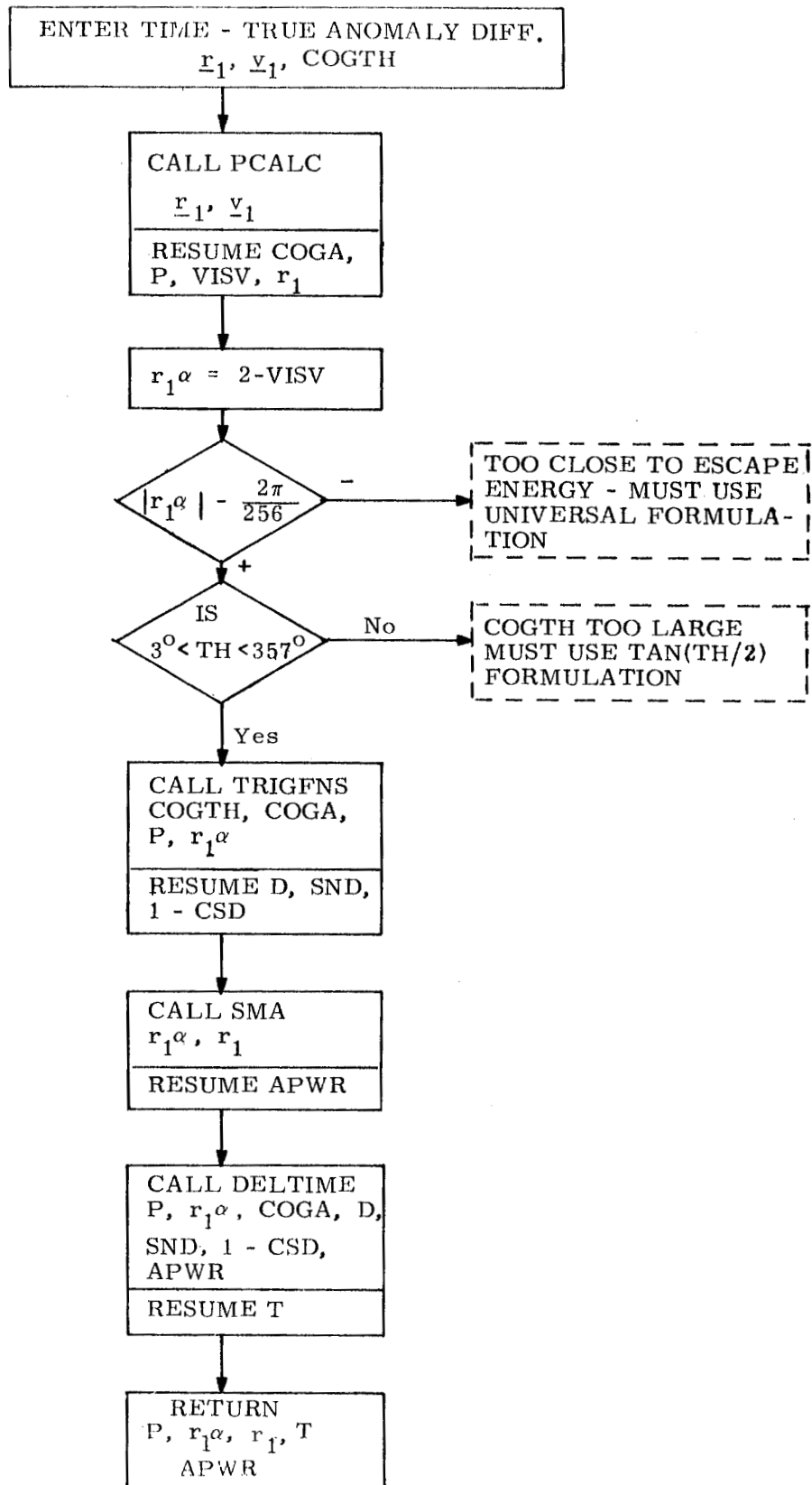


Fig. 5.3-7 Time-True Anomaly Difference Routine

$$r_P = \frac{PR1}{1 - \sqrt{1 - PR1A}} \quad , \quad h_P = r_P - r_{PAD} \quad (5.3.13)$$

Fig. 5.3-8 summarizes the subroutines required by the Lambert Routine of Section 5.3.5 and the Time-True Anomaly Difference of Section 5.3.6.1.

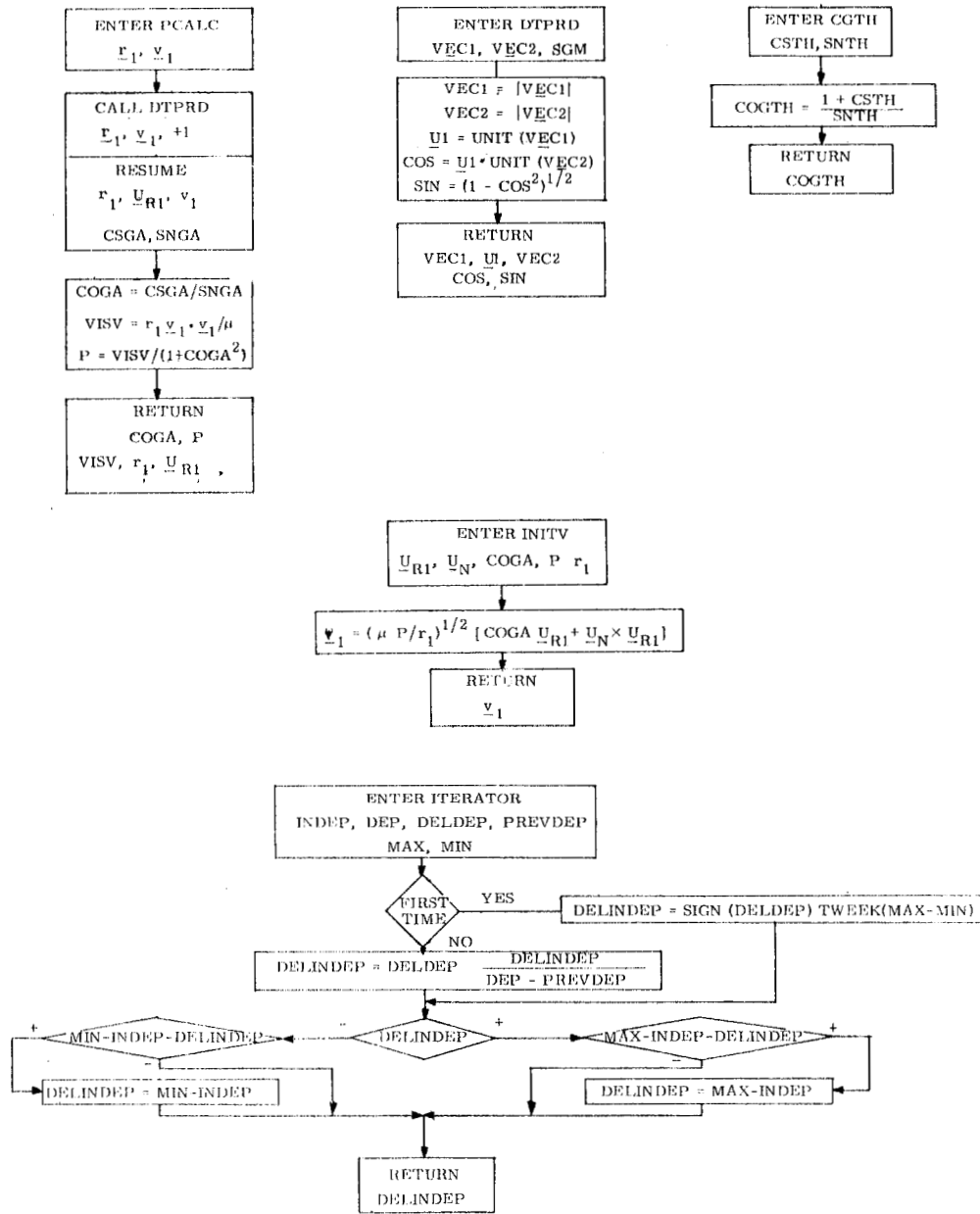


Fig. 5.3-8a Subroutines Called by Lambert and Time-True Anomaly Difference Routines

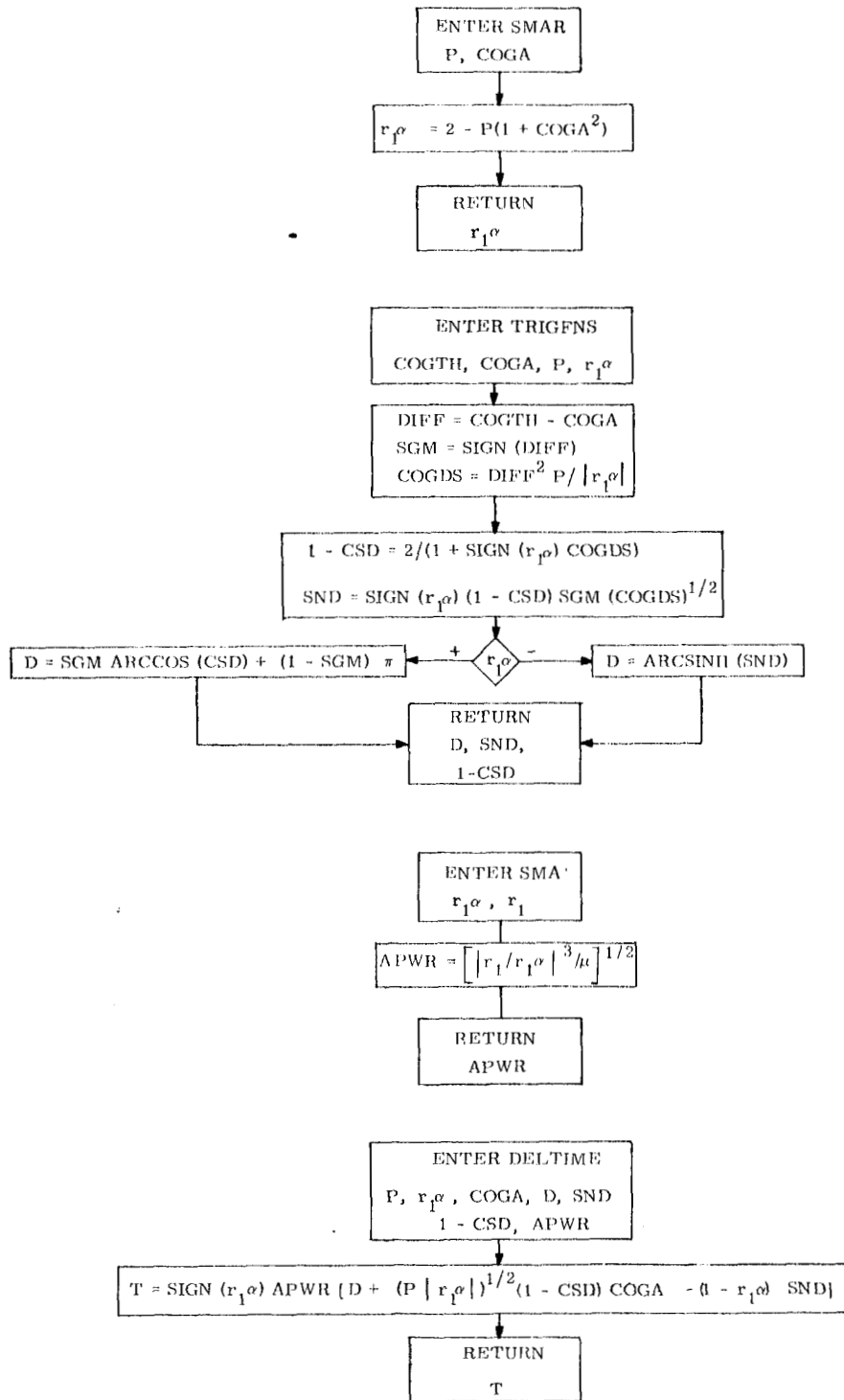


Fig. 5.3-8b Subroutines Called by Lambert and Time-True Anomaly Difference Routines

5.4 Powered Flight Navigation and Guidance

5.4.1 General Comments

The objective of the powered flight guidance routines is to keep track of the vehicle state vector during thrusting maneuvers, and to control or steer the thrust direction such that the desired velocity cut-off conditions are achieved. The powered flight navigation program used to maintain an estimate of the vehicle state vector during all thrusting conditions is referred to as the Average-G Routine and is presented in Section 5.4.2. The basic powered flight guidance concept used for the maneuvers in Mission 207/208A is a velocity-to-be-gained concept with cross-product steering, described in Section 5.4.3. All powered maneuvers controlled by the GNCS on Mission 207/208A are controlled by one of two major powered flight guidance programs which use the cross-product concept of Section 5.4.3. The first of these major powered flight programs is the Rendezvous Intercept Maneuver Routine (Section 5.4.4) which is targeted from a Lambert Routine and is used to control TPI and rendezvous midcourse correction maneuvers. The second major powered flight program is the External ΔV Maneuver Routine (Section 5.4.5) which is used for all other GNCS controlled maneuvers and receives the necessary input data (velocity-to-be-gained) from the Mission Ground Control Center or from the other vehicle.

The powered flight navigation and guidance equations presented in this report are the same as those planned for the lunar landing mission.

5.4.2 Powered Flight Navigation-Average G Routine

During a powered flight maneuver, the state vector estimate will be maintained by numerical integration of the equations of motion using the Average-G equations.

The information about the thrust acceleration comes from the Pulsed Integrating Pendulous Accelerometers (PIPA) in the form of velocity increments (ΔV) over an interval of time (Δt) corresponding to the time of repetitive computations (generally two seconds). The computations are therefore, in terms of discrete increments of velocity rather than instantaneous accelerations.

If \underline{r}_{n-1} and \underline{v}_{n-1} are the position and velocity estimates at the beginning of the nth computational cycle, then \underline{r}_n and \underline{v}_n are computed from

$$\underline{r}_n = \underline{r}_{n-1} + \Delta t \left(\underline{v}_{n-1} + \underline{g}_{n-1} \frac{\Delta t}{2} + \frac{\Delta \underline{v}}{2} \right) \quad (5.4.1)$$

$$\underline{v}_n = \underline{v}_{n-1} + \frac{\underline{g}_{n-1} + \underline{g}_n}{2} \Delta t + \Delta \underline{v} \quad (5.4.2)$$

where \underline{g}_n is the gravitational acceleration and is given by

$$\underline{g}_n = -\frac{\mu_e}{r_n^2} \left\{ \underline{u}_{r_n} + \frac{3}{2} J_2 \left(\frac{r_{eq}}{r_n} \right)^2 \left[(1 - 5 \cos^2 \phi) \underline{u}_{r_n} + 2 \cos \phi \underline{u}_z \right] \right\} \quad (5.4.3)$$

where

$$\cos \phi = \underline{u}_{r_n} \cdot \underline{u}_z \quad (5.4.4)$$

The vectors \underline{u}_{r_n} and \underline{u}_z are unit vectors in the direction of \underline{r}_n and the polar axis of the earth, respectively, μ_e is the gravitational constant of the earth, r_{eq} is the equatorial radius of the earth, and J_2 is the second-harmonic coefficient of the earth's potential function. ($J_2 = 1.0823067 \times 10^{-3}$)

5.4.3 Powered Flight Steering

The steering scheme during powered flight is based on the definition of a velocity-to-be-gained (\underline{v}_g) given by

$$\underline{v}_g = \underline{v}_r - \underline{v} \quad (5.4.5)$$

where \underline{v}_r is the required velocity associated with the current position and is dependent on the targets specified.

The rate of change of \underline{v}_g is given by

$$\begin{aligned} \dot{\underline{v}}_g &= \dot{\underline{v}}_r - \dot{\underline{v}} \\ &= \dot{\underline{v}}_r - \underline{g} - \underline{a}_T \\ &= \underline{b} - \underline{a}_T \end{aligned} \quad (5.4.6)$$

where

$$\underline{b} = \dot{\underline{v}}_r - \underline{g} \quad (5.4.7)$$

\underline{g} is the gravitational acceleration
and \underline{a}_T is the thrust acceleration

The desired thrust direction is defined by

$$\underline{a}_{TD} \times \underline{v}_g = c \underline{b} \times \underline{v}_g \quad (5.4.8)$$

where \underline{a}_{TD} is the desired thrust acceleration and c is a scalar.

If the actual thrust acceleration \underline{a}_T is along \underline{a}_{TD} , the equation

$$\underline{v}_g \times (c \underline{b} - \underline{a}_T) = 0 \quad (5.4.9)$$

will be satisfied. However, in general there is a directional error and the control system aligns the vehicle so that the equation is satisfied.

The command for the attitude control system is generated by

$$\underline{\omega}_c = K \frac{\underline{v}_g \times \underline{\Delta m}}{v_g \Delta m} \quad (5.4.10)$$

where

$\underline{\omega}_c$ = commanded attitude rate to CSM attitude control system (digital autopilot)

$$\underline{\Delta m} = c\underline{b} \Delta t - \Delta \underline{v} \quad (5.4.11)$$

$\Delta \underline{v}$ is the accumulated velocity and

Δt is the computing interval.

The basic powered flight steering represented by the above equations is illustrated in Fig. 5.4-1. The scalar K of this figure is a guidance command gain-setting required for desired dynamic response performance of the combined powered guidance and thrust vector control (autopilot) loops. The initial value of $\Delta \underline{v}_r \approx \dot{\underline{v}}_r \Delta t$ is obtained by precomputing \underline{v}_r which corresponds to the ignition time, then allowing the vehicle to free fall Δt seconds (one computation cycle) and recomputing \underline{v}_r (Section 5.4.6). The difference between these two values of \underline{v}_r is then used as the initial $\dot{\underline{v}}_r \Delta t$.

The commanded-rate signal is computed every two seconds during the powered flight based on an updated \underline{v}_g . The computation of \underline{v}_g depends upon the particular maneuver and is described in the following sections.

The engine (SPS or RCS) is turned on at a specified or computed ignition time. During the powered maneuver steering phase, a time to cut-off, or time-to-go (t_{go}), is computed from the equation:

$$t_{go} = K_1 \left[\frac{\underline{v}_g \cdot \underline{v}_g}{|\underline{v}_g \cdot \underline{\Delta m}|} \right] \Delta t + \Delta t_{tail-off} \quad (5.4.12)$$

where

$$K_1 = 1 - \frac{1}{2} v_g / (32.17405 I_{sp})$$

I_{sp} = specified specific impulse of the selected engine

$\Delta t_{tail-off}$ = the duration of a burn at full or maximum thrust equivalent to the tail-off impulse after the engine-off signal is issued.

It should be noted that $\Delta t_{tail-off}$ is a negative number in erasable storage. When t_{go} falls, for the first time, below a value of 4.0 seconds, the engine-off signal is set to be issued t_{go} seconds later, and the attitude control system command, $\underline{\omega}_c$ is set equal to zero.

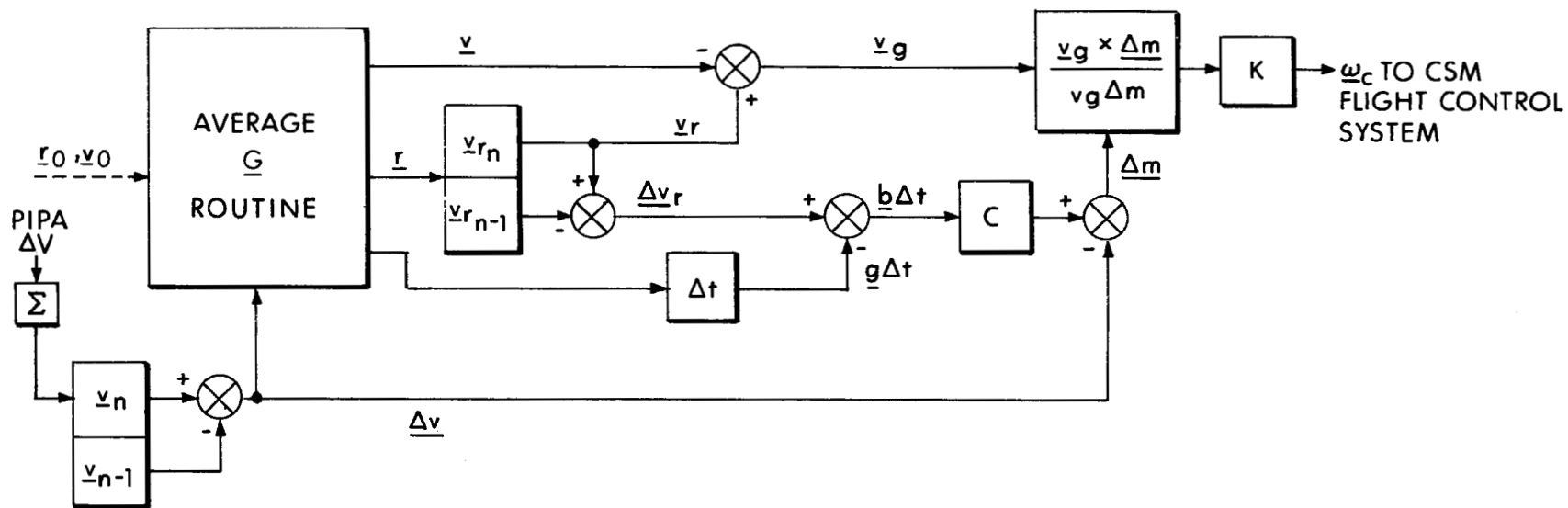


Fig. 5.4-1 CMC Powered Flight Steering Block Diagram

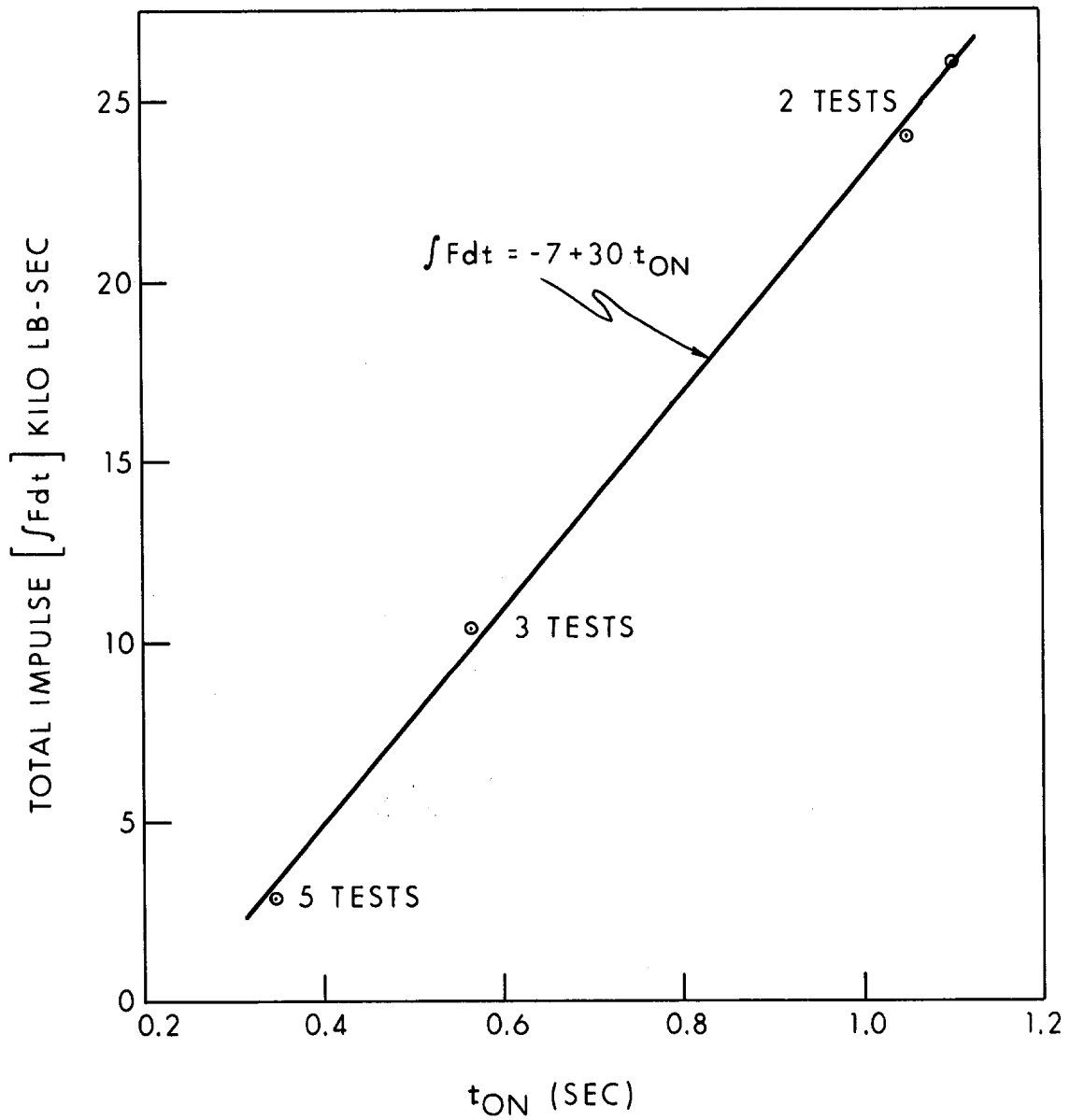


Fig. 5.4-2 SPS Minimum Impulse Test Data (NAA. 4-5-66)

Legend

v_g = velocity to be gained (fps)

wt = vehicle weight in pounds

F = SPS Thrust (lbs)

t_{on} = SPS on time (sec)

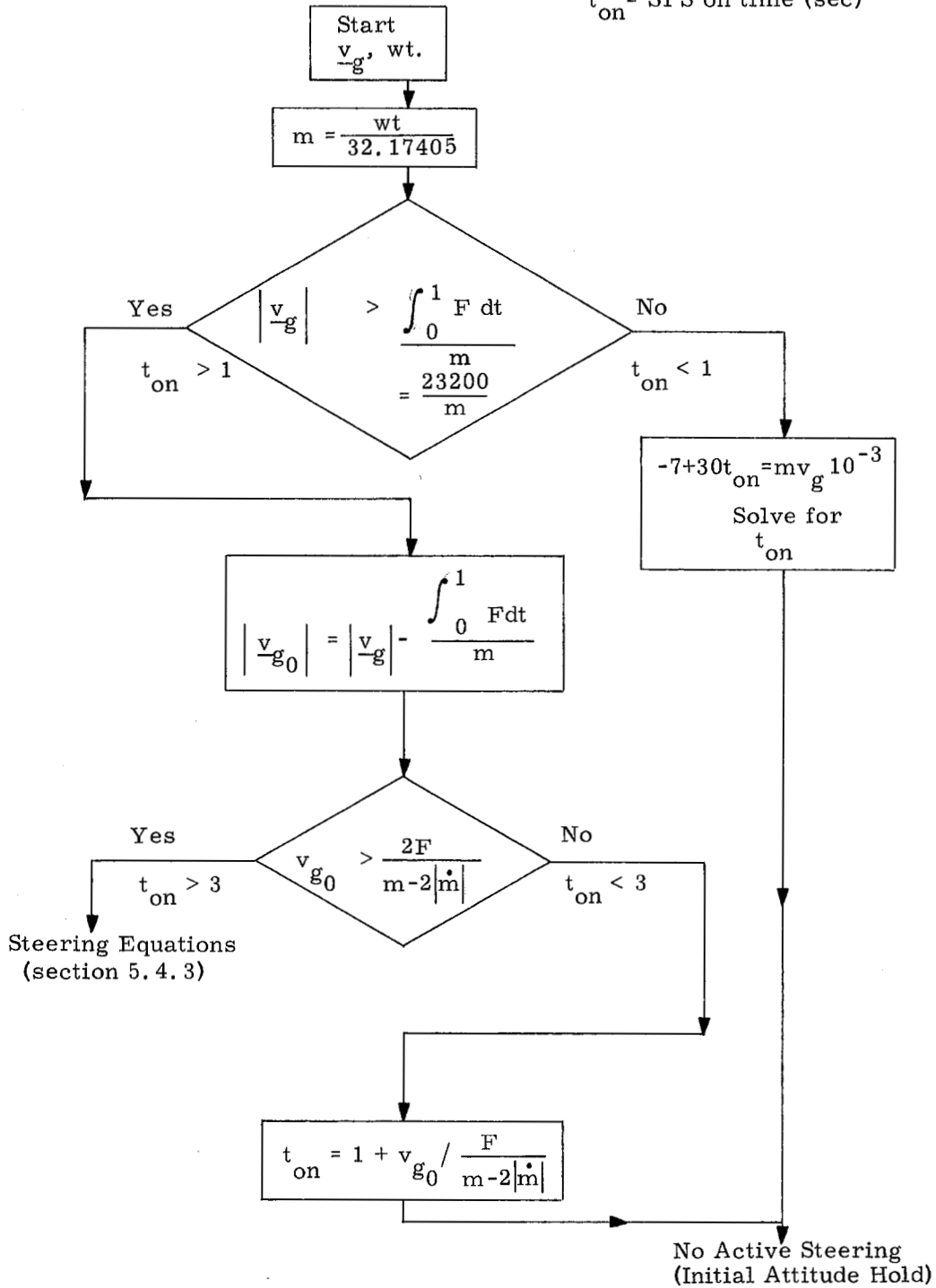


Fig. 5.4-3 Short SPS Maneuver Steering Logic

5.4.3.1 Very Short SPS Thrust Maneuvers

The steering computations are normally done every two seconds. A small interval of time, therefore, elapses before effective steering is achieved. If the required SPS burn is in the order of a second or less, not only is there no time to steer, but it may also be required to set the engine-off signal before the Δv from PIPA's could be measured. Therefore, at the start of the steering computations, an estimate of the interval (t_{on}) between the engine-on and engine-off signals is made. This estimate is based on the engine test data of the integral of thrust vs t_{on} as shown in Fig. 5.4-2.

If t_{on} is less than three seconds, the engine is set to stay on only t_{on} seconds and the vehicle is held at the pre-aligned position. This computation is shown in Fig. 5.4-3.

5.3.4.2 RCS Translation Maneuver Engine-off Criterion

The engine-off criterion for CSM RCS maneuvers is illustrated in Fig. 5.4-4 for both normal and very short thrust maneuvers.

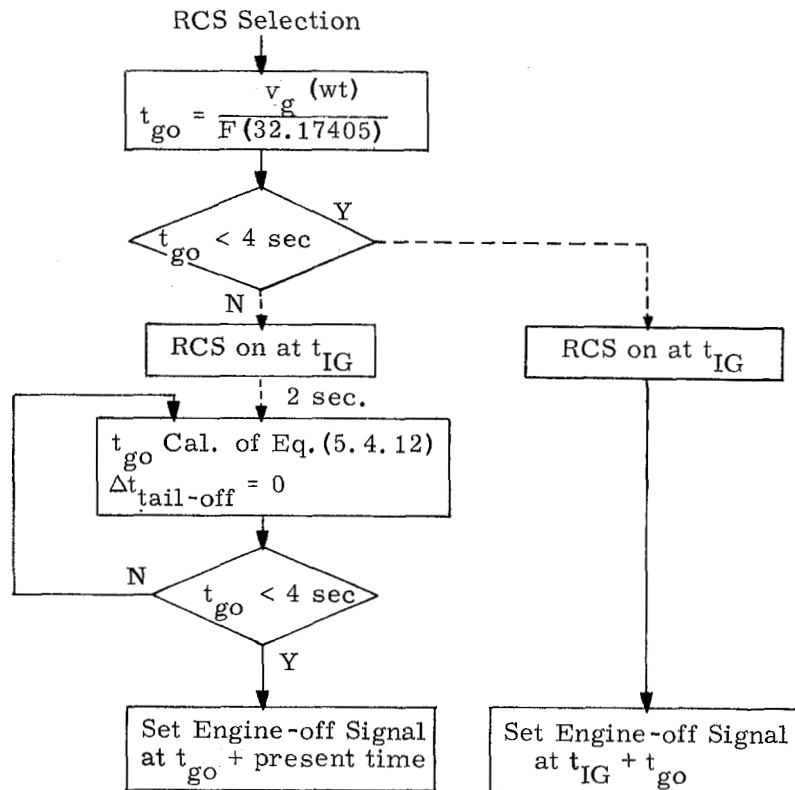


Fig. 5.4-4 CSM RCS Engine-off Criterion

For the case in which the RCS is selected for a maneuver, the maneuver time, t_{go} , is estimated prior to the ignition time, t_{IG} , by the first expression shown in Fig. 5.4-4, where F is the prestored nominal RCS thrust of 100 pounds per jet, and $wt.$ is a DSKY entry of the vehicle weight. If this estimated maneuver time is less than 4 seconds, the RCS engine-off signal is set to be issued at $t_{IG} + t_{go}$ as shown, and the normal t_{go} expression of Eq. (5.4.12) is never used. If the pre-ignition estimate of t_{go} is greater than 4 seconds the normal engine-off criterion is used. With reference to Fig. 5.4-4 the t_{go} computation of Eq. (5.4.12) is first made two seconds after t_{IG} . After two computation cycles (4 seconds after t_{IG}) this calculation is an accurate estimate of the time-to-go in the maneuver. When t_{go} falls below 4 seconds for the first time, the engine-off signal is set to be issued at t_{go} plus the present time as shown.

5.4.4 Rendezvous Intercept Maneuver Guidance

As stated in Section 5.4.1, this powered flight guidance routine is used to control the TPI and rendezvous midcourse correction maneuvers on Mission 207/208A. The basic steering concept is that presented in the previous Section 5.4.3 with the input velocity-to-be-gained being determined by the Lambert Routine of Section 5.3.5. This rendezvous guidance controls the TPI and midcourse correction maneuvers such that the resulting trajectory will intercept the target vehicle orbit at the designated time. It is from this trajectory that the manual terminal rendezvous maneuver is made.

The Rendezvous Intercept Maneuver Routine is used in Programs P-40 of Section 4 when the SPS is chosen for the maneuver, or P-41 when the CSM RCS is chosen. The required initial inputs and targeting for this routine are determined in programs P-34 (pre-TPI program of Section 5.3.3) and P-35 (midcourse correction program of Section 5.3.4).

Input Parameters

1. Ignition Time (t_{IG})
2. Time of flight to intercept (t_F)
3. Target aim point $\underline{r}_2(t_A)$,
 where $t_A = t_F + t_{IG}$ and $\underline{r}_2(t_A)$ is defined in Section 5.3.3.1 (5.4.13)
4. Engine Choice - SPS or RCS

Outputs

1. ω_c = corrective angular rate command to the CSM Flight Control system (see Section 5.4.3)
2. Engine-off Signal Eq. (5.4.12)

Guidance Computations

The rendezvous intercept maneuver guidance computation sequence is illustrated in Fig. 5.4-5. The velocity required to intercept the target aim point r_2 at t_A is determined by the Lambert Routine, and then the associated velocity to be gained \underline{v}_g is derived as shown in Fig. 5.4-5. The velocity-to-be-gained is then used in the cross product steering concept of Section 5.4.3 to determine the required angular rate command to the flight control system, and the time for engine cut-off. As indicated in Fig. 5.4-5 the Lambert Routine is cycled in the computation sequence at half the rate the steering computations. The value of the scalar c in Eq. (5.4.11) of Section 5.4.3 is unity in this guidance routine if the SPS was selected, and $c = 0$ if the RCS was chosen.

5.4.5 External ΔV Maneuver Guidance

The External ΔV Maneuver Guidance is used to control all Mission 207/208A powered maneuvers with the exception of the TPI and midcourse correction maneuvers of the previous section. The External ΔV Guidance is based on the steering concept of Section 5.4.3 with input data supplied by DSKY entries or telemetry uplink. In Mission 207/208A, this powered flight program is used to control all orbital change maneuvers, the CSI and CDH maneuvers of the concentric flight plan rendezvous, and the final deorbit to entry maneuver. The External ΔV Maneuver Program is incorporated in programs P-40 and P-41 of Section 4 depending upon the engine choice of SPS or RCS respectively.

This program is common to both CMC and LGC with the exception of a different output command to the respective vehicle flight control systems. This program is the same as that planned for the lunar landing mission during which it is primarily used to execute the CSM translunar and transearth midcourse correction maneuvers determined by the MSFN in the nominal mission.

The External ΔV Maneuver Guidance Program is designed to add a specified velocity increment along an inertial direction which is partially compensated for the estimated maneuver time.

Input Parameters (DSKY or Uplink)

1. Time of ignition (t_{IG})
2. Specified delta-V ($\Delta \underline{V}_S$) in the local vertical coordinate system of the active vehicle at the time of ignition
3. Anticipated magnitude of the vehicle weight, wt, in pounds.
4. Engine choice; SPS or RCS.

Outputs

1. $\underline{\omega}_c$ = corrective angular rate command to the CSM flight control
2. Engine-off signal

Computations

The local vertical coordinate system is defined by:

$$\begin{aligned}\underline{X} &= \text{UNIT} [\{ \underline{r}(t_{IG}) \times \underline{v}(t_{IG}) \} \times \underline{r}(t_{IG})] = (1, 0, 0) \\ \underline{Y} &= \text{UNIT} [\underline{v}(t_{IG}) \times \underline{r}(t_{IG})] = (0, 1, 0) \\ \underline{Z} &= -\text{UNIT} [\underline{r}(t_{IG})] = (0, 0, 1)\end{aligned}\quad (5.4.14)$$

where $\underline{r}(t_{IG})$ and $\underline{v}(t_{IG})$ are the position and velocity vectors at the time of ignition respectively.

The input column vector $\Delta \underline{V}_S$ is first pre-multiplied by the matrix, the columns of which are \underline{X} , \underline{Y} , and \underline{Z} to yield $\Delta \underline{V}_S$ in the inertial coordinate system.

The input $\Delta \underline{V}_S$ is the required impulsive velocity correction. In order to compensate for the change in position during the maneuver, the input $\Delta \underline{V}_S$ is biased by half the estimated central angle of travel during maneuver. The inplane velocity components of $\Delta \underline{V}_S$ are given by:

$$\Delta \underline{V}_p = \Delta \underline{V}_S - \left(\Delta \underline{V}_S \cdot \underline{U}_p \right) \underline{U}_p \quad (5.4.15)$$

where

$$\underline{U}_p = \text{UNIT} [\underline{v}(t_{IG}) \times \underline{r}(t_{IG})]$$

The approximate central angle θ_T traveled during the maneuver is given by:

$$\theta_T \cong \frac{|\underline{r} \times \underline{v}|}{r^2} \frac{\Delta V_S}{a'_T} \quad (5.4.16)$$

Where a'_T is the estimated constant maneuver acceleration determined from

$$a'_T = \frac{F(32.17405)}{wt} \quad (5.4.17)$$

with F equal to a prestored nominal thrust in pounds based on the astronaut engine selection, and wt is the vehicle weight in pounds which is entered as a DSKY input parameter. The values of F are

$$\begin{aligned}F &= 21400 \text{ pounds} && \text{for the SPS} \\ F &= 100 \text{ pounds/jet} && \text{for the RCS}\end{aligned}\quad (5.4.18)$$

The corrected inplane velocity-to-be-gained is defined as:

$$\Delta \underline{V}_c = \Delta \underline{V}_p \left\{ \text{UNIT} (\Delta \underline{V}_p) \cos \frac{\theta_T}{2} + \text{UNIT} (\Delta \underline{V}_p \times \underline{U}_p) \sin \left(\frac{\theta_T}{2} \right) \right\} \quad (5.4.19)$$

and is illustrated in Fig. 5.4-6. The corrected velocity vector-to-be-gained during the powered flight is then given by:

$$\underline{\Delta V}_T = \underline{\Delta V}_c + (\underline{\Delta V}_S \cdot \underline{U}_p) \underline{U}_p \quad (5.4.20)$$

The general computational sequence for the External ΔV Maneuver Guidance is illustrated in Fig. 5.4-7. The input \underline{v}_g to the steering equations of Section 5.4.3 is initially set equal to $\underline{\Delta V}_T$ of Eq. (5.4.20). During the powered maneuver, \underline{v}_g is updated as shown in Fig. 5.4-7, by the accumulated $\underline{\Delta v}$ measured by the accelerometer. During this program the scalar c of Eq. (5.4.11) is zero.

5.4.6 Initial Thrust Alignment

Before the selected engine is ignited for any particular powered maneuver, the vehicle should be oriented so that on ignition the thrust is in the desired direction at that point. Since the time of ignition is known beforehand, the position and velocity at ignition can be computed prior to the arrival of the vehicle at that point. By integrating over Δt seconds from that point, the vectors \underline{v}_g and $\underline{b}\Delta T$ can be computed as shown in Fig. 5.4-1.

The desired thrust direction can be now calculated (prior to arrival at the ignition point) as

$$\underline{U}_T = \text{UNIT} \left[\underline{q} + (a'_T{}^2 - q^2)^{1/2} \underline{U}_g \right] \quad (5.4.21)$$

where

$$\underline{U}_g = \text{UNIT} (\underline{v}_g) \quad (5.4.22)$$

and

$$\underline{q} = c\underline{b} - (\underline{U}_g \cdot c\underline{b}) \underline{U}_g \quad (5.4.23)$$

and a'_T is an estimate of the magnitude of the thrust acceleration Eq.(5.4.17).

Once \underline{U}_T is computed from Eq. (5.4.21), the vehicle is oriented prior to arrival at the ignition point such that the thrust axis is along \underline{U}_T .

The value of the constant c in Eqs. (5.4.8) through (5.4.11) and Eq. (5.4.23) is equal to zero for all cases of the two programs of Section 5.4.4 and 5.4.5 with exception of the Rendezvous Intercept Maneuver Guidance program when used with the SPS, in which case $c = 1$.

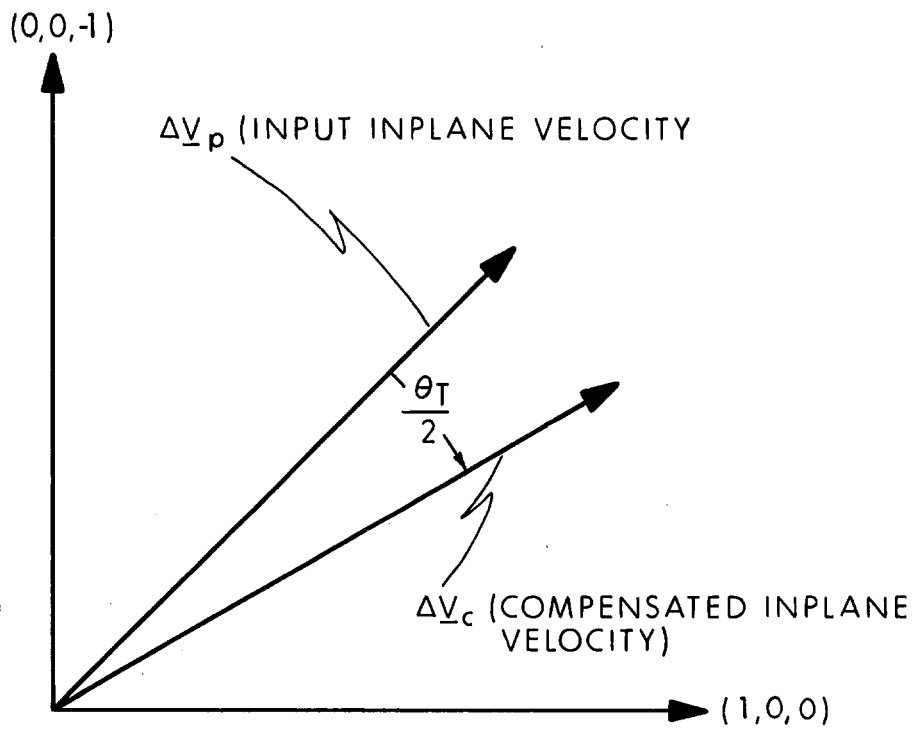


Fig. 5.4-6 Inplane External ΔV Maneuver Time Compensation

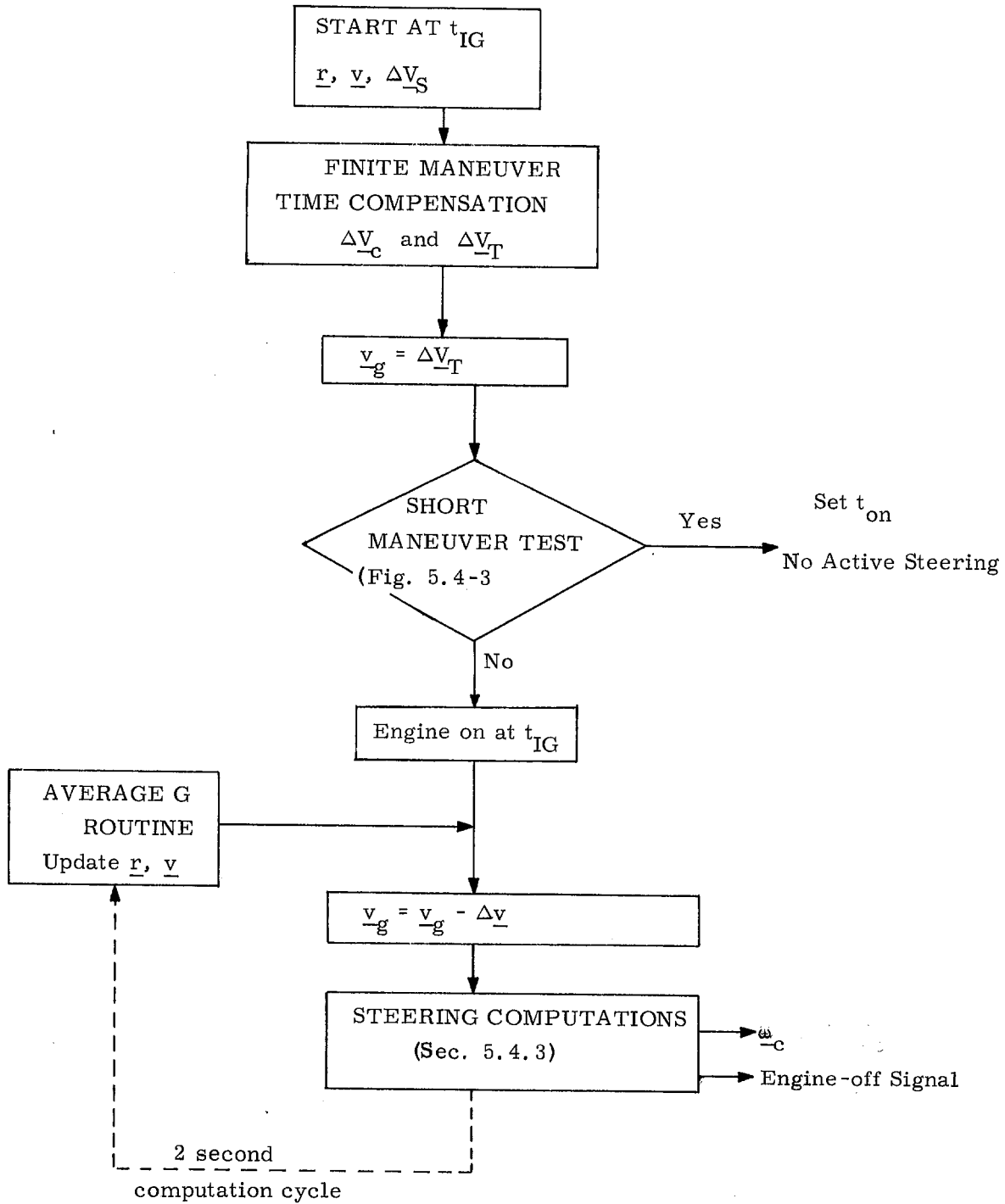


Fig. 5.4-7 External ΔV Maneuver Guidance

5.5 General Service Programs

5.5.1 General Comments

The programs presented in this section are used for computer initialization procedures, basic transformations, alignment subroutines, or are special information programs requiring CMC computations which can be called by the astronaut. The astronaut service computations can be exercised by the astronaut through the keyboard.

The routines described in the following sections are the same as those planned for the lunar landing mission except for scaling, etc., unless otherwise specifically noted.

5.5.2 Transformation Routines

The following transformation routines are used during IMU alignment programs and the Rendezvous Navigation and Orbital Navigation Routines of Sections 5.2.5 and 5.2.7 respectively.

5.5.2.1 IMU Transformations

Let AIG, AMG, AOG be, respectively, the IMU inner, middle and outer gimbal angles. Define the following matrices:

$$Q_1 = \begin{pmatrix} \cos AIG & 0 & -\sin AIG \\ 0 & 1 & 0 \\ \sin AIG & 0 & \cos AIG \end{pmatrix} \quad (5.5.1)$$

$$Q_2 = \begin{pmatrix} \cos AMG & \sin AMG & 0 \\ -\sin AMG & \cos AMG & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (5.5.2)$$

$$Q_3 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos AOG & \sin AOG \\ 0 & -\sin AOG & \cos AOG \end{pmatrix} \quad (5.5.3)$$

Stable Member to Navigation Base Transformation

$$U_{NB} = Q_3 Q_2 Q_1 U_{SM}, \quad [SMNB] = Q_3 Q_2 Q_1 \quad (5.5.4)$$

Navigation Base to Stable Member Transformation

$$\underline{u}_{SM} = Q_1^T Q_2^T Q_3^T \underline{u}_{NB}, \quad [NBSM] = Q_1^T Q_2^T Q_3^T \quad (5.5.5)$$

5.5.2.2. Sextant to Navigation Base Transformation

$$\underline{u}_{NB} = \begin{pmatrix} \sin PA & \cos SA \\ \sin PA & \sin SA \\ \cos PA \end{pmatrix} \quad (5.5.6)$$

where PA, SA are the sextant precision (trunnion) angle and shaft angle respectively, and \underline{u}_{NB} is the line of sight unit vector in navigation base coordinates.

5.5.2.3. REFSMMAT

The matrix required to transform a vector from the Basic Reference Coordinate system to the coordinate system established by the IMU Stable Member is called REFSMMAT. Each time the IMU is realigned REFSMMAT will change accordingly. For the 207/208 A mission there are nominally 4 types of IMU alignments. Each type of alignment and the method for computing REFSMMAT is discussed below.

1. Pre-launch Alignment

Prior to launch the IMU Stable Member is aligned to a local vertical axis system.

$$\underline{u}_z = \text{UNIT}(\underline{r}) \text{ (local vertical)}$$

$$\underline{u}_x = \text{UNIT}(\underline{A}) \text{ where } \underline{A} \text{ is a horizontal vector pointed at the desired launch azimuth angle.} \quad (5.5.7)$$

$$\underline{u}_y = \underline{u}_z \times \underline{u}_x$$

The REFSMMAT associated with this alignment is simply

$$\text{REFSMMAT} = \begin{bmatrix} -\underline{u}_x^T & - \\ -\underline{u}_y^T & - \\ -\underline{u}_z^T & - \end{bmatrix} \quad (5.5.8)$$

2. Star Alignment

When two star sightings are made on board a new REFSMMAT may be computed in the following manner. Let the two unit star vectors expressed in the Stable Member coordinate system be \underline{US}_1 and \underline{US}_2 and let the same unit star vectors expressed in the Basic Reference Coordinate system be \underline{UR}_1 and \underline{UR}_2 . Define the following two systems of orthogonal coordinates.

$$\begin{aligned}\underline{u}_x' &= \underline{US}_1 \\ \underline{u}_y' &= \text{UNIT}(\underline{US}_1 \times \underline{US}_2) \\ \underline{u}_z' &= \underline{u}_x' \times \underline{u}_y'\end{aligned}\tag{5.5.9}$$

$$\begin{aligned}\underline{u}_x &= \underline{UR}_1 \\ \underline{u}_y &= \text{UNIT}(\underline{UR}_1 \times \underline{UR}_2) \\ \underline{u}_z &= \underline{u}_x \times \underline{u}_y\end{aligned}\tag{5.5.10}$$

where the unprimed system is expressed in the Basic Reference Coordinate system and the primed system is expressed in the IMU Stable Member coordinates. For this case REFSMMAT is given by the following matrix.

$$\text{REFSMMAT} = \begin{bmatrix} \underline{u}_x \cdot \underline{u}_x' & \underline{u}_x \cdot \underline{u}_y' & \underline{u}_x \cdot \underline{u}_z' \\ \underline{u}_y \cdot \underline{u}_x' & \underline{u}_y \cdot \underline{u}_y' & \underline{u}_y \cdot \underline{u}_z' \\ \underline{u}_z \cdot \underline{u}_x' & \underline{u}_z \cdot \underline{u}_y' & \underline{u}_z \cdot \underline{u}_z' \end{bmatrix}\tag{5.5.11}$$

3. Alignment for Thrusting Maneuvers

During certain thrusting maneuvers the IMU will be aligned according to the following equations

$$\begin{aligned}\underline{u}_x &= \text{UNIT}(\underline{X}_{\text{CSM}}) \\ \underline{u}_y &= \text{UNIT}(\underline{X}_{\text{CSM}} \times \underline{r}) \\ \underline{u}_z &= \underline{u}_x \times \underline{u}_y\end{aligned}\tag{5.5.12}$$

The associated transformation matrix is given by

$$\text{REFSMMAT} = \begin{bmatrix} -\underline{u}_x^T & - \\ -\underline{u}_y^T & - \\ -\underline{u}_z^T & - \end{bmatrix}\tag{5.5.13}$$

4. Alignment to Local Vertical

The IMU Stable Member may also be aligned to the local vertical at a specified time. The Stable Member axes are given by:

$$\begin{aligned}\underline{u}_y &= \text{UNIT} (\underline{v} \times \underline{r}) \\ \underline{u}_z &= \text{UNIT} (-\underline{r}) \\ \underline{u}_x &= \underline{u}_y \times \underline{u}_z\end{aligned}\tag{5. 5. 14}$$

The associated REFSMMAT is again found from Eq.(5. 5. 13).

5. 5. 3 Star Selection Routine

The purpose of the Star Selection Routine is to select the best pair of stars for fine alignment of the IMU with little or no CSM attitude change being required to permit both stars to be seen with the optics. All possible pairs of a total of 37 stars are checked by this routine. The manner in which the selection is made is shown in the logic flow diagram of Fig. 5. 5-1.

When a pair of stars is selected for testing, a check is made to see if either star is occulted by the Earth, Moon, or Sun. The routine then checks to see if the stars are separated by 40 to 66 degrees. Although the ideal separation is 90 degrees, an upper limit of 66 degrees is used to insure that both stars may be seen with the optics without requiring an attitude maneuver. Afterwards, a check is made to see if both stars can be seen in the present optics cone of view. Although the visual cone of the optics is larger than 66 degrees, this value is adopted to insure that both stars can be seen anytime during the 5 degree limit cycle attitude operation. The reduction in cone size also accounts for uncertainties in IMU stable member orientation (including CSM attitude) associated with coarse alignment of the IMU.

If a pair of stars is within the optics cone of view, their separation angle is compared with that of any previously stored pair and the pair with the largest angle is stored. If a pair of stars is not within the optics cone of view, the status of the flag is checked to see if any previous pair were found in the cone of view, and if not, the minimum pitch and yaw attitude maneuver is determined to enable the optics to acquire this pair. This attitude maneuver is then compared with that of any previously stored pair and the pair requiring the smallest pitch and yaw maneuver is stored. It should be noted that any pair found in the optics cone of view without an attitude maneuver being required will always supercede any pair requiring a maneuver.

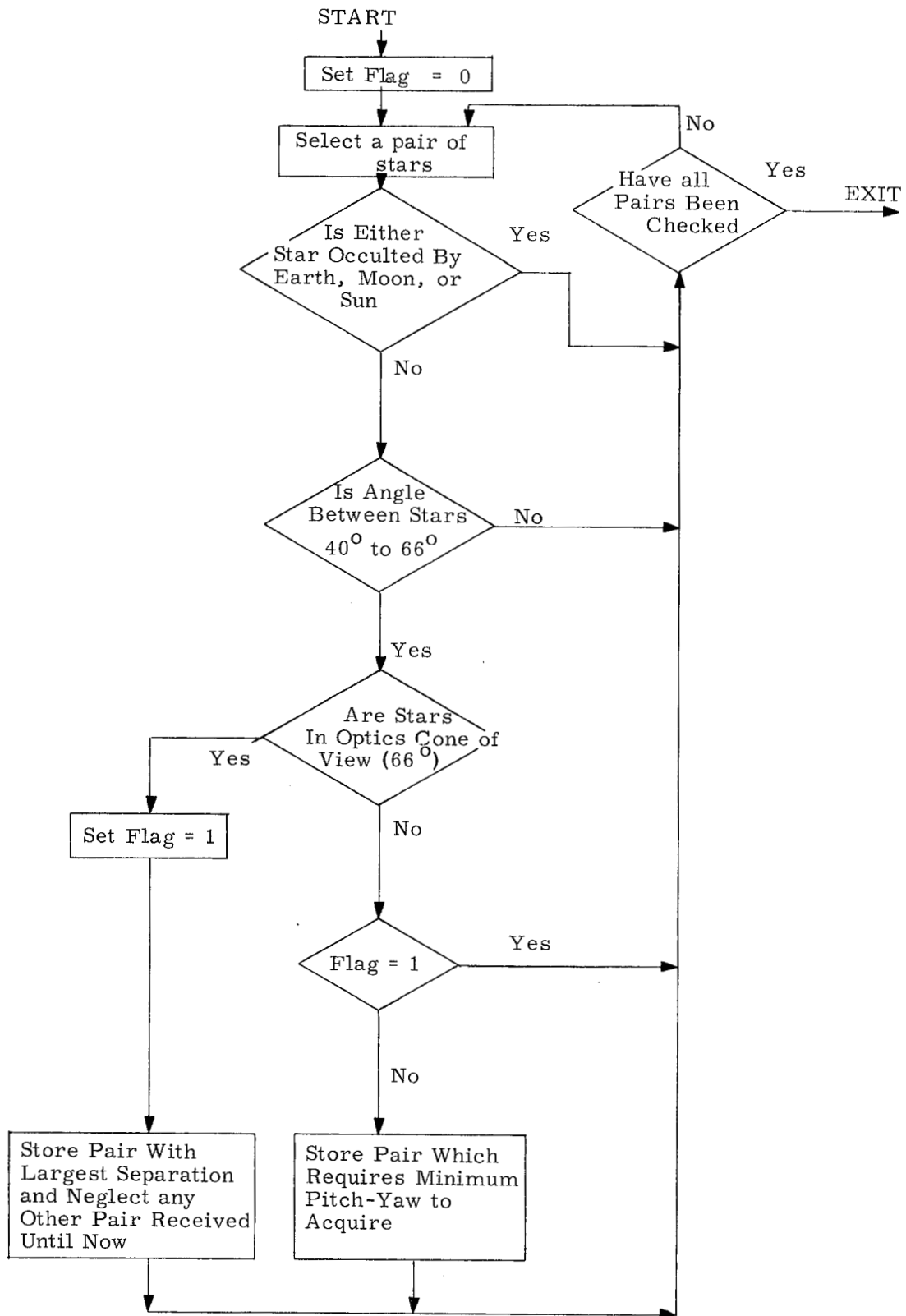


Fig. 5.5-1 Star Selection Routine Logic Diagram

5. 5. 4 Ground Track Routine

The astronaut specifies a future time (GET). The output is the estimated location of the point at which the CSM will be at the specified time.

The estimated CSM state vector is extrapolated to the specified time by means of the Orbital Integration Routine. The resulting inertial position is converted to geodetic latitude, longitude, and altitude by means of the Latitude-Longitude Routine and these data are displayed. This routine is a mode of program P-21 of Section 4.

5. 5. 5 LGC Initialization Program

This program is a combined procedure between the CSM and LM used to manually initialize the LGC prior to LM separation. After the LGC is activated the first requirement is to synchronize the LGC clock with that of the CMC. This is a count-down and mark procedure in which the Enter button is depressed on both DSKY's at the same time and each computer displays the time of the Enter. By subtracting these two times the clock difference is obtained which is used to increment the LGC clock. This procedure should be repeated to obtain an average clock difference. The CMC and LGC clock synchronization can also be checked by the Mission Ground Control Center using down-link data, which can provide a more precise difference to be used by the LM astronaut to increment the LGC clock.

In the lunar landing mission the following parameters are next voice-linked from the CSM and entered in the LGC as initialization parameters:

<u>Parameter</u>	<u>Words</u>
1) $\underline{R}_{\text{CSM}}$: CSM position vector	3
2) $\underline{V}_{\text{CSM}}$: CSM velocity vector	3
3) t_{CSM} : CSM state vector time	3
4) $\underline{R}_{\text{LS}}$: lunar landing site vector	3
5) t_{LS} : time $\underline{R}_{\text{LS}}$ was valid	3
6) t_{EPHEM} : Time difference between zero GET and 1 July of the reference Besselian year	<u>3</u>
Total:	18

In the above procedure, all words are entered in octal and require 10 digits (double precision).

In Mission 207/208A the LGC initialization program must be modified so that only the CSM state vector and t_{EPHEM} will be used (items 1, 2, 3, and 6 above) and all other parameters deleted. This program is referred to as P-26 in Section 4.

5.6 Entry Guidance

The entry guidance program is described by the logic flow charts in Fig. 5.6-1 thru Fig. 5.6-16 for control of the CM entry vehicle. A detailed description of this guidance and steering concept is presented in MIT/IL Report R-532, "Reentry Guidance for Apollo," R. Morth, January 1966.

Figure 5.6-1 illustrates the overall picture of operations during entry. Each block in Fig. 5.6-1 is described in detail in following figures. Fig. 5.6-2 defines the symbols which represent computed variables stored in erasable memory. The value and definition of constants is given in Fig. 5.6-3.

The initialization routine shown in Figure 5.6-4 is entered only once at the start of entry. Besides setting the appropriate variables to their initial values, this routine presets the variable SELECTOR to INITROLL. For all possible Mission 207/208A situations SELECTOR will later be set to KEP2 by the logic in INITROLL. KEP2 then performs the same functions as the initial roll phase in higher-speed entries and the only significant steering takes place in final phase. An initial attitude of lift-up is selected by setting L/DINIT TO LAD. This initial attitude can be changed by the astronaut.

Every pass through the entry equations (done once every 2 seconds) is begun with the section called navigation (see Fig. 5.6-5) and is the same as that presented in Section 5.4.2. This integrates to determine the vehicle's new position and velocity vector. This navigation routine is started prior to the deorbit maneuver in Mission 207/208A and is continuously operated from that time to landing.

Next, the targeting section updates the desired landing site position vector and computes some quantities based on the vehicle's position and velocity and the position of the landing site. (See Fig. 5.6-6).

The mode selector chooses the next sequence of calculations depending upon the phase of the entry trajectory that is currently being flown. The initial roll section maintains whatever roll angle was previously selected in the initialization routine and decides when to start the next phase, as shown in Fig. 5.6-7.

The next phase maintains a constant drag trajectory while testing to see if it is time to enter the up-control phase. The testing is presented in Figs. 5.6-8 and 5.6-9. The constant drag equations are given in Fig. 5.6-10. The other phases (up-control, ballistic, and final) are listed in Figs. 5.6-11, 5.6-12, and 5.6-13. (See Fig. 5.6-14.) The final phase is accomplished by a

stored reference trajectory with linear interpolation between the stored points. Its characteristics as well as the steering gains are stored as shown in Fig. 5.6-14. The routine that prevents excessive acceleration build-up (G limiter) is given in Fig. 5.6-15. Finally, the section that does the lateral logic calculations and computes the commanded roll angle is shown in Fig. 5.6-16.

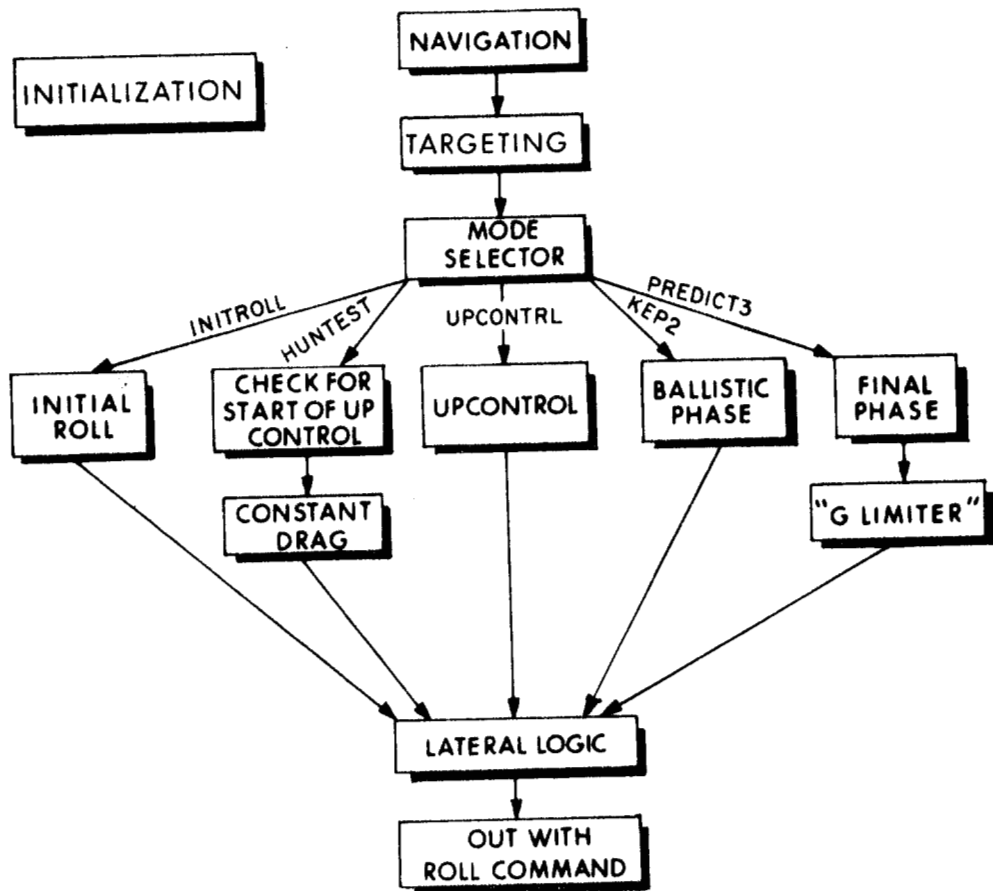


Fig. 5.6-1 Entry Computation

VARIABLE	DESCRIPTION	MAXIMUM VALUE *	COMPUTER NAME
URTO	INITIAL TARGET VECTOR	2 (UNIT VECTOR)	= RTINIT
UZ	UNIT VECTOR NORTH	2	= (UZ) OR UNITW
V	VELOCITY VECTOR	2 VSAT	= (V)
R	POSITION VECTOR	2 EXP 29 METERS	= RN
VI	INERTIAL VELOCITY	128 M/CENTISEC	= VPIP
RTE	VECTOR EAST AT INITIAL TARGET	2	= RTEAST
UTR	NORMAL TO RTE AND UZ	2	= RTNORM
URT	TARGET VECTOR	2	= (RT)
UNI	UNIT NORMAL TO TRAJECTORY PLANE	2	
DELV	INTEGRATED ACCEL. FROM PIPAS	5.85 16384 CM/S	
G	GRAVITY VECTOR	1/32 M/CS/CS	= GRAVITY
AO	INITIAL DRAG FOR UPCONTRL	805 FPSS	FPSS=FT/SEC/SEC
AHOOKDV	TERM IN GAMMAL CALC. = AHOOK DVL	805X16 VSAT FPS FPSS	
A1	DRAG VALUE IN FACTOR CALCULATION	805 FPSS	
ALP	CONST FOR UPCONTRL	1	
ASKEP	KEPLER RANGE	21600 NM	NM = NAUTICAL MILE
ASP1	FINAL PHASE RANGE	21600 NM	
ASPUP	UP-RANGE	21600 NM	
ASP3	GAMMA CORRECTION	21600 NM	
ASPDWN	RANGE DOWN TO PULL-UP	21600 NM	
ASP	PREDICTED RANGE	21600 NM	
COSG	COSINE(GAMMAL)	2	= COSG/2
D	TOTAL ACCELERATION	805 FPSS	
DHOOK	TERM IN GAMMAL COMPUTATION	805 FPSS	
DIFF	THETNM-ASP (RANGE DIFFERENCE)	21600X16 NM	
DIFFOLD	PREVIOUS VALUE OF DIFF	21600X16 NM	
DR	REFERENCE DRAG FOR DOWNCONTROL	805 FPSS	
DREFR	REFERENCE DRAG	805 FPSS	
DVL	VS1-VL	2 VSAT	
E	ECCENTRICITY	4	
F1	DRANGE/D DRAG (FINAL PHASE)	2700/805	
F2	DRANGE/D RDCT (FINAL PHASE)	2700/2VS NM/FPS	
F3	DRANGE/D (L/D)	2700 NM	
FACT1	CONST FOR UPCONTRL	2 VSAT	
FACT2	CONST FOR UPCONTRL	1	
FACTOR	USED IN UPCONTRL	1	
GAMMAL	FLIGHT PATH ANGLE AT VL	1 RADIAN	* MAXIMUM VALUE DENOTES UNSCALED VARIABLE VALUE WHEN SCALED
GAMMAL1	SIMPLE FORM OF GAMMAL	1 RADIAN	VARIABLE HAS MAXIMUM VALUE OF ONE.

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Fig. 5.6-2 COMPUTER VARIABLES

VARIABLE -----	DESCRIPTION -----	MAXIMUM VALUE -----	COMPUTER NAME -----
K1ROLL	INDICATOR FOR ROLL SWITCH		
K2ROLL	INDICATOR FOR ROLL SWITCH		
LATANG	LATERAL RANGE	4 RADIANS	
LEQ	EXCESS C.F. OVER GRAV=(VSG-1)GS	128.8 FPSS	
LEWD	UPCONTROL REFERENCE L/D	1	
L/D	DESIRED LIFT TO DRAG RATIO (VERTICAL PLANE)	1	
L/DINIT	COMMANDED L/D IN INITIAL PHASE	1	
PREDANGL	PREDICTED RANGE (FINAL PHASE)	2700 NM	
Q7	MINIMUM DRAG FOR UPCONTROL	805 FPSS	
RDOT	ALTITUDE RATE	2 VSAT	
RDOTREF	REFERENCE RDOT FOR UPCONTROL	2 VSAT	
RDOTR	REFERENCE RDOT FOR DOWNCONT	2 VSAT	
ROLLC	ROLL COMMAND	8 REVOLUTIONS	
RTOGO	RANGE TO GO (FINAL PHASE)	2700 NM	
SL	SINE OF LATITUDE	1	
T	TIME	16384 SEC	= TENTRY
THETA	DESIRED RANGE (RADIANS)	2 PI RADIANS	= THETAH
THETNM	DESIRED RANGE (NM)	21600 NM	
V	VELOCITY MAGNITUDE	2 VSAT	
V1	INITIAL VELOCITY FOR UPCONTROL	2 VSAT	
V1OLD	PREVIOUS VALUE OF V1	2 VSAT	
VCORR	VELOCITY CORRECTION FOR UPCONTROL	2 VSAT	
VL	EXIT VELOCITY FOR UPCONTROL	2 VSAT	
VREF	REFERENCE VELOCITY FOR UPCONTROL	2 VSAT	
VS1	VSAT OR V1, WHICHEVER IS SMALLER	2 VSAT	
VBARS	$VL^2 / VSAT^2$	4	
VSQ	NORMALISED VEL. SQUARED = $V^2 / VSAT^2$	4	= VSQUARE
WT	EARTH RATE TIMES TIME	1 REVOLUTION	= WIE (DTEAROT)
X	INTERMEDIATE VARIABLE IN G-LIMITER	2 VSAT	
Y	LATERAL MISS LIMIT	4 RADIANS	

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Fig. 5.6-2a COMPUTER VARIABLES (CONTINUED)

EXTRA COMPUTER ERASABLE LOCATIONS NOT SHOWN ON FLOW CHARTS

VARIABLE	DESCRIPTION	MAXIMUM VALUE
GOTOADDR	ADDRESS SELECTED BY SEQUENCER	
XPIBUB	BUFFER TO STORE X PIPA COUNTS	
YPIBUB	BUFFER TO STORE Y PIPA COUNTS	
ZPIBUB	BUFFER TO STORE Z PIPA COUNTS	
PIPCTR	COUNTS PASSES THRU PIPA READ ROUTINE	
JJ	INDEX IN FINAL PHASE TABLE LOOK-UP	
M1	INDEX IN FINAL PHASE TABLE LOOK-UP	
GRAD	INTERPOLATION FACTOR IN FINAL PHASE	
FX	DRANGE/D L/D = F3	2700 NM
FX + 1	AREF	805 FPSS
FX + 2	RTOGO	2700 NM
FX + 3	RDOTREF	VSAT/4
FX + 4	DRANGE/D RDOT = F2	21600/2VS NM/FPS
FX + 5	DRANGE/D DRAG = F1	2700/805 NM/FPSS
UNITV	UNIT V VECTOR	2
UNITR	UNIT R VECTOR	2
TEM1B	TEMPORARY LOCATION	
SWITCHES		INITIAL STATE
GONEPAST	INDICATES OVERTHOOT OF TARGET	NON-BRANCH (0)
RELVELSW	RELATIVE VELOCITY SWITCH	NON-BRANCH (0)
FGSW	FINAL PHASE SWITCH	NON-BRANCH (0)
HUNTIND	INITIAL PASS THRU HUNTEST	NON-BRANCH (0)
HIND	INDICATES ITERATION IN HUNTEST	NON-BRANCH (0)
INRLSW	INDICATES INIT ROLL ATTITUDE SET	NON-BRANCH (0)
LATSW	INHIBIT DOWNLIFT SWITCH IF SET	NON-BRANCH (0)

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Fig. 5.6-2b COMPUTER VARIABLES (CONCLUDED)

CONSTANTS AND GAINS		VALUE	
C1	FACTOR IN ALP COMPUTATION	1.25	
C16	CONSTD GAIN ON DRAG	.01	
C17	CONSTD GAIN ON RDOT	.001	
C18	BIAS VEL. FOR FINAL PHASE START	500	FPS
C20	MAX DRAG FOR DOWN-LIFT	175	FPSS
CH00K	FACTOR IN AHOOK COMPUTATION	.25	
CH1	FACTOR IN GAMMAL COMPUTATION	.75	
D0	CONTROLLED CONSTANT DRAG	130	FPSS
D2	DRAG TO CHANGE LEWD	175	FPSS
DT	COMPUTATION CYCLE TIME INTERVAL	2	SEC.
GMAX	MAXIMUM ACCELERATION	322	FPSS (10 G-S)
KA	DRAG TO ROLL UP IF DOWN INITIALLY (=KAT)	64.4	FPSS
KR1	OPTIMIZED UPCONTROL GAIN	3.4	
KR2	OPTIMIZED UPCONTROL GAIN	.0034	
KDMIN	INCREMENT ON C7 TO DETECT END OF KEPLER PHASE	.5	FPSS
KLAT	LATERAL SWITCH GAIN	.0125	
KTETA	TIME OF FLIGHT CONSTANT	1000	
K44	GAIN USED IN INITIAL POLL SECTION	29942088	FPS
LAD	MAX L/D (MIN ACTUAL VEHICLE L/D)	.3	
LATBIAS	LATERAL SWITCH BIAS TERM	.4	NM
L/DKMINP	LAD COS(15 DEG)	.2895	
LEWD1	NOMINAL UPCONTROL L/D	.1	
LEWD2	UPCONTROL L/D HIGH DRAG CASES	.2	
LOD	FINAL PHASE L/D	.18	
POINT1	FACTOR TO REDUCE UPCONTROL GAIN	.1	
Q2	FINAL PHASE RANGE - 23500 Q3	-1002	NV
Q3	FINAL PHASE DRANGE/D V	.07	NV/FPS
Q5	FINAL PHASE DRANGE/D GAMMA	7050	NM/RAD
Q6	FINAL PHASE INITIAL FLIGHT PATH ANGLE	.0349	RAD
Q7F	MIN DRAG FOR UPCONTROL	6	FPSS
Q7MIN	MIN VALUE FOR Q7 IN FACTOR CALCULATION	35	FPSS
Q19	FACTOR IN GAMMAL1 CALCULATION	.2	
VFINAL1	VELOCITY TO START FINAL PHASE ON INITIAL ENTRY	26000	FPS
VFINAL	FACTOR IN INITIAL UP-DOWN CALC	25000	FPS
VLMIN	MINIMUM VL	18000	FPS
VMIN	VELOCITY TO SWITCH TO RELATIVE VEL	VSAT/2	
VRCONTRL	RDOT TO START INTO HUNTEST	700	FPS
VCORLIM	MAX VALUE OF VCORR	1000	FPS
25NM	TOLERANCE TO STOP RANGE ITERATION	25	NM
VQUIT	VELOCITY TO STOP STEERING	1000	FPS
CONVERSION FACTORS AND SCALING CONSTANTS			
ATK	ANGLE IN RAD TO NV	3437.7468	NM/RAD
GS	NOMINAL G VALUE FOR SCALING	32.2	FPSS
HS	ATMOSPHERE SCALE HEIGHT	28500	FT
J	GRAVITY HARMONIC COEFFICIENT	.00162345	
KWE	EQUATORIAL EARTH RATE	1546.70168	FPS
MUE	EARTH GRAVITATIONAL CONSTANT	3.986032233	F 14 CURIC M/ SEC SEC
RE	EARTH RADIUS	21202900	FT
VSAT	SATELLITE VELOCITY AT RE	25766.1973	FPS
WIE	EARTH RATE	.0000729211505	RAD/SEC

Fig. 5.6-3 CONSTANTS, GAINS AND CONVERSIONFACTORS

INITIALIZATION

```

--
URT0 = TARGET VECTOR AT TIME = ZERO

-- --
STE = UZ*URT0

-- --
UTR = RTE*U7

--
URT = INITIAL TARGET VECTOR AT NOMINAL TIME OF ARRIVAL
      (FOR THIS CALCULATION)

      = URT0 + UTR(COS WT - 1) + RTE SIN WT
      WHERE WT = W TNOM

-- -- --
UNI = UNIT (V*UNIT(R))

LATANG = URT.UNI

THETA = ARCCOS(URT.UNIT(R))

K1ROLL = 0
K2ROLL = -SIGN(LATANG)

Q7 = Q7F

SELECTOR = INITROLL

L/DINIT = LAD
L/D = LAD

INITIALIZE SWITCHES

GONEPAST = 0      RELVELSW = 0
EGSW = 0         HUNTIND = 0
HIND = 0         INRLSW = 0
LATSW = 0

```

Fig. 5.6-4 ENTRY PROGRAM INITIALIZATION

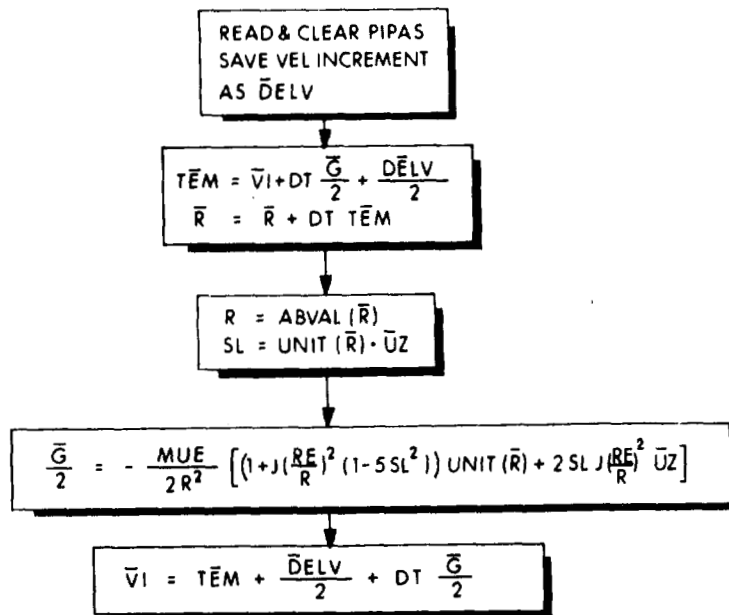


Fig. 5.6-5 "Average-G" Navigation Routine

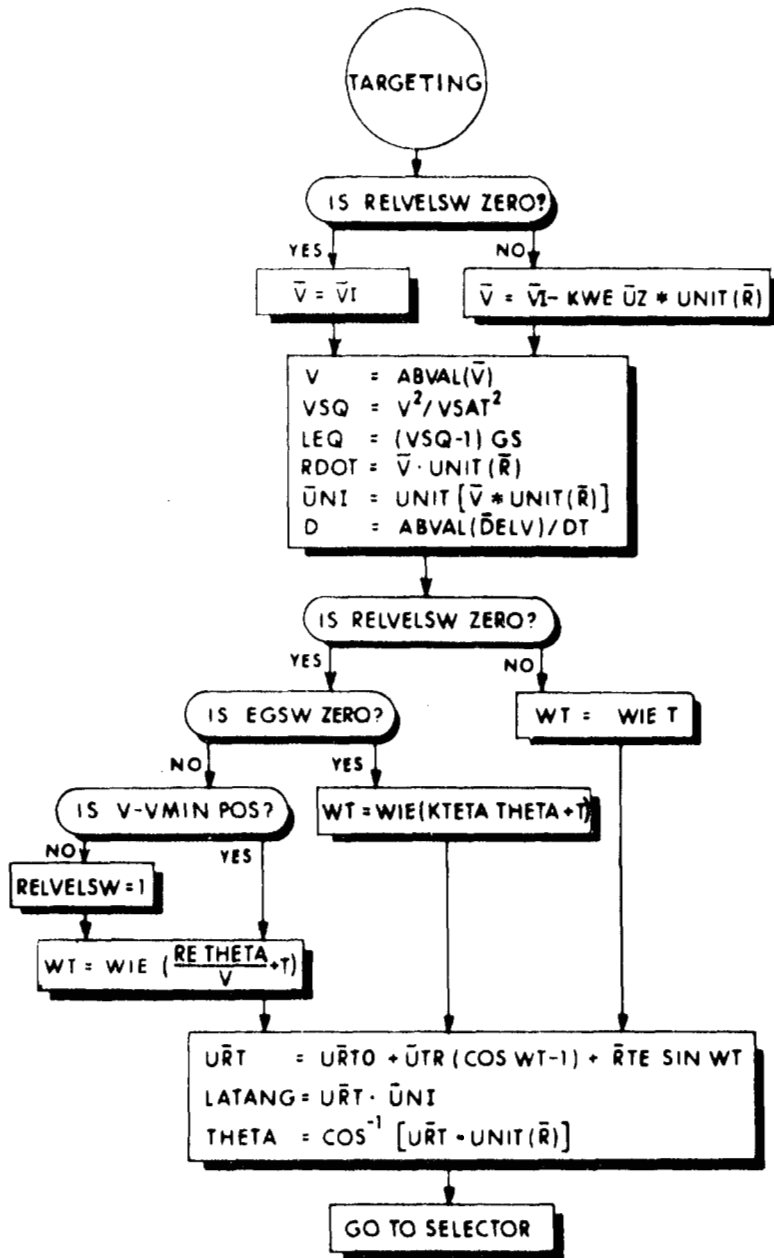


Fig. 5.6-6 Targeting

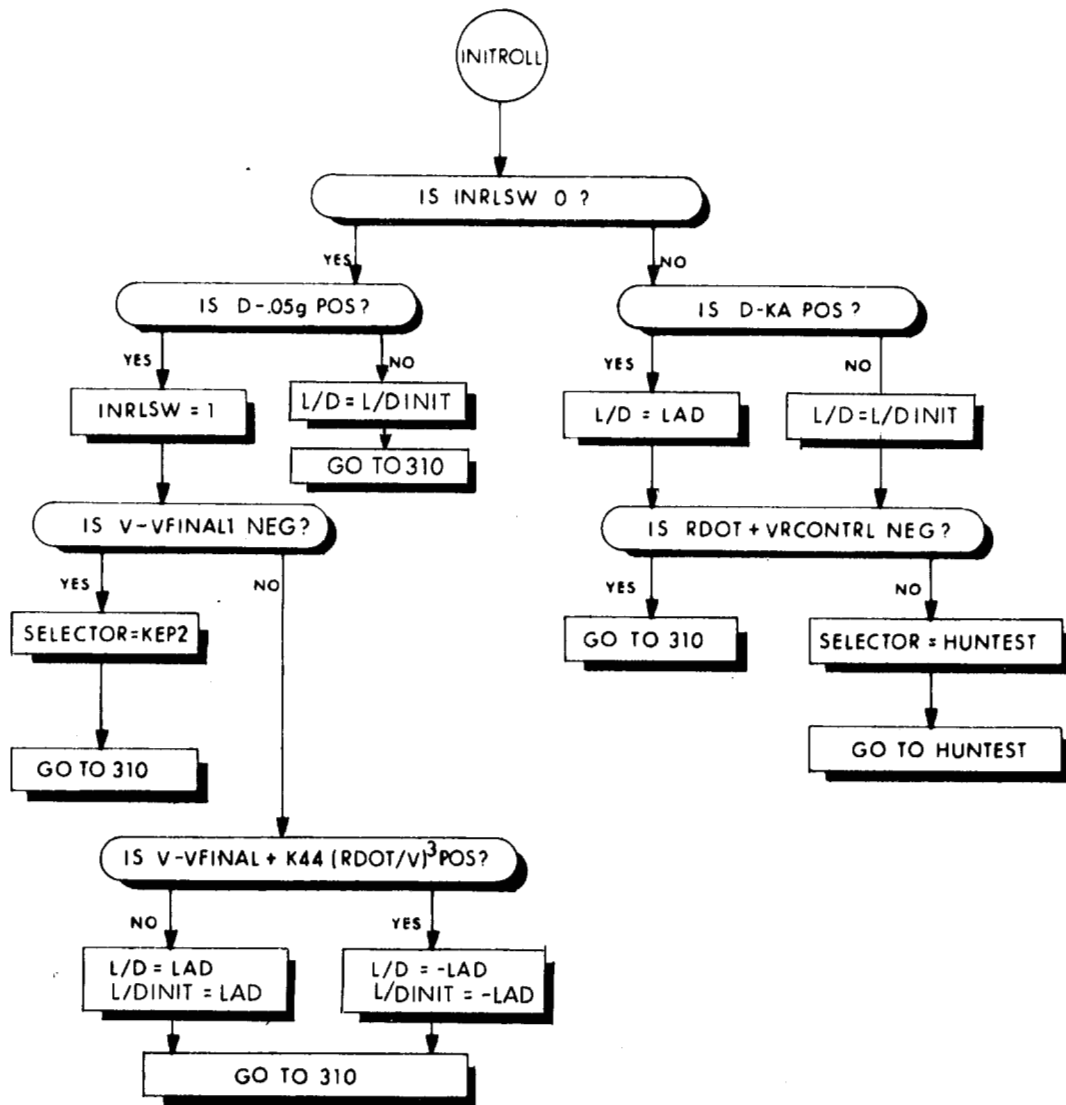


Fig. 5.6-7 Initial Roll

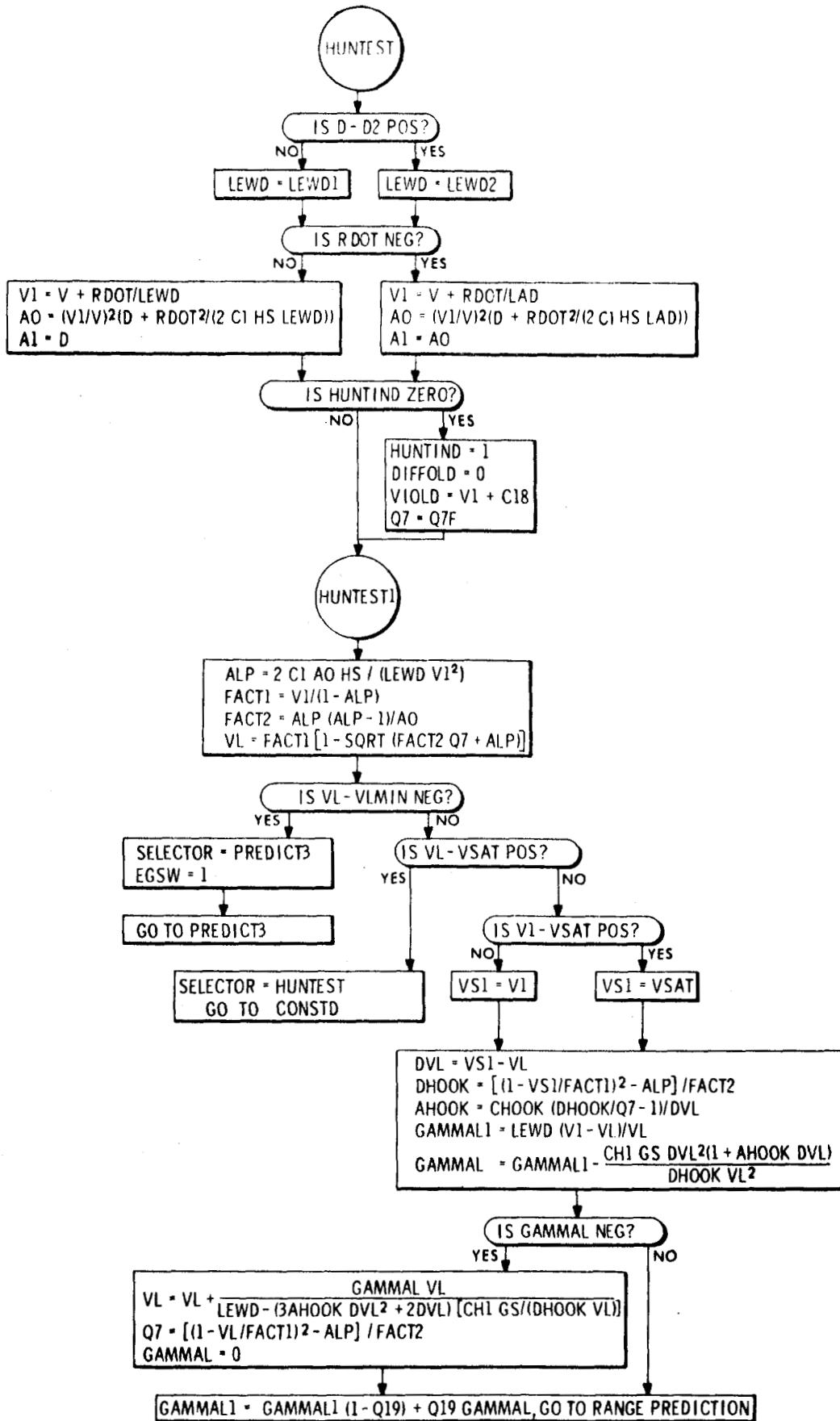


Fig. 5.6-8 Hunttest

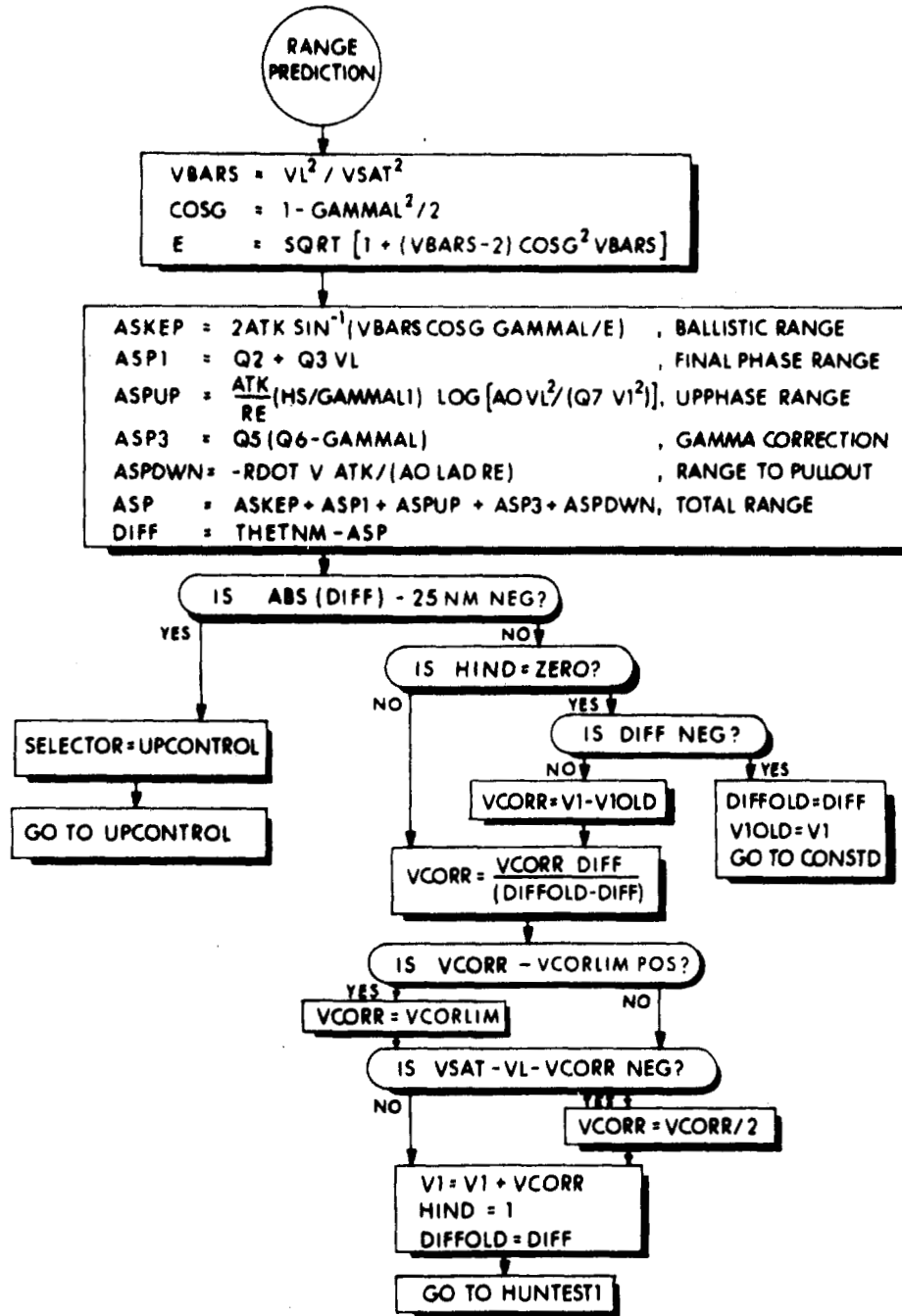


Fig. 5.6-9 Range Prediction

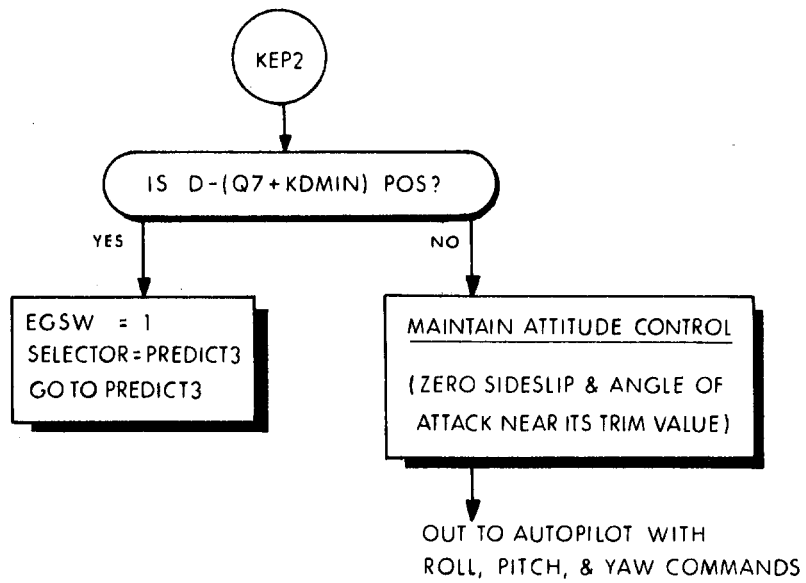


Fig. 5.6-12 Ballistic Phase

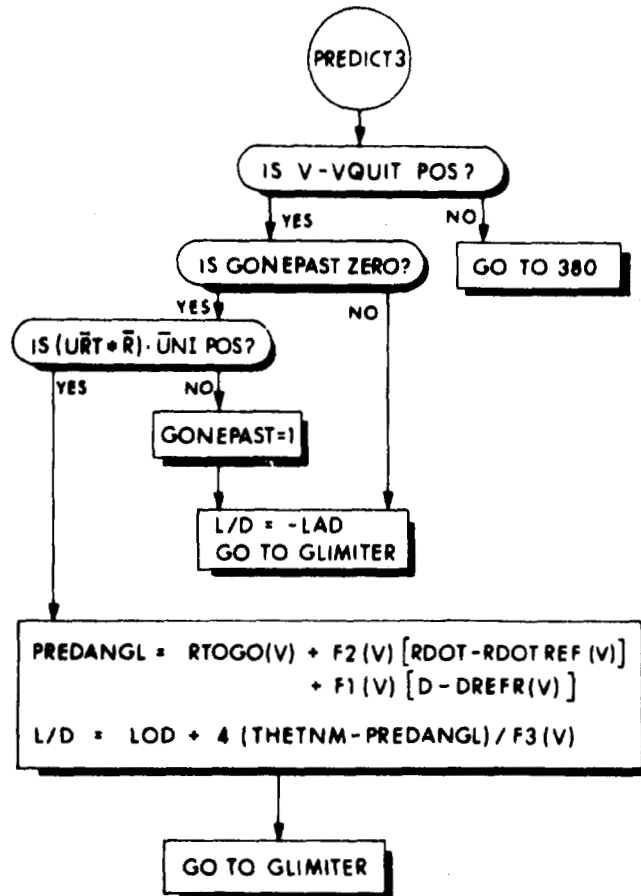


Fig. 5.6-13 Final Phase

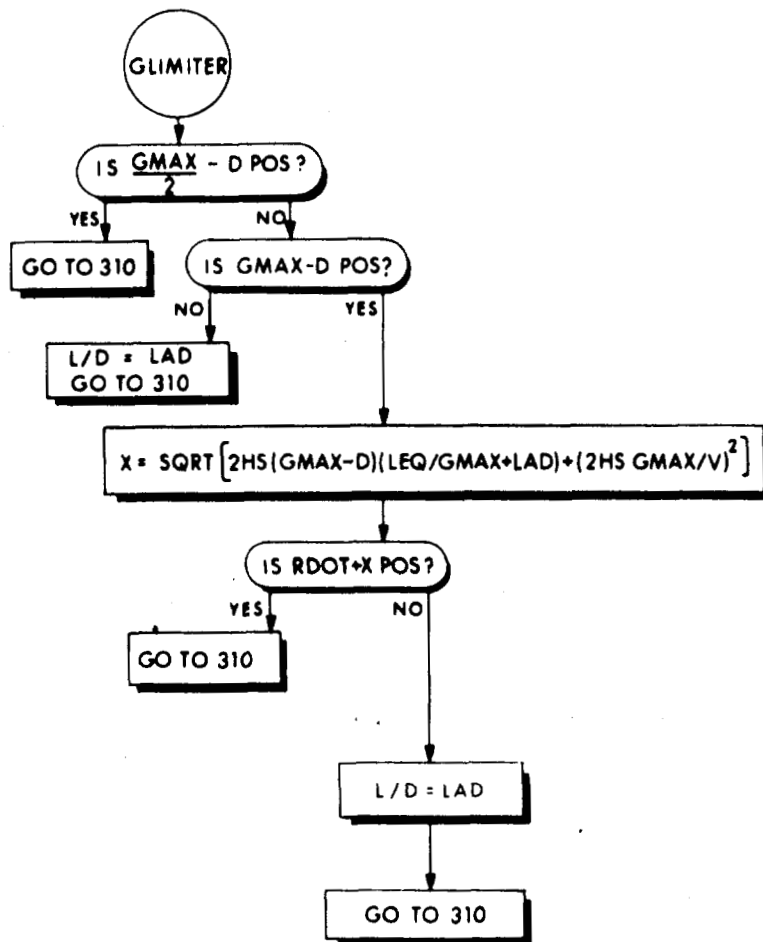


Fig. 5.6-15 G-Limiter

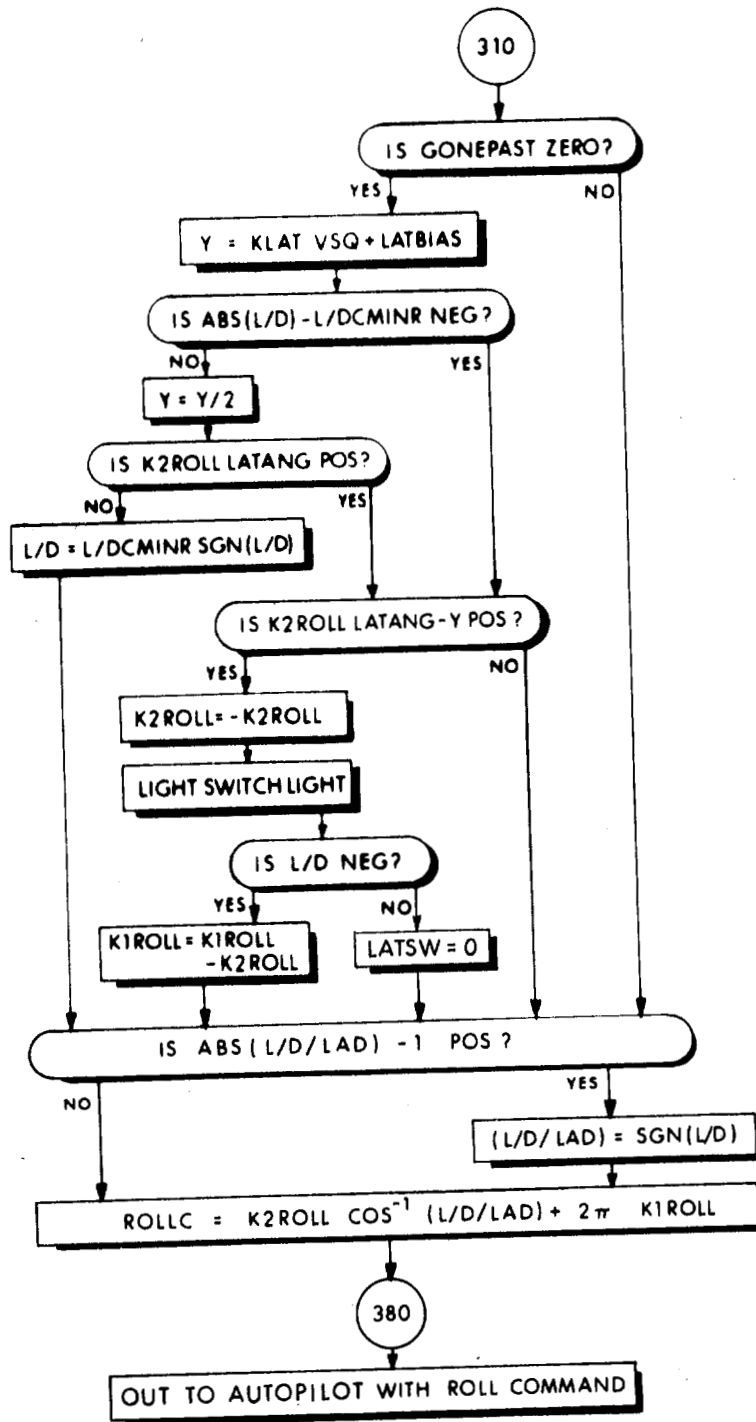


Fig. 5.6-16 Lateral Logic

