MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APOLLO

GUIDANCE, NAVIGATION AND CONTROL

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USERS' GUIDE TO APOLLO GN&CS MAJOR MODES AND ROUTINES

(REV. 1)

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FOREWORD

This document is an attempt to present, in one volume, a comprehensive, user-oriented description of the APOLLO GN&C system. The objective is to comprise all major modes, routines, and extended verbs defined by the Guidance System Operations Plan (GSOP) and to describe their operation, theory, and interrelationships in sufficient detail for a crew member or mission controller to gain the prerequisite understanding on which to base a more rigorous study of specific, flight-particular details and procedures.

Essentially, then, the GN&C Users' Guide is designed to be system, rather than mission, oriented in that procedural details vary from mission to mission. As a training text defining basic procedures, the Guide will be revised as necessary to remain current; it should not, however, be construed as reflecting the most recent procedures or system configuration. For specific information regarding a particular mission, refer to the appropriate MSC-approved Guidance Syystem Operations Plan (GSOP), Crew Procedures Document, Mission Techniques Document, and Crew Checklist.

Jack C. Reed

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APOLLO Documentation Group

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CMC PRELAUNCH PROGRAMS

B L A N K

2.2.1 P00, CMC Idling Program

P00 is used to maintain the CMC in a state of readiness for entry into other programs. While P00 is operating, the Coasting Integration Routine maintains the CMC's CSM and LM state vectors extrapolated to current time, unless extrapolation is specifically terminated.

2.2.1.1 Computational Modes

P00 operates in either of the two modes: (1) state-vector extrapolation allowed; (2) state-vector extrapolation inhibited. Ordinarily, the crew selects P00 by keying VERB 37 ENTR 00 ENTR, and state-vector extrapolation occurs as described under "Computation Sequence," paragraph 2.2.1.2. Keying VERB 96 ENTR, however, terminates extrapolation, and P00 is maintained in an idle state awaiting further crew action.

2.2.1.2 Computation Sequence

In the extrapolation mode, P00 computation is as follows: (1) every 10 minutes, the need for extrapolation is tested; (2) if the current time minus the state-vector time equals at least four time steps (Δt), the CSM state vector is extrapolated, by precision integration, to approximately the present; (3) except when SURFLAG is set (VERB 44 ENTR), the LM state vector is extrapolated to synchronize with that of the CSM. This synchronizing step is accomplished each time the need for extrapolation is tested—whether the CSM state vector is extrapolated or not. [The value of Δt is a function of the conic position vector ($\underline{r}_{con}$) and the gravitational constant of the primary body (μ_P).] Extrapolation is never to a time in advance of the present; therefore, "approximately the present" means the present minus some fraction of a maximum time step:

$$\Delta T_{MAX} = \text{MINIMUM}\left(\frac{\underline{R}_{con}^{3/2}}{0.3\sqrt{\mu_P}},\ 4000\ \text{sec}\right)$$

In the extrapolation-inhibited mode (initiated by VERB 96 ENTR), the computational sequence is as follows (refer to Figure 2.2.1-1):

1. VERB 96 sets QUITFLAG, causing extrapolation to cease at the end of the current time step (Δt).
2. P00 idles until crew reselects VERB 37 ENTR xx ENTR.

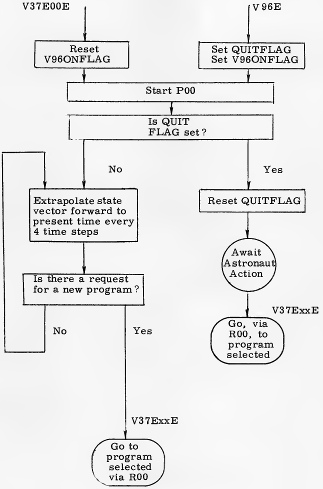


Fig. 2.2.1-1. CMC Idling Program (CSM P00)

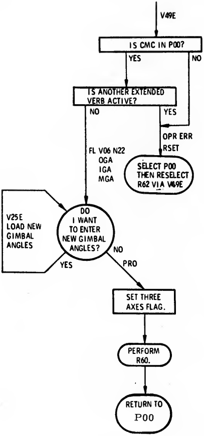


Fig. 2.2.1-2. Crew-defined Maneuver Routine (CSM R62)

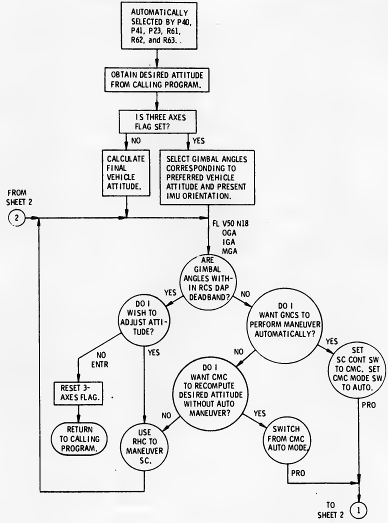


Fig. 2.2.1-3. Attitude Maneuver Routine (CSM R60) (Sheet 1 of 2)

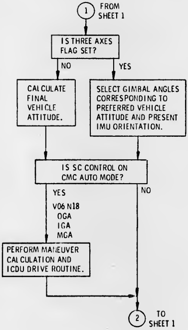


Fig. 2.2.1-3. Attitude Maneuver Routine (CSM R60) (Sheet 2 of 2)

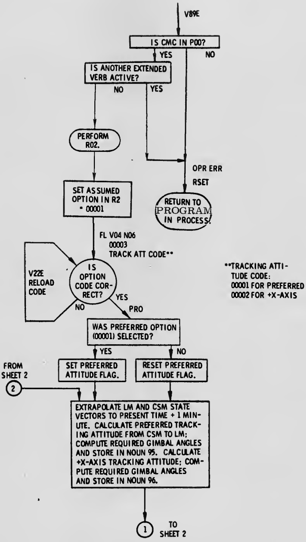


Fig. 2.2.1-4. Rendezvous Final Attitude Routine (CSM R63) (Sheet 1 of 2)

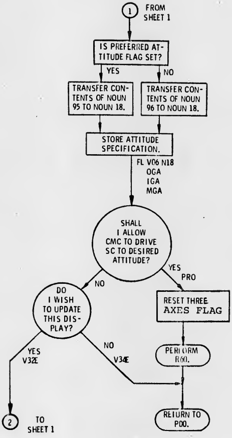


Fig. 2.2.1-4. Rendezvous Final Attitude Routine (CSM R63) (Sheet 2 of 2)

2.2.1.3 Procedures

P00 is entered manually by the crew's keying VERB 37 ENTR 00 ENTR. VERB 96 ENTR stops extrapolation, enters P00 automatically, and allows extrapolation to resume upon the crew's reselecting VERB 37 ENTR 00 ENTR. The only displays are 00 in the PROG lights and such other displays as presented when the crew calls up a routine or an extended verb. P00 exits by the crew's selecting a new program (VERB 37 ENTR xx ENTR).

2.2.1.4 Program Coordination

As an idling program, P00 can be selected whenever there are no functional requirements for the GNCS other than maintaining a current state vector for the two vehicles. Attitude maneuvers can be performed either manually or automatically by the RCS digital autopilot (RCS DAP). (See GSOP Section 3.) Gimbal-lock must be avoided during attitude maneuvers, however, by the crew's monitoring the FDAI ball or by keying VERB 16 NOUN 20 ENTR and monitoring the CDU angles. Gimbal angles for GNC-controlled attitude maneuvers are calculated either by the Crew-defined Maneuver Routine (R62) or by the Rendezvous Final-attitude Routine (R63).

2.2.1.4.1 Crew-defined Maneuver Routine (R62).—This routine can only be entered during P00. The routine allows the crew to specify a GNC-controlled attitude maneuver. DAP rates and deadband limits will be as specified by the crew's prior execution of the Digital Autopilot Data Load Routine (R03).

Routine R62 is entered by the crew's keying VERB 49 ENTR. (See Figure 2.2.1-2.) If the current program is P00 and no other extended verb is being performed, the DSKY flashes VERB 06 NOUN 22 and displays the final gimbal angles (to the nearest 0.01 deg) for a desired attitude maneuver. (See Table 2.2.1-I.) If P00 is not operating or if another extended verb is active, the DSKY OPR ERR light illuminates to inform the crew that improper conditions exist for entering R62.

Responding to the FL VERB 06 NOUN 22, the crew keys PRO when satisfied with the gimbal angles displayed. To change the gimbal angles, the crew keys VERB 2x ENTR, loads the desired outer-, inner-, and middle-gimbal angles in registers R1, R2, and R3, respectively, and then keys PRO.

After setting a flag specifying the three-axis inertial orientation option for the attitude maneuver, R62 calls the Attitude Maneuver Routine (R60). (See Figure 2.2.1-3.) Routine R60 immediately flashes a request to perform an automatic maneuver (FL

TABLE 2.2.1-I

CMC IDLING (P00) DSKY PROCEDURES (SHEET 1 OF 3)

No.	Entry Point	Display	PROG Light	Purpose	Register	CMC Operation	Crew Action	Remarks .
A	P00 (VERB 37 ENTR 00 ENTR or VERB 96 ENTR)	---	00	Maintain CMC in a state of readiness for entry into other programs.	---	Perform state vector extrapolation if entered by V37 E00E; if entered by V96E, no extrapolation takes place.	During attitude maneuvers, monitor FDAI ball or key in VERB 16 ENTR NOUN 20 ENTR to monitor the CDU angles to prevent gimbal lock. Calculation of the gimbal angles are performed either by the Crew-Defined Maneuver Routine (R62) or the Rendezvous Final Attitude Routine (R63). Both of these use the Attitude Maneuver Routine (R60). (See B-1 through B-4 and C-1 through C-5).	Termination of extrapolation is done by keying V96E. Another program cannot be entered during extrapolation. Reinitialize extrapolation by keying V37E00E.
CREW-DEFINED MANEUVER ROUTINE (R62) INTERFACE								
B-1	R62 (VERB 49 ENTR)	FL V06 N22	00	Request crew specify final gimbal angles for a GNC-controlled attitude maneuver.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, call Attitude Maneuver Routine (R60).	PRO, or key VERB 25 ENTR to load new gimbal angles; then PRO.	If CMC not in P00 or another extended verb is active, the OPR ERR light is illuminated.
B-2	R60 (Called by R62)	FL V50 N18	00	Request automatic attitude maneuver to specified final gimbal angles.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform attitude maneuver.	PRO	
B-3	---	V06 N18	00	Nonflashing display of final gimbal angles as maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform maneuver calculation and ICDU drive to achieve final gimbal angles.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to avoid and complete maneuver manually. Observe that the nonflashing V06 N18 returns to FL V50 N18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to FL V50 N18.

TABLE 2.2.1-I

CMC IDLING (P00) DSKY PROCEDURES (SHEET 2 OF 3)

No.	Entry Point	Display	PROG Light	Purpose	Register	CMC Operation	Crew Action	Remarks
B-4	---	FL V50 N18	00	Request maneuver to trim attitude within RCS DAP deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO recycle attitude maneuver. Upon crew's ENTR, exit R60/R62.	If displayed gimbal angles and present a attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing V06 N18 display to return until trim maneuver has completed; then FL V50 N18 returns. PRO again repeats the sequence; ENTR terminates R60/R62.
RENDEZVOUS FINAL ATTITUDE ROUTINE (R63) INTERFACE								
C-1	R63 (VERB 89 ENTR)	FL V04 N06	00	Requests response to option code for assumed tracking attitude.	R1 00003 R2 oooox R3 Blank R1 is option code for assumed tracking attitude. R2 is the tracking attitude code: 00001 for preferred 00002 for +X-axis.	Calculates the final gimbal angles for an attitude maneuver to an appropriate CSM orientation for CSM-LM docking.	Depress PRO to compute angles; use V22E to change tracking attitude code; then depress PRO.	NOTE: – Although the "preferred" code will be selected and displayed automatically by the program, the actual option desired will probably be the +X-axis. Consequently, the crew will normally have to use V22E to change the code from 00001 to 00002.
C-2	---	FL V06 N18	00	Requests response to computed gimbal angles.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Calculates and stores attitude specification for +X-axis or preferred tracking.	Depress PRO to accept angles; use V32E to recycle to V04 N06. Use V34E to exit R63.	
C-3	R60 (Called by R63)	FL V50 N18	00	Request automatic attitude maneuver to specified final gimbal angles.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform attitude maneuver.	PRO	
C-4	---	V06 N18	00	Nonflashing display of final gimbal angles.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform maneuver calculation and ICDU drive to achieve final gimbal angles.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to avoid and complete maneuver manually. Observe that the nonflashing V06 N18 returns to FL V50 N18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to FL V50 N18.

TABLE 2.2.1-1

CMC IDLING (P00) DSKY PROCEDURES (SHEET 3 OF 3)

No.	Entry Point	Display	PROG Light	Purpose	Register	CMC Operation	Crew Action	Remarks
C-5	---	FL V50 N18	00	Request maneuver to trim attitude within RCS DAP.	R1 xxx. xx deg OGA R2 xxx. xx deg IGA R3 xxx. xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, exit R60/R63.	If displayed gimbal angles and present attitude <u>do not</u> agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude <u>agree</u> within deadband limits, key ENTR.	PRO causes nonflashing V06 N18 display to return until trim maneuver has completed; then FL V50 N18 returns. PRO again repeats the sequence, ENTR terminates R60/R63.

VERB 50 NOUN 18) to the displayed gimbal angles. To have the maneuver performed automatically, the crew places the SC CONT switch in the CMC position, the CMC MODE switch in AUTO, and keys PRO. The DSKY changes from a FL VERB 50 NOUN 18 display to a non-flashing VERB 06 NOUN 18 display (see Table 2.2.1-I) and performs an automatic maneuver to the desired orientation. The maneuver rate will be that selected the last time Routine R03 was performed. To avoid gimbal lock, the crew monitors the FDAI ball and attitude-error needles; if the middle-gimbal angle begins to exceed 70 deg, the crew can take over manually and complete the maneuver with the rotational hand controller (RHC). At the completion of the automatic maneuver—or anytime the RHC is removed from detent—the flashing VERB 50 NOUN 18 display returns: "Please perform automatic maneuver." If the achieved attitude and the displayed gimbal angles agree, within deadband limits, the crew terminates R60 by keying ENTR; R62 also exits, and the program returns to P00. (VERB 34 ENTR also terminates R60 and goes to P00.) If the crew is not satisfied with the achieved attitude, he can either key PRO to recycle the automatic maneuver or perform further adjustments with the RHC.

2.2.1.4.2 Rendezvous Final-Attitude Routine (R63).—This routine provides a means of calculating the final gimbal angles for an attitude maneuver to an appropriate CSM orientation for CSM-LM docking. When the gimbal angles have been calculated, the routine calls the Attitude Maneuver Routine (R60) for a GNC-controlled attitude maneuver. Time can be saved, therefore, by setting the SC CONT switch to CMC before R63 is called; similarly, for automatic maneuvers, Routine R03 can be performed before R63 is called, and the CMC MODE switch can be placed in AUTO. Routine R63 can only be called from P00.

Keying VERB 89 ENTR, the crew observes an immediate flashing VERB 04 NOUN 06 (Figure 2.2.1-4) unless one of the following error or alarm conditions exists:

1. If the current program is not P00 or if another extended verb is active, the DSKY OPR ERR light illuminates.
2. If the IMU is not on and aligned to an orientation known by the CMC, the IMU Status Check Routine (R02) displays a PROG alarm.

Assuming no error or alarm condition, register R1 of the VERB 04 NOUN 06 displays will contain the code (00003) designating assumed tracking attitude; register R2 will contain the option code (00001) for the "preferred" tracking axis; register R3 will be blank. Ordinarily, however, the appropriate final rendezvous tracking attitude is not the "preferred," but the CSM X-axis pointed at the LM. Before keying PRO, therefore, the crew must key VERB 22 ENTR and load option code 00002 in register

R2. PRO then causes R63 to extrapolate the CSM and LM state vectors to the present +1 minute, calculate the appropriate CSM attitude, and compute the required gimbal angles. The gimbal angles are then displayed by a flashing VERB 06 NOUN 18. (See Table 2.2.1-I.) If the crew is satisfied with the angles displayed and wishes the GNC to control the maneuver, he keys PRO, which causes the Attitude Maneuver Routine (R60) to be called. (Routine R60 is as described in paragraph 2.2.1.4.1.) Otherwise, the crew either can key VERB 32 ENTR to recycle R63 for a later solution or can terminate R63 by keying VERB 34 ENTR, which returns the program to P00. In the nominal condition, the maneuver to point the CSM X-axis at the LM is completed in R60; R63 then returns, only to exit to P00.

2.2.1.4.3 Other P00-limited Extended Verbs.—In addition to R62 and R63, the following extended verbs are only executed during P00:

a. DSKY Light Test (V35)
b. Load FDAI Error Needles (V43)
c. Display on DSKY the Sum of Each Bank (V91)

2.2.1.4.3.1 DSKY Light Test (V35).—This extended verb (Figure 2.2.1-5) provides a means of determining whether all display lights are operational. While in P00, the crew keys VERB 35 ENTR, which causes all display-panel lights to illuminate for 5 sec. VERB 35 then exits. If P00 is not operating, VERB 35 ENTR will cause the OPR ERR light to illuminate.

2.2.1.4.3.2 Load FDAI Error Needles (V43).—This extended verb (Figure 2.2.1-6) is used to load crew-specified angles into the FDAI error needles. Although intended primarily for use on the ground, VERB 43 can be called anytime P00 is operating and neither of the following conditions exists:

a. After liftoff, another extended verb active. (Before liftoff, VERB 43 will override any other extended verb.)
b. The IMU is in the coarse-align or zero ICDU mode.

If P00 is not the active program, or if either condition a or b exists, keying VERB 43 ENTR will cause an OPR ERR light. Otherwise, the DSKY displays a flashing VERB 21 NOUN 22, with registers R1, R2, and R3 corresponding to roll, pitch, and yaw respectively. All three registers will be blank until error angles are entered by the crew. The maximum error angle that can be processed is ±16.88 deg. If a larger value is loaded, the routine will interpret it as 16.88 deg. Also, depending upon the FDAI scale setting, the maximum needle indication in pitch and yaw is 15 deg (roll, 50 deg). Loading the desired error angles in register R1, R2, and R3 (to

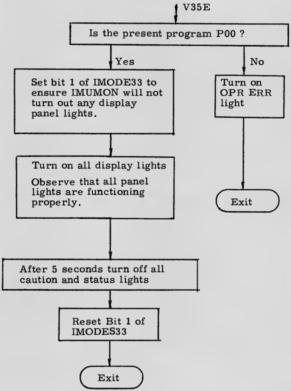


Fig. 2.2.1-5. DSKY Light Test (CSM Regular Verb V35)

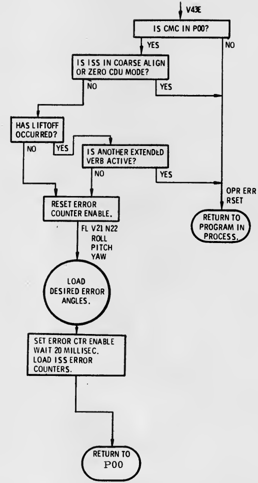
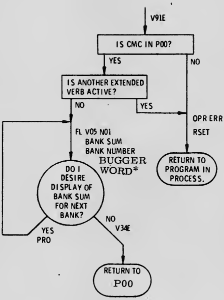


Fig. 2.2.1-6. Load IMU Attitude Error Needles (CSM Extended Verb V43)



*"BUGGER WORD" is a factor required to make $|R1| = |R2|$. If $|R1| \neq |R2|$, there is an error in the bank.

Fig. 2.2.1-7. CMC Display Sum of Each Bank (CSM Extended Verb V91) nearest 0.01 deg), the crew observes a corresponding deflection on the error needles. As soon as the angle data are loaded, the display blanks and VERB 43 exits. The FDAI needles will continue to indicate the loaded angles. To load new angles (zero, for example), the crew must again key VERB 43 ENTR and repeat the loading procedure.

2.2.1.4.3.3 Display on DSKY the Sum of Each Bank (V91).—VERB 91 is a means of fixed-memory checkout. The test can be performed whenever P00 is operating and no other extended verb is active. (See Figure 2.2.1-7.)

Keying VERB 91 ENTR, the crew observes a flashing VERB 05 NOUN 01, with register R1 displaying the sum of the bits contained in the bank whose number is displayed in register R2. Register R3 displays the factor ("bugger word") required to make $|R1| = |R2|$. If $|R1| \neq |R2|$, there is an error in the bank, and use of the CMC should be terminated pending instructions from the ground. To check the next bank, the crew keys PRO, observes that $|R1| = |R2|$, and so on, repeating the procedure until the last bank (43) has been checked. To terminate VERB 91, the crew keys VERB 34 ENTR.

2.2.1.5 Restrictions and Limitations

If VERB 96 is used to halt integration during Rendezvous Navigation (P20), CSM-LM state-vector synchronization may be lost, and the W-matrix (paragraph 4.3.1) may become invalid and must be reinitialized before resuming navigation.

2.2.1.6 Alarms

Viewing a PROG alarm light on the DSKY, the crew keys VERB 05 NOUN 09 ENTR for a display of the alarm code—unless the code has been displayed automatically. After taking corrective action, the crew keys RSET to extinguish the PROG light and alarm and continues with the program. Alarms most likely encountered in P00 are as follows:

a. Alarm 01520 indicates that the IMU is being initialized when entry to P00 is attempted, whether by a VERB 37 ENTR 00 ENTR or by VERB 96 ENTR. This is a R00 alarm and applies to all programs. Correction is to reselect program when IMU reinitialization has been completed.
b. Alarm 00210 indicates IMU not operating when Routine R02 is performed at the beginning of the Rendezvous-Final-Attitude-Maneuver Routine (R63). Correction is to power up the IMU before selecting R63.

c. Alarm 00220 indicates IMU not aligned to CMC-known orientation (no REFSMMAT) when R02 is performed at the beginning of the Rendezvous-Final-Maneuver Routine (R63). Correction is to perform the IMU-Orientation-Determination Program (P51) before selecting R63.

d. Alarm 20430 indicates a subsurface state vector or, mathematically, computational overflow during state-vector extrapolation. Possible causes are: (1) bad state vector, (2) wrong ephemeris parameters, etc.

2.2.1.7 Restarts

P00 is restart protected.

2.2.2 P01, Initialization

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2.2.3 P02, Gyrocompassing

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2.2.4 P03, Optical Verification of Gyrocompassing

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2.2.5 P06, CMC Power Down

The primary function of the Power Down Program (Figure 2.2.5-1) is to transfer the CMC from the operate to the standby condition. The standby condition is the normal condition of the PGNCS when it is not in use. Maximum average power dissipation of the PGNCS during the standby condition brings the system down from 100 Watts to 10 Watts. P06 is used mainly during such periods as coasting flight and eat and sloop periods.

2.2.5.1 Procedures

Program initiation is accomplished with the input to the DSKY of a VERB 37 ENTR 06 ENTR by the astronaut. The program flashes VERB 50 NOUN 25 on the DSKY. The purpose of the flashing verb noun is a Checklist function, with R1 containing the Checklist code 00062_8, indicating the need for a crew response. If the crew key in VERB 96 ENTR, state vector extrapolation is discontinued. The crew respond by keying the CMC to the standby condition using the PRO key. The crew depress PRO and hold it until the STBY light comes on and the DSKY goes blank. A second PRO will terminate the program.

Once the program has been selected, the CMC will be shut down unless a computer restart is performed (VERB 69 ENTR) before the depression of PRO for the standby condition. After P06 selection, the CMC will not honor a new program request (VERB 37 ENTR), a terminate (VERB 34 ENTR), a VERB 33 ENTR, or an ENTR in response to the CMC standby request.

2.2.5.2 Restrictions and Limitations

Should the CMC be allowed to go below the power level for the standby condition, the CMC would require reinitialization of erasable memory via a VERB 36 ENTR and updating of the relative state vectors and GET.

The standby period can be permitted to last up to 23.3 hours. At least once during this time, the CMC must be brought out of standby, or the GET must be updated. Also, the power to the ISS should not normally be permitted to fall below standby power requirements.* For example, the IMU HEATER circuit breakers must be left on except in extreme emergency. If the IMU heaters are off for extended periods, the IMU calibration is no longer valid.

2.2.5.3 Restarts

P06 has no restart capability. Should a restart occur during P06, the crew would have to re-enter the program.

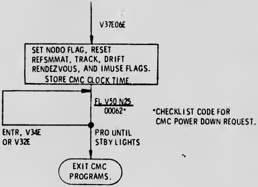

Figure 2.2.5-1. CMC Power Down Program (P 06)

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* This condition is particularly critical for the LGC Power Down Program. Refer to paragraph 2.3.2.

SUBSECTION 2.3

LUNAR MODULE COMPUTER (LGC) PRELAUNCH PROGRAMS

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SECTION 3.0

BOOST/ASCENT

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3.1 INTRODUCTION TO BOOST/ASCENT

Four programs constitute the boost and ascent capabilities of the Command Module (CM) and the Lunar Module (LM). These powered-flight programs provide initialization data for the computer and monitoring capabilities for the crew:

P11, Earth-orbit Insertion Monitor—CMC (paragraph 3.2.1)
P12, Nominal Ascent Program—LGC (paragraph 3.3.1)
P70, Descent Propulsion System Abort—LGC (paragraph 3.3.2)
P71, Ascent Propulsion System Abort—LGC (paragraph 3.3.3).

The four programs have been grouped together mainly for convenience of outline. Despite some superficial similarities, however, the four boost/ascent programs are essentially different. For example, P11 calculations are based on pad-loaded polynomial coefficients representing the nominal attitude profile for boost to earth orbit. These coefficients are used by the Attitude Error Subroutine discussed in paragraph 3.2.1.2.3.

Calculations for the LGC programs, P12, P70, and P71, however, are based on the relationship between the current state vectors of the CSM and the LM. These calculations are performed and used by the Ascent Guidance to put the LM in an orbit suitable for rendezvous. The Ascent Guidance is the controlling routine for P12, P70, and P71 and is explained in detail in subsection 3.3.

Further, although all four programs provide initialization data, the parameters initialized and the methods used for initialization are different. Refer, therefore, to the appropriate paragraph for a detailed explanation of the initialization functions.

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SUBSECTION 3.2

CMC BOOST PROGRAMS

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3.2.1 P11, Earth-orbit-insertion Monitor—CMC

P11 is used to monitor the progress of the launch vehicle from liftoff until earth orbit has been achieved.

P11 performs the following functions:

a. Indicates to the astronaut that the CMC has received the liftoff discrete.
b. Zeros the CMC clock and updates the reference ephemeris time.
c. Computes the initial CMC state vector and starts the AVERAGEG cycle.
d. Computes REFSMMAT.
e. Monitors attitude errors, altitude, velocity, and rate of altitude change.

P11 does not require any crew inputs. P11 outputs are the liftoff time, the reference ephemeris time of liftoff, REFSMMAT, the DSKY NOUN 62 display, and the FDAI needles display of attitude errors. [The attitude errors are computed by taking the difference of the actual measured attitude and the stored desired attitude (computed by using polynomial equations). Refer to Section 5, GSOP, paragraph 5.3.5, for an explanation of the polynomial equations.]

Table 3.2.1-I gives the DSKY displays for P11; Table 3.2.1-II lists the extended verbs.

3.2.1.1 Options

During P11 the crew have the option of taking manual control of the SII and the SIVB stages of the Saturn vehicle if the Saturn platform fails. This option is discussed in subsection 3. 2.

3.2.1.2 Computational Sequence

P11 is usually automatically selected by P02 (the Gyro Compassing Program) when the CMC receives the liftoff discrete. If P11 has not been automatically entered at liftoff, the crew can key VERB 75 ENTR to start P11.*

P11 consists of four major subroutines: Time, State, Attitude Error, and Display. The Time subroutine, or beginning of P11, is selected by P02 within 0.5 sec of

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*VERB 75 ENTR is a backup system used in case the hardware does not set the proper bit when the umbilical cord is removed.

TABLE 3.2.1-I

DSKY DISPLAYS ASSOCIATED WITH P11

DSKY	Initiated by	Purpose	Condition	Register
V06N62	P11	Display	Inertial velocity (VI) Rate of altitude change (HDOT) Altitude (H)	R1 xxxxx. ft/sec R2 xxxxx. ft/sec R3 xxxx. x n. mi.
FL V16N44	R30 (V82E)	Display of orbital parameters	Apogee Altitude Perigee Altitude Time of free fall	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min,sec
N32E	Astronaut	Display time from perigee in R30		R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec
N50E	Astronaut	Display splash error in R30	Δr miss distance Perigee Time of free fall	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min,sec

TABLE 3.2.1-II

EXTENDED VERBS USED WITH P11

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters	See paragraph 3.2.1.4
75 ENTR	Enter P11	To manually initiate P11	This is the backup case and is essentially a part of P02.

receipt of the liftoff discrete. The State subroutine is executed immediately after Time and is through within 1 sec of receipt of the liftoff discrete. The cycling of the Attitude Error subroutine is then started, updating the attitude error display on the FDAI needles approximately every 0.5 sec until P11 exits. (The pitch polynomial calculation defines pitchover of the spacecraft longitudinal axis from the pad local vertical at liftoff.) After the completion of the pitch program until P11 exits, the desired gimbal angles are maintained constant. As the Attitude Error subroutine is started, the Display subroutine is being executed every 2 seconds following the AVERAGEG computation. The Attitude Error subroutine is not synchronous with the Display subroutine.

3.2.1.2.1 Time Subroutine.—The Time subroutine reads the actual liftoff time, zeros the CMC clock at liftoff, updates the reference ephemeris time, and sets up the other subroutines. The Time subroutine of P11 is entered within 0.5 sec of the receipt of the liftoff discrete. The clock and the reference ephemeris time are not changed for the remainder of the mission unless updated by P27.

3.2.1.2.2 State Subroutine.—The State subroutine computes the CMC state vector (in reference coordinates) at liftoff and starts the AVERAGEG calculations using the computed state vector. It also computes the REFSMMAT matrix, which relates the IMU stable member orientation to the Reference Coordinate System. The State subroutine has no immediately visible output; it completes its computations within 1 second of the receipt of the liftoff discrete.*

3.2.1.2.3 Attitude Error Subroutine.—The Attitude Error subroutine computes and transmits to the FDAI needles the difference between a computed nominal Saturn launch vehicle attitude profile and the actual attitude profile, as measured by the CM IMU. The subroutine is cycled approximately every 0.5 second. After the CMC pitch polynomial calculation exits, the desired gimbal angles are maintained constant.

3.2.1.2.4 Display Subroutine.—Using the results of each AVERAGEG cycle, the Display subroutine computes the inertial velocity (v), the rate of change of altitude ($\dot{H}$ or HDOT), and the altitude (H). The subroutine updates the display of these quantities (VERB 06 NOUN 62) every 2 seconds following the AVERAGEG cycle.

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* The output of the State subroutine is used as input for computing other things and never appears to the crew as such.

3.2.1.3 P11 Procedures

Figure 3.2.1-1 is a flowchart of P11. Figure 3.2.1-2 is a typical time-line of crew activity from launch to earth orbit. Since P11 is automatically selected by P02, the crew must first monitor the DSKY for display of major mode 11. In the backup mode, P11 may be selected in P02 by keying VERB 75 ENTR.

As the Attitude Error subroutine begins, the crew can monitor the FDAI attitude error needles indication of launch vehicle attitude. During a nominal launch and after separation of the launch escape tower, the crew will note the gradual saturation of the pitch needle.* The yaw needle should remain close to zero at all times. The roll needle will reflect the beginning of the roll program shortly after the launch tower is cleared and will move to about 18 degrees at a rate of 1 deg/sec. After the CMC pitch polynomial calculations exit, the desired attitude will be frozen until a new program is selected.

The DSKY will display VERB 06 NCUN 62, updating the display every 2 seconds after the AVERAGEG cycle, through the three boost stages until P00 is selected following SIVB shutdown. The crew monitor the VERB 06 NOUN 62 display by comparing the displayed values with the Launch Phase Cue Card values.

P11 is exited by keying VERB 37 ENTR xx ENTR to select a new major mode. AVERAGEG cycling will continue until a new major mode has been selected.

3.2.1.4 Auxiliary Routine

The crew may call the Orbital Parameter Display Routine (R30) during P11 by keying VERB 82 ENTR. (Refer to paragraph 9. 2. 3 for a flowchart of R30.) R30 computes apogee altitude, perigee altitude, and time of free fall and displays these values via VERB 16 NOUN 44. If perigee altitude is greater than 300, 000 ft, R30 sets time of free fall to minus 59 min 59 sec and computes time from perigee. A display of time from perigee can be called by keying NOUN 32 ENTR. The splash error may be called by keying NOUN 50 ENTR.** If the apogee is above 300, 000 ft altitude and the perigee is below 300, 000 ft altitude above the launch pad, splash

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* Gradual saturation of the pitch needle means that the pitch needle gradually proceeds to full deflection.

**The splash error is the difference between the desired (pad-loaded) splashpoint and the splashpoint resulting from an immediate abort.

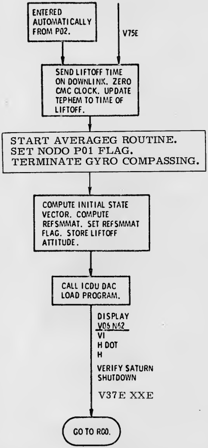

Figure 3.2.1-1. Earth-orbit-insertion Monitor Program (P11)

Program Time	Event	VERB-NOUN Display	DSKY Registers
-00:09	Ignition	PROG 02 VERB 75	R1 BBBBB R2 BBBBB R3 BBBBB
+00:01	Liftoff	VERB 06 NOUN 62	R1 xxxxx ft/sec R2 xxxxx ft/sec R3 xxxx. x n. mi.
00:10	Clear launch tower		
00:12	Start of Pitch and Roll Program		
00:30	Roll Program complete		
00:42	Abort Mode IB		
01:56	Abort Mode IC		R3 0016. 5 n. mi.
02:37	Pitch Program complete		
02:43	SIC/SII staging		
02:44	SII ignition		
03:18	Key VERB 82 ENTR Key PRO	FL VERB 16 NOUN 44 VERB 06 NOUN 62	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min, sec R1 xxxxx ft/sec R2 xxxxx ft/sec R3 xxxx. x n. mi.
08:56	Abort Mode IV (2 burn)		R1 ≥ 22200 ft/sec R3 ~ 100 n. mi.
09:11	SII off		
09:12	SII/SIVB staging		
09:15	SIVB ignition		
10:16	Abort Mode IV (1 burn)		R1 ≥ 23400 ft/sec
11:29	Key VERB 82 ENTR Key PRO	FL VERB 16 NOUN 44	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min, sec
11:39	Insertion		

Figure 3.2.1-2 Typical Time-line of Crew Activity from Launch to Earth Orbit

error will be displayed as the distance between the predicted and the desired abort target; otherwise, splash error will be displayed as the distance between the present position and the desired abort target.

The computations made during this routine are updated about every 2 seconds if the AVERAGEG routine is on when R30 is called. The crew must key PRO to return to the NOUN 62 display of P11.

3.2.1.5 Alarms

There are no program alarms associated with P11.

3.2.1.6 Restarts

P11 is restart protected. The only crew indication of a restart would be the illumination of the RESTART light.

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3.3 LGC ASCENT PROGRAMS

The Nominal Ascent Program (P12), the Descent Propulsion System Abort Program (P70), and the Ascent Propulsion System Abort Program (P71) are essentially three initialization programs whose primary function is to supply targeting information for Ascent Guidance. After the initialization phase is completed by P12, P70, or P71, the Ascent Guidance operates independently of the program that initialized it. Figure 3.3 -1 shows a nominal liftoff and Ascent Guidance profile for the G-Mission. Since predetermined phasing is not possible for aborts, there is no nominal profile for P70 or P71.

Ascent Guidance is used to insert the LM into an orbit suitable for a subsequent rendezvous with the CSM. This purpose is achieved by maneuvering the LM to a desired velocity vector at a specified altitude and distance from the CSM orbital plane. The nominal LM insertion orbit is coplanar with the CSM orbit.

In the Nominal Ascent Program, P12, the crew has the option of specifying a plane change—limited to 0. 5 deg or 8 n.mi.—for the LM to achieve a parallel but non-coplanar orbit with the CSM. The crew would use the plane-change option if the indicated out-of-plane distance from the launch site to the CSM plane is too large for the allowable Δv budget. In the DPS Abort Program, P70, and the APS Abort Program, P71, the plane change is automatically limited to 0. 5 deg.

To control the ascent maneuver to the three velocity (i.e., downrange, crossrange, and radial) and two position (i.e., crossrange and injection radius) constraints on injection, the following guidance concepts are used:

a. The engine configuration allows control in the thrust direction only (i.e., radial and crossrange position and velocity are explicitly controlled).
b. The desired velocity in the downrange position is achieved by terminating thrust at the proper time.
c. The best perfomance is achieved when the required velocity change is in the downrange direction.

Powered Ascent Guidance consists of the three major phases listed below:

a. Pre-ignition phase*

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* The pre-ignition phase applies to the Nominal Ascent Program, P12. (Refer to paragraph 3.3.1.) Both the DPS Abort Program (P70) and the APS Abort Program (P71), however, have an initialization phase before entering the vertical rise or Ascent Guidance phases.

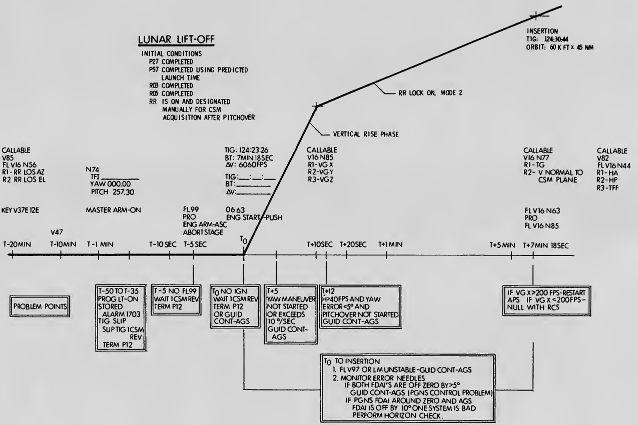

Figure 3.3-1. Nominal Liftoff and Ascent Guidance Profile (G-Mission)

b. Vertical rise phase control (divided into vertical rise and pitchover phases)

c. Ascent Guidance phase.

The Powered Ascent Guidance uses two coordinate systems in addition to the six major coordinate systems used in the navigation and guidance programs. (For a discussion of these six major coordinate systems, refer to subsection 7. 1.)

The first of these special coordinate systems is the Instantaneous Local Vertical Coordinate System. This system is used in the velocity control portion of the Ascent Guidance computations. The second, the Target Coordinate System, is an inertial moon-centered–pseudo-system in which one axis is an arc length. Both of these coordinate systems are illustrated in Figure 3.3-2.

The initialization phases of P12, P70, and P71 are discussed in paragraphs 3. 3. 1, 3. 3. 2, and 3. 3. 3, respectively.

Following initialization and ignition, when the targets are provided, Ascent Guidance enters the vertical rise phase control. The actual vertical rise phase lasts approximately 8 seconds, or until the radial velocity of the LM is greater than 40 ft/sec. The PGNCS holds the LM at an attitude at which the LM +X-axis is parallel to the LM position vector at t_{IG}.

Before APOLLO 12, the pitchover maneuver following the vertical rise was not permitted until the LM +Z-axis was within 5 deg of the horizontal component of the computed thrust vector. This restraint could delay the start of the pitchover phase, costing a substantial Δv penalty. Consequently, the test was removed. Ascent Guidance will still attempt to align the Z-axis properly during the vertical rise phase, but the pitchover maneuver will commence regardless of the LM orientation after the vertical rise phase is completed.

The pitchover phase of vertical rise control begins when the radial velocity exceeds 40 ft/sec. At this time, the PGNCS commands the LM to pitch down, about the Y-axis, an amount defined by the guidance equations. Note that during this pitchover maneuver, the X-axis override option available to the crew is inhibited until 10 seconds after completion of the vertical rise phase.*

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* Actual inhibition time is ten seconds, although two seconds pass after inhibition is completed, before the X-axis override can be used.

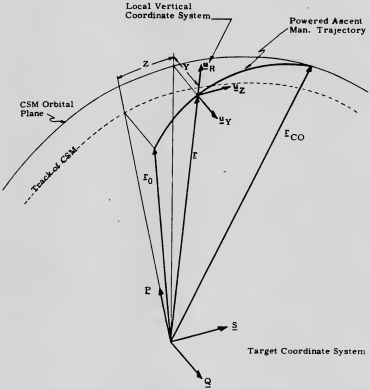

Figure 3. 3-2. Powered Ascent Guidance Coordinate Systems

The vertical rise and pitchover maneuvers of the vertical rise phase control portion of Ascent Guidance also apply to both the DPS Abort Program (P70) and the APS Abort Program (P71), with additional restraints controlling the vertical rise phase.

If the abort is initiated at an altitude greater than 25,000 ft, no vertical rise is used and the abort maneuver enters directly into the Ascent Guidance phase. If the abort takes place at an altitude less than 25,000 ft, the vertical rise phase is entered.

The vehicle attitude during Ascent Guidance is controlled by FINDCDUW, which is the interface program converting the thrust vector commands of Ascent Guidance to CDU angles for the DAP (Digital Autopilot). FINDCDUW checks to see if the commanded maneuver will take the LM +X-axis through the downward vertical. If the commanded maneuver will do so, the command is replaced by a command to vertical thrusting until the +X-axis is within 30 deg of the upward vertical, or 90 deg of the computed command.

Ascent Guidance is essentially used in the same way by P12,P70, and P71. The notable differences are that the abort programs (P70 and P71) provide continuous targeting throughout Ascent Guidance, whereas P12 provides fixed targets at the start.

The Ascent Guidance equations use the targets (i.e., ZDOTD, RDOTD, YD, YDOTD, and RD) to determine in which direction to point the thrust vector. The Ascent Guidance phase is initiated after vertical rise is completed. The computational sequence is initiated by the Servicer routine and is repeated every 2 seconds. Briefly, the computational sequence is as follows. The existence of an "engine on" command is checked, and the velocity increment measured by the PIPAs over the last computational cycle is compared to the established minimum value. This thrust filter bypass computation is performed in addition to the Thrust Monitor Routine (R40). If the engine thrust test is successful, the thrust filter computation, which smooths out the PIPA results by averaging several successive PIPA Δv readings, is processed.

After the thrust filter computations are completed, the following parameters are computed every 2 seconds:

a. Local vertical coordinate system
b. Local velocity components
c. Local position computation (i.e., radial and crossrange positions)
d. Velocity-to-be-gained

e. Time-to-go estimation

f. Engine-off test.

When the t_{go} (time-to-go) falls below 2 seconds, no new Ascent Guidance coefficient computations are made. The remainder of the maneuver is performed using the previous values computed.

3.3.1 P12, Nominal Ascent Program—LGC

P12 is basically an initialization program with the following two functions:

a. To supply targets for the Ascent Guidance
b. To initialize the required engine parameters for the Ascent Guidance.*

The program controls the nominal LM ascent from the lunar surface, but can also be used when an early liftoff is necessary—after the Landing Confirmation Program (P68) has been selected.

The crew select P12 by keying in VERB 37 ENTR 12 ENTR, allowing sufficient time (at least 5 minutes) to complete the pre-ignition phase.

For the early liftoff, the target values used are the same as those used for the late and lunar surface aborts, P70 and P71 (i.e., ZDOTD = 5509.3 fps; RDOTD = 19.5 fps) to save time. For the nominal liftoff, however, the crew must change these values by DSKY inputs.

3.3.1.1 Nominal Liftoff

For a nominal ascent, the crew call P12 far enough ahead of time to permit recognition and response to the following displays:

a. Time of ignition (t_{IG}). This should be set at the desired liftoff time since a lunar surface alignment has already been performed.
b. Targets—ZDOTD, RDOTD and crossrange. Nominally, the crew change ZDOTD and RDOTD.
c. FDAI angles and time from t_{IG}. FDAI readings to be expected by the crew after pitchover and countdown to t_{IG}.

3.3.1.2 Early Liftoff

If a LM system malfunction, such as an APS propellant leak, is discovered, an early liftoff is carried out. For an early liftoff, the crew set t_{IG} as close to the current time as permits them to sequence through the above displays without DSKY

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* For a detailed explanation of the Ascent Guidance as it relates to P12, refer to subsection 3.3.

inputs. Required flight plan procedure is shown below: (Note that t_{IG} has been set at 1380 sec.)

EVENT	TIME FROM IGNITION (PDI IGNITION)
Touchdown	690-775 sec (711 is nominal)
Stay/No-Stay	780 sec
VERB 37 ENTR 68 ENTR	980 sec
VERB 37 ENTR 12 ENTR	990 sec (P12 must be selected at least 5 minutes before ignition, i.e., by PDI+1080.)
GO/NO-GO for P12	1375 sec
Liftoff	1380 sec

If at sometime during the above procedure, the decision is made to stay, the crew terminate P12 and then proceed with lunar surface operations such as alignment (P57).

3.3.1.3 Targeting

The objective of targeting is to set up a group of conditions necessary to achieve a suitable injection trajectory to complete the rendezvous maneuver. The necessary targeting parameters for P12 depend on whether P12 is used in a nominal ascent or in an early liftoff. It is important to note here that in a nominal ascent of P12 there is a 400-ft overshoot to orbit injection.

During the last part of the burn, the crew would usually key VERB 16 NOUN 85 into the DSKY to display the Δv remaining. This information would allow the crew to make the decision whether or not to null out the residuals (after the burn) by using the RCS jets to achieve the targets.

The injection targeting parameters for P12 that are stored in the LGC are as follows:

a. ZDOTD

b. RDOTD

c. T_{IG}, time of ignition

d. $Y_D = 0$ (desired injection out-of-plane distance measured from the CSM orbital plane)

e. $R_D = R_{LS} + 60,000$ ft

f. YDOTD = 0

RDOTD, ZDOTD and crossrange (related to Y_D) are displayed to the crew via VERB 06 NOUN 76. In the nominal ascent, during pre-ignition, the crew modify the first 2 parameters by keying in the following values in response to VERB 06 NOUN 76:

a. ZDOTD = velocity corresponding to a 45-n. mi. apolune orbit
b. RDOTD = approximately 32.0 ft/sec radial velocity.

The above two values must be entered by the crew during each nominal ascent use of P12. The crew also have the option of changing crossrange if the stored crossrange value (required to achieve $Y_D = 0$) is large enough to strain the Δv budget. A crossrange value should not be specified, however, that causes the ascent trajectory to cross through the CSM orbital plane. Note that the initially displayed value of crossrange will be the distance between the LM position vector at t_{IG} and the CSM orbital plane, (i.e., the total out-of-plane maneuver vector at t_{IG} required during the ascent to make the LM and CSM orbits coplanar). The remaining stored parameter values are not modified for the nominal ascent.

In an early liftoff, none of the injection parameters stored in the LGC are modified by the crew because of a lack of time. These prestored injection parameters control the ascent maneuver to cutoff (see paragraph 3.3.1.9, below) at an altitude of approximately 60,000 ft, resulting in a 30-n. mi. apolune. Then, the ground supplies data for the crew to perform a P30-P41 boost maneuver at perilune to change the apolune from 30 to 45 n. mi., making the early liftoff apolune equivalent to that of a nominal ascent.

3.3.1.4 Related Routines and Extended Verbs

Following is a list of related routines associated with P12, and a brief explanation of each.

a. R02 is the IMU Status Check Routine.
b. R10 is the Landing Analog Display Routine; however, R10 use of the rendezvous radar CDU's is inhibited by P12. (Refer to paragraph 3.3.2.2.1 for a detailed explanation of R10.)
c. R41 is the State Vector Integration Routine. (Refer to paragraph 6.3.1.2.2 for an explanation of R41.)

d. R47 is the AGS Initialization Routine.* (Refer to paragraph 3.3.2.2.4 for an explanation of R47.)

e. R40 is the Thrust Fail Routine and monitors APS engine thrust failure.*

f. R03 is the DAP Data Load Routine.*

Table 3.3.1-I lists the extended verbs that can be used in P12.

3.3.1.4.1 DPS/APS Thrust Fail Routine (R40).—The Thrust Fail Routine, R40, monitors the IMU PIPA outputs for evidence of DPS or APS thrust failure. R40, automatically called by Servicer during P12, initiates engine-fail procedures if the monitor indicates a lack of thrust during engine on; that is, engine thrust remains below a given level for five cycles of the Δv monitor following ignition or during a thrusting maneuver if the engine thrust falls below a given level for 2 cycles. During liftoff, if R40 fails to recognize APS thrusting, Ascent Guidance will inhibit guidance steering and hold attitude. This failure would be indicated to the crew by a flashing VERB 97 NOUN 63 display. If the crew determine that the PGNCS is not controlling the spacecraft properly at this time, they can switch to the AGS. First, however, they should verify that the failure is genuine. A failure that is not genuine is indicated by termination of the flashing VERB 97 NOUN 63 display following a PRO on the display.

The following is a list of responses to the flashing VERB 97 NOUN 63 display:

a. The crew can, by keying PRO, re-initialize and re-enable the Δv monitor to check again whether there is sufficient thrust.

b. The crew can, by keying ENTR, return to the point in the program sequence at the flashing VERB 99 display in P12. The crew then have the following two options:

    1. They can key ENTR to the flashing VERB 99 display in order to trim.
    2. They can key PRO to the VERB 99 display to attempt to re-ignite the APS.

A peculiarity of R40 results if the APS engine does not ignite at liftoff. The LGC does not detect the absence of APS thrust as an engine thrust failure. Consequently,

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*R40 is called automatically following ignition; R03 is called before P12 is entered; and R47 is called before P12 by keying in VERB 47 ENTR into the DSKY.

TABLE 3.3.1-I

EXTENDED VERBS USED WITH P12 (SHEET 1 OF 4)

VERB	Identification	Purpose	Remarks
61 ENTR	Display Mode I DAP attitude errors.	Display on the FDAI error needles the difference between the current CDU and the DAP command angles.	This process can be selected by the crew any time during P12. The crew can use Mode I error display to monitor the DAP's ability to track automatic steering commands.
62 ENTR	Display Mode II total attitude errors.	Display on the FDAI error needles the total attitude error – (NOUN 22) desired ICDU angles minus (NOUN 20) present ICDU angles.	This process can be selected by the crew any time during P12. The crew can use Mode II error display to assist them in manually maneuvering the LM.
76 ENTR	Minimum Impulse Command Mode.	Enables the Minimum Impulse Mode of the DAP. The crew can then perform manual attitude control about all the vehicles axes with the ACA in the Minimum Impulse Mode. In addition RCS jet firings are discontinued on the lunar surface with the MODE CONT switch in ATT HOLD.	Extended VERB 76 can be selected by the crew at any time.* The crew must put the GUID CONT switch to PGNS and the MODE CONT switch to ATT HOLD.

* In particular on the lunar surface.

TABLE 3.3.1-I

EXTENDED VERBS USED WITH P12 (SHEET 2 OF 4)

VERB	Identification	Purpose	Remarks
(76 cont)			The Minimum Impulse Mode will remain enabled until canceled by the rate command mode selection (Extended VERB 77 or P63) or a fresh start. The Rate Command Mode is also automatically established at P12 ignition. It is strongly recommended that no powered flight maneuver be attempted in this Minimum Impulse Mode.
77 ENTR	Rate Command and Attitude Hold Mode.	Enables the Rate Command Mode of the DAP and sets the desired ICDU angles equal to the actual ICDU angles. The crew can then perform manual attitude maneuvers about all vehicle axes with the ACA in the RateCommand Mode.	Extended VERB 77 can be selected by the crew at any time. The Rate Command Mode will remain enabled until canceled by the Minimum Impulse Mode (see Extended VERB 76). The GUID CONT and MODE CONT switches should be set in the same way as in Extended VERB 76. The Rate Command Mode is established at DPS ignition in P63 and is automatically established in P12 at t_{IG}.

TABLE 3.3.1-I

EXTENDED VERBS USED WITH P12 (SHEET 3 OF 4)

VERB	Identification	Purpose	Remarks
82 ENTR	Orbital Parameter Display Routine (R30).	Provides the crew with pertinent orbital parameters computed by the LGC, updated every 2 seconds during AVERAGEG, to supplement orbital information provided by the ground.	Extended VERB 82 is manually selected by the crew after the engine is shut down in P12 and the LM has achieved an orbit. If TFF is not computable (perilune altitude is greater than 35,000 ft) the LGC will set TFF equal to -59B59, compute TF PER and store it in NOUN 32, which the crew can also call.

TABLE 3.3.1-I

EXTENDED VERBS USED WITH P12 (SHEET 4 OF 4)

VERB	Identification	Purpose	Remarks
85 ENTR	Display RR LOS azimuth and elevation.	To display RR antenna azimuth and elevation to the crew via VERB 16 NOUN 56 on the DSKY.	This process is selected by the crew any time another extended verb or routine is not active. The crew should note that if the RR is not in the AUTO mode the displayed angles may be incorrect due to the difference between the RR CDU and the RR resolver power supply phasing. When the RR POWER ON-AUTOBIT (bit 2 of channel 33) shows that the RR circuit breaker is pulled or the RR switch is in AUTO TRACK or SLEW, then the Zero RR CDU bit (bit 1 of channel 12) is set.

the flashing VERB 97 NOUN 63 display will not appear after this failure to ignite, no matter how long the failure persists.

The responses to the VERB 97 NOUN 63 display are not appropriate when the APS fails to ignite on the lunar surface. The Δv monitor does not consider lunar surface engine failure to be genuine, because the PIPAs are measuring the lunar gravity thrust of the surface against the LM. The APS threshold of 308 PIPA pulses over a 2-second period is below the magnitude of one lunar g ($1.62\ m/sec^2$ = lunar g; $1.54\ m/sec^2$ = threshold value). This threshold is necessary to prevent the flashing VERB 97 from appearing during P66 after touchdown on the lunar surface, while the crew are deciding whether to use the abort stage option at liftoff. Figure 3. 3. 1-1. flowcharts R40.

3.3.1.5 Computational Sequence

Before selecting P12, the crew must perform the following:

a. Update the LM and CSM state vectors in both the PGNCS and the AGS using either P22 or P27.
b. Align the IMU using P57.
c. Align the AGS to the PGNCS to allow ground control to monitor the gyro drift performance of both systems.
d. Perform the DAP Data Load Routine (R03).

At least 5 minutes before liftoff, P12 is selected and the pre-ignition phase of P12 begins. Table 3.3.1-II lists the displays for P12. Figure 3.3.1-2 gives the logical flow of P12.

The crew call P12 by keying in VERB 37 ENTR 12 ENTR into the DSKY. The first step in P12 is a check on the availability of the IMU using the IMU Status Check Routine (R02). If the IMU is not on, or the Inertial Subsystem (ISS) orientation is not known, an alarm will occur. The crew can interrogate this alarm by keying in VERB 05 NOUN 09 ENTR into the DSKY. The DSKY will display alarm code 00210* if the IMU is not on; and will display alarm code 00220* if the ISS orientation is unknown. If either alarm occurs, the crew should follow the procedure described in paragraph 3.3.1.6.

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*Alarm codes 00210 and 00220 can appear in R1, R2, or R3.

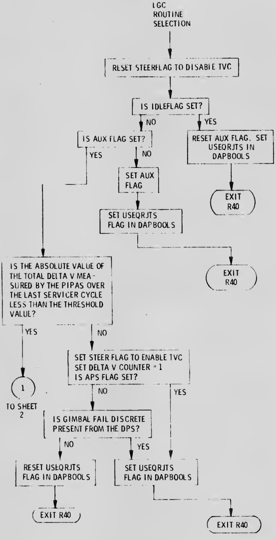


Figure 3. 3. 1-1. DPS/APS Thrust Fail Routine (R40) (Sheet 1 of 3)

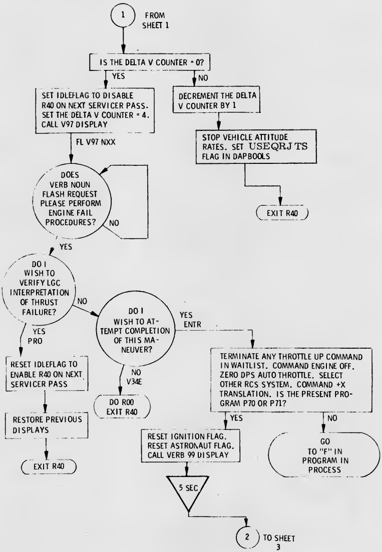


Figure 3. 3. 1-1. DPS/APS Thrust Fail Routine (R40) (Sheet 2 of 3)

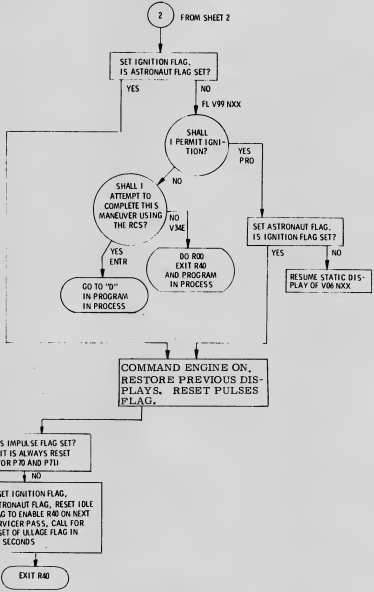


Figure 3.3.1-1. DPS/APS Thrust Fail Routine (R40) (Sheet 3 of 3)

TABLE 3.3.1-II

DISPLAYS ASSOCIATED WITH

NOMINAL ASCENT (P12) (SHEET 1 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
FL V37	R00	Request astronaut to select program	---	---
V05 N09 E	Astronaut (in R02)	Verify program alarm	00210 = ISS not on 00220 = IMU orientation unknown	R1 R2 { xxxxx* R3
FL V06 N33	P12	Display time of APS ignition for ascent for approval and/or update	Time of liftoff in hrs, mins, secs	R1 ooxxx hrs R2 oooxx min R3 oxx. xx sec
V25 E	Astronaut	Load desired t_{IG} (AS)	---	R1 ooxxx hrs R2 oooxx min R3 oxx. xx sec
FL V06 N76 ** or V06 N76 E	P12 or astronaut	Display of target parameters downrange velocity, radial velocity and crossrange for approval and/or update	ZDOTD (downrange velocity) RDOTD (radial velocity) Cross-range	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x n.mi.
V24 E	Astronaut	Change downrange and radial velocity data	---	R1 xxxx. x ft/sec R2 xxx. x ft/sec (R3 unchanged)
V23 E	Astronaut	Change crossrange to reduce amount of delta R for the ascent maneuver	---	R1 unchanged R2 unchanged R3 xxxx. x n. mi.
FL V50 N25	P12	Request DESIRED modes for guidance and attitude control for ascent be selected as follows: GUID CONT→PGNS ATT CONT→AUTO	ENTR = bypass request PRO = accept request by changing modes first	R1 00203_8 R2 Blank R3 Blank

* Alarm code may appear in R1, R2, or R3

** Can be called in P12 after t_{IG} . Any change to R3 (cross-range) is not effective, after the automatic display appears.

TABLE 3.3.1-II

DISPLAYS ASSOCIATED WITH

NOMINAL ASCENT (P12) (SHEET 2 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
V06 N74	P12	Display time from ignition, predicted FDAI yaw at completion of yaw maneuver and predicted FDAI pitch at completion of pitch maneuver for comparison with actual values	Time from ignition (counted down) FDAI yaw angle predicted FDAI pitch angle predicted	R1 xxBxx min, sec R2 xxx.xx deg R3 xxx.xx deg
V05 N09 E	Astronaut (R41)	Verify program alarm in R41	01703 = t_{IG} slipped during state vector integration	R1 R2 { 01703 * R3
FL V99 N74	P12	Please perform APS engine on enable at t_{IG} -5 sec	Same displays as V06 N74	R1 xxBxx min, sec R2 xxx.xx deg R3 xxx.xx deg
V06 N63	P12 (nominal display)	Display current velocity, rate of change of altitude, and altitude of the LM for monitoring during entire APS burn	Magnitude of LM inertial velocity Present rate of change of altitude Present altitude of the LM above the position vector at t_{IG}	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxxx ft
V05 N09 E	Astronaut (FINDCDUW routine)	Verify program alarm	00401 - desired middle gimbal angle exceeds 70 deg. 00402 - FINDCDUW not controlling attitude	R1 R2 { xxxxx* R3

* Alarm code may appear in R1, R2, or R3

TABLE 3.3.1-II

DISPLAYS ASSOCIATED WITH

NOMINAL ASCENT (P12) (SHEET 3 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
FL V16 N63	P12	Informs crew of APS engine shutdown	Same as V06 N63; i.e., inertial velocity, present altitude, present rate of change of altitude	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxxx ft
FL V16 N85* or V16 N85E	P12 or astronaut*	Monitor v_G components during APS burn and after APS shutdown to monitor v_G residuals during RCS trimming	Components of the present velocity to be gained vector along LM X, Y, Z axis (VGX, VGY, VGZ)	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
V16 N77E	Astronaut	To display additional components to be used in monitoring APS engine shutdown	Estimated time of flight from present time to ascent injection (i.e., TG) Magnitude of velocity vector component normal to the CSM orbital plane (V (Y))	R1 xxBxx min, sec (-polarity) R2 xxxx.x ft/sec R3 Blank **
V85 E giving FL V16 N56	Astronaut	To display RR LOS azimuth and elevation before t_{IG}	Azimuth - angle between LM X/Z plane and the RR LOS vector Elevation - angle between the LM +Z-azis and the projection of the RR LOS vector on the LM X/Z plane	R1 xxx.xx deg R2 xxx.xx deg R3 Blank

*V16 N85 can be called anytime after t_{IG} to monitor v_G components during the APS burn.

**R3 would not be blank if keyed in over another display in which R3 was not blank (i.e. V06 N63).

TABLE 3.3.1-II

DISPLAYS ASSOCIATED WITH

NOMINAL ASCENT (P12) (SHEET 4 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
V82 E*	Astronaut	To call R30, the Orbital Parameter Display routine	---	---
FL V16 N44	R30	Display orbital parameter information to supplement ground information	Apolune altitude of LM orbit Perilune altitude of LM orbit Time of free fall to 35,000 ft	R1 xxxx.x n.mi. R2 xxxx.x n. mi R3 xxBxx min, sec
(FL) V06 N32 E** or (FL) V16 N32 E	Astronaut	Display time from perilune ***	TFF perilune in hrs, mins, secs	R1 ooxxx hrs R2 oooxx min R3 oxx.xx sec

* VERB 82 can be keyed in after APS engine shutdown (i.e. after V16 N63)

** NOUN 32 display flashes if keyed in over a flashing display. V06 or V16 can be used to call the NOUN 32 display.

*** If TFF is not computable, i.e., perilune exceeds 35,000 ft., the LGC sets TFF to -59B59 and computes TF perilune storing it in the NOUN 32 display.

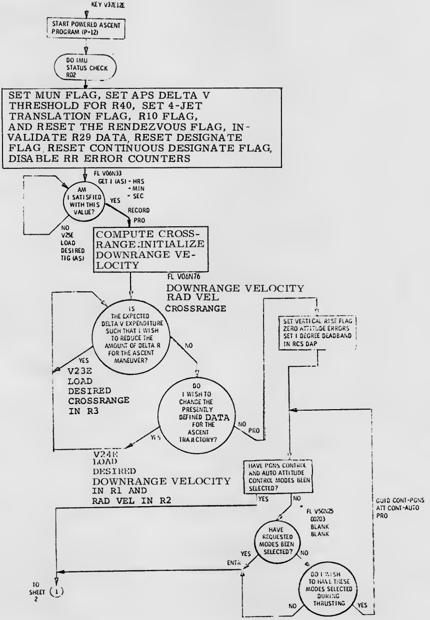
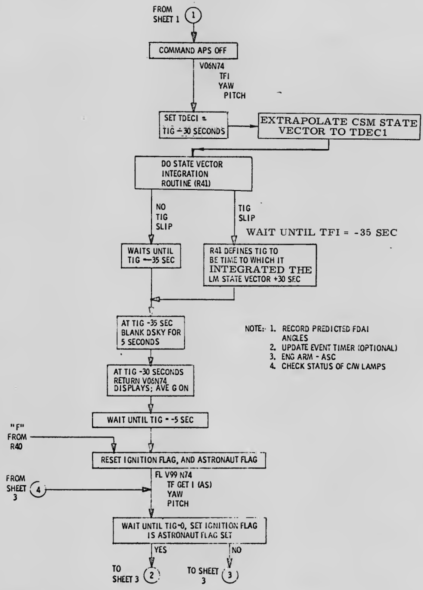


Figure 3.3.1-2. Nominal Ascent Program (P12) (Sheet 1 of 5)



NOTE: 1. RECORD PREDICTED FDAI ANGLES
2. UPDATE EVENT TIMER (OPTIONAL)
3. ENG ARM - ASC
4. CHECK STATUS OF C/W LAMPS

Figure 3.3.1-2. Nominal Ascent Program (P12) (Sheet 2 of 5)

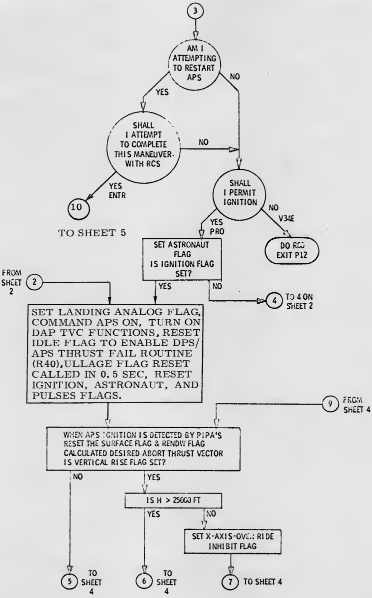


Figure 3.3.1-2. Nominal Ascent Program (P12) (Sheet 3 of 5)

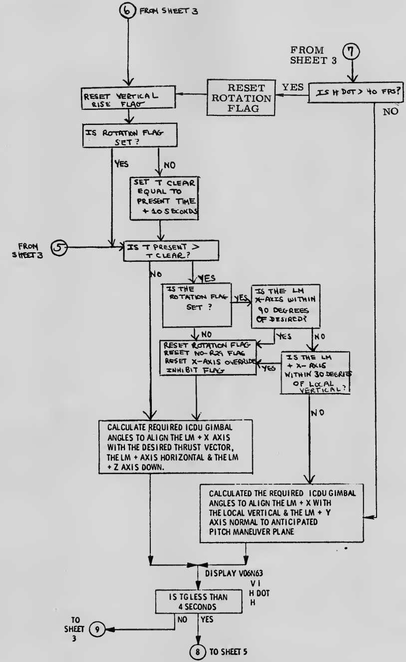


Figure 3.3.1-2. Nominal Ascent Program (P12) (Sheet 4 of 5)

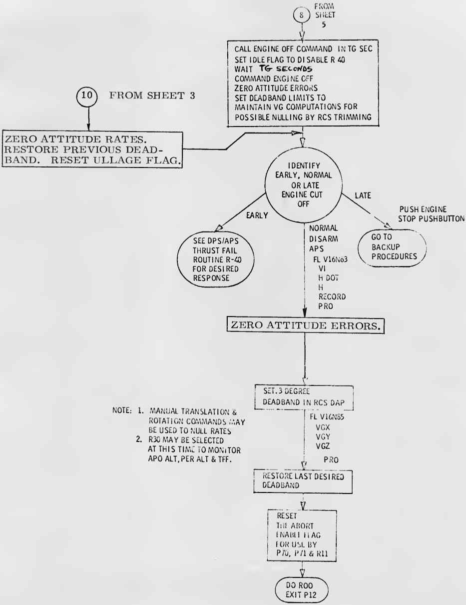


Figure 3.3.1-2. Nominal Ascent Program (P12) (Sheet 5 of 5)

The crew then see the flashing VERB 06 NOUN 33 display containing the t_{IG} value on the DSKY. If the t_{IG} is satisfactory, the crew record it and key in PRO to continue. If the crew wish to update the value of t_{IG} displayed, VERB 25 ENTR is keyed in and R1, R2 and R3 are loaded with the new value of t_{IG} before PRO is keyed.

Following the computation of targeting information by the LGC, the DSKY displays—via the flashing VERB 06 NOUN 76—downrange velocity, radial velocity, and crossrange in R1, R2 and R3, respectively for crew approval. If the crew accept the values displayed on the DSKY, they key PRO to continue P12. In a nominal liftoff, however, the crew update the values of downrange and radial velocity for the ascent maneuver by keying in VERB 24 ENTR into the DSKY and loading the new values in R1 and R2 before keying PRO to continue. The crew now also have the option of specifying a new value for the crossrange displayed in R3 by keying in VERB 23 ENTR and loading R3 at this time. After the target information has been updated in the LGC, the crew should check that the GUIDANCE CONT switch is set to PGNS and the spacecraft PGNS switch on the MODE CONT panel is in AUTO. If the switches are not set as indicated, a flashing VERB 50 NOUN 25 display appears, with R1 having a value of 00203, requesting that the crew perform the above settings. If the request is redundant, or the request is to be rejected, the crew key ENTR into the DSKY to allow P12 to continue. If the crew change the modes, they key PRO as the response to the display.

The next display the crew see on the DSKY is the static VERB 06 NOUN 74 display of TFI, the predicted FDAI yaw, and predicted FDAI pitch angles during the early phases of Ascent Guidance. (Refer to subsection 3.3 for a description of the two early phases of Ascent Guidance.) The crew monitor the NOUN 74 display—in particular the TFI value. During the countdown phase, the LGC CMPTR ACTY light will go on indicating that the State Vector Integration Routine (R41) has been called to update the state vector. If the t_{IG} is slipped during R41 computations, the program alarm light illuminates. If the crew key VERB 05 NOUN 09 ENTR into the DSKY, alarm code 01703 appears indicating that t_{IG} has been slipped.* The crew should follow procedures defined in paragraph 3.3.1.6 on alarms. At t_{IG}-35 seconds, the DSKY blanks for five seconds and returns at t_{IG}-30 with the static VERB 06 NOUN 74 display indicating to the crew that AVERAGEG integration has started. Then, at t_{IG}-5 seconds, the DSKY changes from VERB 06 to a flashing VERB 99. This is a request to the crew to please perform engine on enable. In response to the flashing VERB 99 display, the crew can terminate P12 at this time by keying in

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*Alarm code 01703 can appear in R1, R2, or R3.

VERB 34 ENTR into the DSKY. The crew perform the engine on enable by putting the ENG ARM switch on the ENGINE THRUST CONT panel to the ASC setting. If the crew key in PRO, the DSKY returns to the VERB 06 NOUN 74 display until ignition takes place. When TFI is zero, the crew depress the ABORT STAGE and the START pushbuttons to protect against single-point engine shutdown failure.

At liftoff and during the entire APS burn in P12, the Thrust Fail Monitor Routine (R40) is active in order to detect any thrust failures and initiate engine thrust fail procedures. If the LGC detects thrust failure, a flashing VERB 97 appears to the crew. The crew have the option of keying in PRO to verify that there really is a failure, ENTR to complete the maneuver, or VERB 34 ENTR to terminate P12. (A more detailed explanation of the responses is given in paragraph 3.3.1.4.1.) The crew can also key in VERB 37 ENTR 00 ENTR at this time to terminate P12.

Upon a successful ignition, the Ascent Guidance takes over. During the entire APS burn, the crew monitor the VERB 06 NOUN 63 display on the DSKY giving values of VI, HDOT, and H, as well as the FDAI readings, in order to identify PGNCS and engine performance and anticipate engine shutdown. During the early phases of the ascent, the crew will attempt to override any action of the LGC to command an early engine shutdown. Note that R40 is not called in the event of an LGC-commanded shutdown. If the LGC calls for a premature cutoff, the crew would probably go to the AGS or, in the case of a small remaining Δv, use the RCS jets for insertion. The crew continue to monitor the VERB 06 NOUN 63 display noting that the inertial velocity in R1 is increasing. When a predetermined velocity or time to go has been reached, as indicated either by the NOUN 63 display of VI or, optionally by the NOUN 77 display of TG (which is the estimated time of flight from present time to ascent injection), the crew prepare for engine shutdown by first performing APS/RCS propellant interconnect and then putting the ENG ARM switch on the ENGINE THRUST CONT panel to OFF. Putting the ENG ARM switch to OFF removes manual engine-on signal and enables automatic shutdown by P12. As stated above, the crew can either monitor the VERB 06 NOUN 63 display during ascent or, optionally, they can key in VERB 16 NOUN 77 ENTR into the DSKY to display TG and V(Y) (which is the magnitude of the LM velocity component normal to the CSM orbital plane) and use the value of TG to monitor for shutdown. When they are finished with the NOUN 77 display, the crew should depress the KEY REL pushbutton on the DSKY to return to NOUN 63.

Shutdown of the APS should occur when VI, as seen in NOUN 63, is equal to or greater than 5510 ft/sec, or TG, as seen in NOUN 77, is less than 1 sec. If this shutdown does not occur, the crew should reset the ABORT STAGE pushbutton.

After the automatic shutdown, the crew record the values on the DSKY, which at shutdown changes to a flashing VERB 16 NOUN 63. If the crew want to terminate P12, in response to the flashing VERB 16 NOUN 63 display, they key VERB 34 ENTR into the DSKY, or—in response to the flashing display—the crew can key PRO to display VERB 16 NOUN 85 on the DSKY and examine the velocity residuals. If they desire to null out the v_G values, the crew set the spacecraft PGNS switch to ATT HOLD and use the attitude controller assembly (ACA) and the thrust translation controller assembly (TTCA) to null out VGX, VGY, VGZ. When the crew are satisfied with the residuals as seen in NOUN 85, they key in PRO or VERB 34 ENTR (terminate) into the DSKY to terminate P12 or optionally they can call R30, the Orbital Parameter Display Routine, (by keying in VERB 82 ENTR into the DSKY) and then re-establish the NOUN 85 display to terminate P12 as above.

3.3.1.6 Alarms

In addition to the normal output that can be expected from P12, alarms may occur requiring crew action. The crew can obtain a display of the alarm code by keying in VERB 05 NOUN 09 ENTR. The following is a list of alarms that may occur during P12 and a brief explanation of each:

a. Alarm 00220 occurs if the IMU is not aligned.
b. Alarm 00210 occurs if the IMU is not operating.
c. Alarm 01703 occurs if the t_{IG} is slipped during state vector integration.
d. Alarm 00401 occurs if the desired middle gimbal angle exceeds 70 degrees.
e. Alarm 00402 occurs if the FINDCDUW is not controlling attitude.

If alarm code 00220 is displayed, the crew should depress RSET on the DSKY and align the IMU. If the IMU is already aligned, the crew must set the REFSMMAT flag.

Alarm code 00210 is unlikely to occur. Should it occur, however, indicating the IMU is not operating, the crew should depress RSET on the DSKY, turn on the IMU, wait 15 minutes, then perform a P57 alignment.

Should alarm code 01703 be displayed, indicating that the t_{IG} has been slipped during state vector integration, the crew should depress RSET on the DSKY. If t_{IG} has been slipped appreciably, t_{IG} will be re-established after one CSM revolution. There is , however, specified ignition total allowable time delay. This is the total time the thrusting maneuver may be delayed beyond the LGC-calculated t_{IG}. It is up to the crew to account for this time.

Alarm code 00401 is unlikely to occur, since it is displayed if the desired middle gimbal angle exceeds 70 degrees, warning the crew that continuing the maneuver might yield gimbal lock. If this alarm occurs, it probably indicates that the PGNCS is not functioning properly and the crew should switch to AGS.

Alarm code 00402 is displayed if the FINDCDUW routine is not controlling attitude. The crew should either terminate thrust or go to the AGS as backup.

3.3.1.7 Restarts

P12 is restart protected. Should a software restart occur, and no other restart protection exists at that point, the PROG alarm light would be illuminated and the program would go back to the last flashing display before the restart. Should a hardware restart occur, the RESTART light on the DSKY would be illuminated.

3.3.1.8 Primary Guidance (PGNCS) and Abort Guidance (AGS) Navigation Control Systems

If the Primary Guidance, Navigation and Control System should fail during P12, the crew can switch to the Abort Guidance System to take the LM to a safe orbit.

The AGS calculates information in a manner analogous to the PGNCS and normally operates parallel to the PGNCS during descent and ascent. In this way, the AGS serves as a check on the PGNCS. The crew can monitor the performance of the PGNCS by switching from one system to another. While the LM is under AGS control, the PGNCS still operates. During a thrusting maneuver done under AGS control, the LGC will continue computations of the position and velocity, desired thrust vector, and desired attitude errors, but the PGNCS will not be responsible if any register overflows occur.

3.3.1.9 P12 Engine Shutdown

Engine shutdown involving the Ascent Propulsion System (APS) may occur during P12 for two reasons:

a. Shutdown occurring normally because target conditions have been achieved
b. Shutdown occurring prematurely because of a lack of thrust. Premature shutdown, noted by the Thrust Fail Routine, R40, is indicated to the crew by a flashing VERB 97 NOUN 63 display on the DSKY. (Refer to

paragraph 3.3.1.4.1 for a description of R40 and responses to flashing VERB 97 NOUN 63.)

The crew get an approximation to the time of P12 engine shutdown by keying in VERB 16 NOUN 85 to get the v_G display or by keying in VERB 16 NOUN 77 to get the estimated time of flight from present time to time of injection. (See Table 3.3.1-II.)

In the v_G display, R1, R2 and R3 contain the components of the velocity to be gained vector along the LM X, Y and Z axes, respectively (i.e., VGX, VGY, VGZ). When VGX reaches 200 ft/sec with engine on, the PGNCS system prepares for a controlled shutdown. As VGX approaches zero, the engine should shut off. If not, the crew push the engine STOP pushbutton.

Under normal conditions (i.e., target conditions have been achieved), following APS engine shutdown, the VGX residual should be trimmed by firing the RCS jets. Under premature shutdown conditions, if the APS cannot be restarted, the RCS jets are used to attain insertion (i.e., to achieve target conditions). In the latter case, however, the RCS jets may be used to attain insertion only if the APS fails less than 60 seconds before injection. Note that if insertion were obtained with a degraded PGNCS or AGS, a tweak burn would be performed within 2 minutes after insertion. Thrusting parameters Δv_x and t_{IG} are supplied by the ground 30 seconds after insertion. The PGNCS program, P47, would be used for this burn.

3.3.1.10 FDAI Displays

An important aspect of the P12 pre-ignition phase is the display to the crew of those FDAI readings associated with the early phases of the ascent maneuver. These displays, obtained by the VERB 06 NOUN 74 display (see the computational sequence), include (1) the yaw angle that should be present on the FDAI at the end of the vertical rise phase before pitchover, and (2) the FDAI pitch attitude after pitchover has been completed. A comparison of these displays with FDAI readings indicates to the crew whether or not the PGNCS guidance is functioning properly. If not, the crew can switch to the AGS as backup. For a detailed explanation of the vertical rise and pitchover maneuvers associated with Ascent Guidance, refer to subsection 3.3.

3.3.2 P70, Descent Propulsion System Abort

P70 (like P12 and P71) is basically an initialization program whose function is to supply targets for Ascent Guidance. (Refer to subsection 3.3.) P70 is used for Descent Propulsion System (DPS) aborts and can be called at any time from ignition at PDI until P68, the Landing Confirmation Program, is called. P70, however, should not be used during the last part of the landing maneuver and surface stay—up to the entry of P68—since the DPS fuel is almost depleted by then. (At least 1 minute of low DPS-thrust fuel should be left when the abort (P70) is called in order to attain 15 seconds of maximum DPS thrust.)

P70 serves to (1) set up guidance targets, and (2) initialize the engine parameters needed for the Ascent Guidance. These parameters are computed by taking into account the current mass at the time of the abort (i.e., at the time P70 is called).

During the powered landing maneuver programs (P63, P64, and P66) the Abort Discretes Monitor Routine (R11) checks both the ABORT (P70) and the ABORT STAGE (P71) pushbuttons to determine if either pushbutton has been depressed. (Refer to paragraph 3.3.3 for an explanation of P71, the APS abort.) If the ABORT pushbutton has been depressed, R11 calls up P70, terminating the landing programs. P70 (as well as P71) is capable of controlling the abort maneuver to achieve ascent orbit injection analogous to that achieved by P12. (Refer to paragraph 3.3.1.) P70 can also be called manually by keying VERB 37 ENTR 70 ENTR into the DSKY. The method by which either of the abort programs is called is determined by time limitations.

Timing within an abort maneuver, itself, is variable, ranging from a few seconds using the RCS jets to nearly the full 7 min 10 sec of the nominal ascent. If the abort occurs early in PDI, Ascent Guidance will put the LM in a high apolune orbit (approximately 130 n. mi.) that allows the CSM to catch up with the LM. If the abort occurs late in PDI, Ascent Guidance will put the LM in a low apolune orbit (approximately 30 n. mi.) that allows the LM to catch up to the CSM. Figure 3.3.2-1 illustrates abort criteria. The figure should be used as a reference for answering specific questions on aborting.

Primarily, P70 would control a non-PGNCS, non-DPS failure during the landing sequence if the abort occurred after PDI and before touchdown. Figure 3.3.2-2 illustrates the timeline for an abort during the landing sequence. Note that the LM Guidance Computer (LGC) does not automatically select the APS Abort Program (P71) if the DPS runs out of fuel. Therefore, the crew must anticipate fuel exhaustion

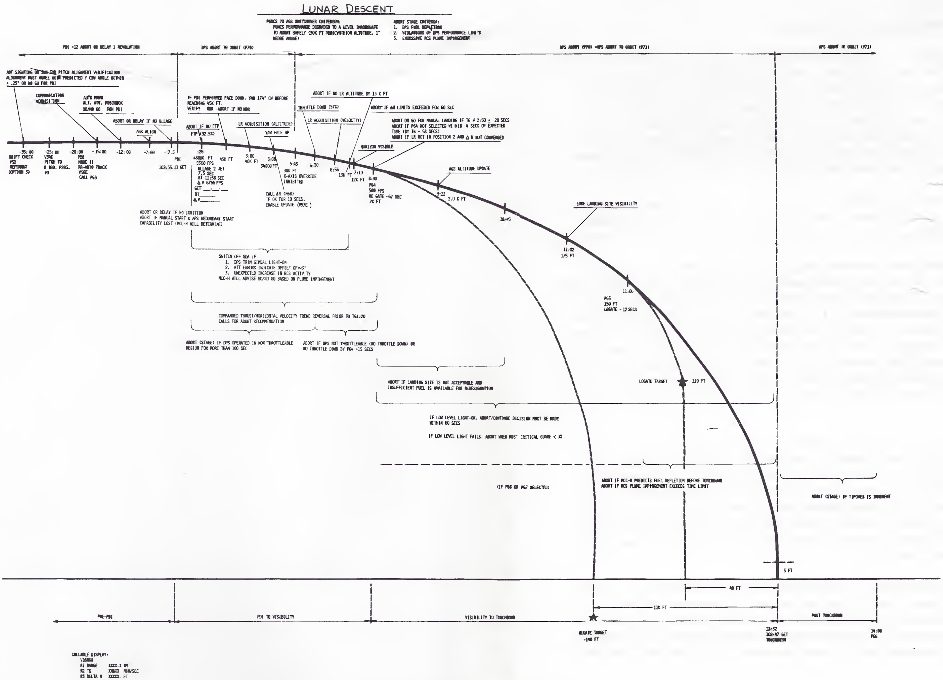

Figure 3.3.2-1. Abort Criteria

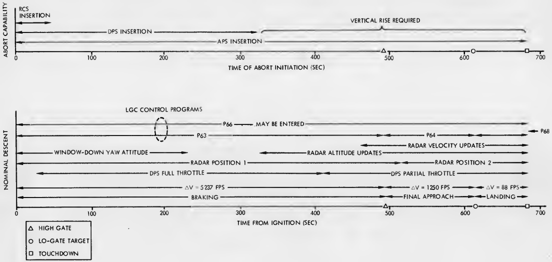

Figure 3.3.2-2. Powered Descent Timelines

and be prepared to select P71. P70 does, however, indicate engine cutoff and notifies the crew of this cutoff by a flashing VERB 97 when DPS fuel is depleted before orbit insertion is achieved. Refer to paragraph 3.3.2.2.3.

In an abort, an overshoot of 2.4 ft/sec downrange velocity could occur and is acceptable. Thus, during the last part of the burn, the crew could key VERB 16 NOUN 85 into the DSKY to obtain the display of the velocity remaining. After the burn the crew then have the option of nulling out the velocity residuals using the RCS jets. The decision to fire the RCS jets is based on the following:

a. The value of v_G remaining at DPS cutoff
b. Whether the DPS has been staged or not.

3.3.2.1 Abort Targeting

Abort targeting is an automatic process. Since aborts can happen at any time, no predetermined phasing is possible. Refer to subsection 3.3 for a listing of targets provided during P12, P70 and P71.

Some attempt must be made, however, to have the insertion targets provide an orbit which facilitates the rendezvous. Thus for APOLLO 11, ZDOTD was a cubic function of the time at which the abort had taken place. This calculation was done only once, however, during the initialization. For APOLLO 12, a continuous targeting scheme was developed. In this scheme, the major axis (i.e., the period of the orbit) of the targeted orbit is selected as a linear function of the current phase angle (θ) between the LM and the CSM. Then ZDOTD is computed from the major axis and the estimated insertion altitude. This computation is repeated every 2 sec during Ascent Guidance. As the LM approaches cutoff, the current phase angle approaches the phase angle for insertion.

During initialization, depending on the phase angle at abort (currently, if the CSM has a lead angle greater than 6.72 deg, the second orbit rendezvous is selected), a choice is automatically made between two different linear functions of θ —one representing first orbit rendezvous, the other second orbit rendezvous. The selection of the linear functions is final and is not re-examined during the burn. The crossrange value is restricted in magnitude to a pad-loaded value. Presently the maximum allowable value is constrained to 0.5 deg or 8 n. mi.

3.3.2.2 Related Routines and Extended Verbs

The following is a list of routines associated with P70:

a. Landing Analog Display Routine (R10)
b. Abort Discretes Monitor Routine (R11)
c. DPS/APS Thrust Fail Routine (R40)
d. AGS Initialization Routine (R47).

These routines are described in some detail below.

3.3.2.2.1 Landing Analog Displays Routine (R10).—Figure 3.3.2-3 is a flowchart of R10. R10 is used to monitor the display inertial data discrete. The absence of this discrete indicates that the crew have selected one or more of the following LGC-calculated display parameters for display on the LM meters:

a. Forward velocity
b. Lateral velocity
c. Altitude—the present altitude of the LM above the lunar radius at the designated landing site
d. Altitude rate—present rate of change of altitude.

R10 calculates these display parameters and transmits them to the LM meters when the display inertial data discrete is available. This routine is automatically called every 0.25 second by the Abort Discretes Monitor Routine (R11). Note that R11 will be inhibited from using the RR CDUs (forward and lateral velocity crosspointer) during P12, P70 and P71. Thus, only the altitude and altitude rate will be displayed in P12, P70 and P71. R10 is terminated when AVERAGEG is terminated.

3.3.2.2.2 Abort Discretes Monitor Routine (R11). —Figure 3.3.2-4 is a flowchart of R11. R11 is used to monitor the abort and abort stage discretes to the LGC, which indicate whether the crew desire to abort from the powered landing maneuver. If the crew depress the ABORT pushbutton (for a DPS abort maneuver, P70) or the ABORT STAGE pushbutton (for an APS abort maneuver, P71), R11 selects the correct LGC program for the abort commanded by the crew. In addition, R11 calls the Landing Analog Display Routine (R10). Refer to paragraph 3.3.2.2.1.

R11 is called every 0.25 second by the R10/R11/R12 Service Routine (R09), only when AVERAGEG is in progress, during P12, P63, P64, P66, P70 or P71.

THIS ROUTINE AUTOMATICALLY CALLED
DURING P12, P63, P64, P66, P70 AND P71

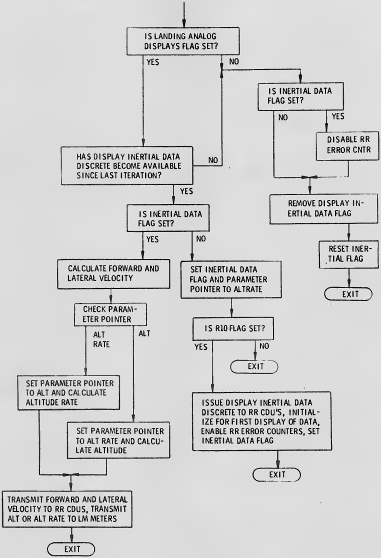

Figure 3.3.2-3. Landing Analog Displays Routine (R10)

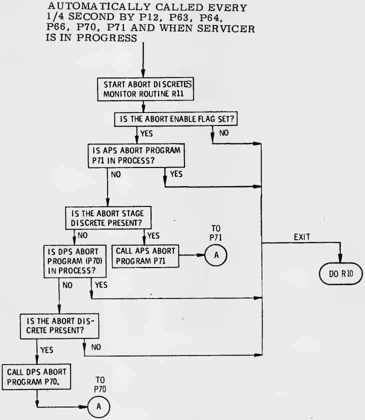

Figure 3.3.2-4. Abort Discretes Monitor Routine (R11)

3.3.2.2.3 DPS/APS Thrust Fail Routine (R40).—The Thrust Fail Routine (R40), automatically called by P70 every 2 seconds, monitors the IMU PIPA outputs for evidence of DPS thrust failure during the DPS abort (P70). R40 initiates engine-fail procedures if the thrust monitor indicated a lack of engine thrust upon engine turn-on or during a thrusting maneuver. Refer to paragraph 3.3.1 for a flowchart of R40.

Initially, the thrusting program (i.e., P70) will set the Δv counter to 4. Consequently, R40 would not initiate engine-fail procedures after the nominal ignition time, unless engine thrust is detected to be below 36 cm/sec for 4 cycles of the Δv monitor. The DPS abort (P70) sets the threshold value for the Δv comparison equal to 36 cm/sec. This value is set so that normal 10 percent throttling of the DPS will not indicate a thrust failure. During a thrusting maneuver, R40 would be called if engine thrust is below a given level for 2 cycles of the Δv monitor.

Engine thrust failure is indicated to the crew by a flashing VERB 97 NOUN 63 on the DSKY during the DPS Abort (P70). Before responding to this flashing VERB 97 display, the crew should verify that the thrust failure is indeed genuine. (See responses to the display, below.) The following are the responses to the VERB 97 NOUN 63 display in P70.

a. If the crew wish to verify the LGC interpretation of thrust failure, they key in PRO at the time the flashing VERB 97 display first appears. If the flashing display terminates, the failure was not genuine and the DPS Abort (P70) continues with the normal thrusting display restored. If the flashing display reappears, they must follow one of the procedures discussed below.

b. If the crew wish to terminate P70, they key VERB 34 ENTR (terminate) into the DSKY. This termination of P70 indicates that the crew do not wish to complete the DPS maneuver.

c. If the crew want to complete the DPS abort, they key in ENTR to the flashing VERB 97 display. The crew then have the following choices before continuing the DPS Abort:

    1. To attempt completion of the DPS Abort maneuver using the RCS jets, the crew key in ENTR to the flashing VERB 97 display. Then, in response to the flashing VERB 99 display, the crew key in ENTR. (See paragraph 3.3.2.3.)

2. To attempt a restart of the DPS in P70, the crew first key in ENTR to the flashing VERB 97 display and then key in PRO to the flashing VERB 99 display to continue the DPS Abort.*

3. To terminate P70, the crew can also key in VERB 34 ENTR (terminate) into the DSKY in response to the flashing VERB 99 display if they do not want to re-ignite the DPS or use the RCS jets.

3.3.2.2.4 AGS Initialization Routine (R47).—Figure 3.3.2-5 is a flowchart of R47. R47 is used to provide the AGS abort electronics assembly (AEA) with the LM and CSM state vectors in LM IMU coordinates. R47 does this by means of the LGC digital downlink. R47 zeros the ICDU, LGC and AEA gimbal angle counters (only when the IMU is on, but the IMUSE flag is not set) simultaneously establishing a common zero reference to measure the gimbal (Euler) angles. These Euler angles define the LM attitude with respect to the IMU Stable Member. R47 establishes the ground elapsed time (GET) of the AEA clock as zero if the clock is initialized during this routine. (Flashing VERB 06 NOUN 16 is used to define the zero value for the clock in terms of GET. Refer to Figure 3.3.2-5.)

The capability of selecting another program (other than P00) by keying in VERB 37 ENTR into the DSKY is inhibited by the LGC during R47. If VERB 37 is used, program alarm 01520 will result. If the crew desire to select another program, they must either complete R47 or select P00. R47 can be selected by the crew anytime—when no other extended verb is in use. The crew would select R47 by keying VERB 47 ENTR into the DSKY before the Powered Landing Programs (P63, P64, and P66) or P12 is selected.

Table 3.3.2-I lists the extended verbs available to the crew during P70 and gives a brief explanation of each.

3.3.2.3 Computational Sequence

When the DPS Abort (P70) is called, the thrust magnitude filter is initialized. Because there is a decrease in vehicle mass during the descent burn before entry of P70,

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* The LGC will not perform throttle control (i.e., throttle will be set to minimum by the LGC). Ascent Guidance will not attempt to control the thrust vector until the thrust level exceeds a minimum value. Therefore, unless the crew advance the throttle soon after the attempted restart of the DPS, an overburn might result. Consequently, after restarting the DPS, any further DPS throttle control in P70 must be done by the crew.

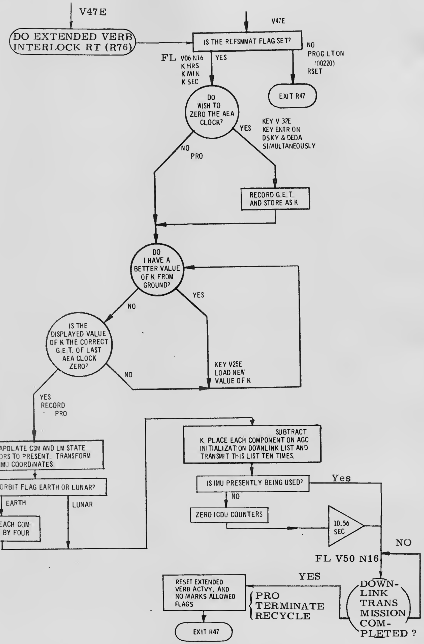

Figure 3.3.2-5. AGS Initialization Routine (R47)

TABLE 3. 3. 2-I

EXTENDED VERBS USED WITH DPS ABORT (P70) (SHEET 1 OF 3)

Verb	Identification	Purpose	Remarks
61 ENTR	Display Mode I DAP attitude errors.	Display on the FDAI error needles the difference between the current CDU and the DAP command angles.	This process can be selected by the crew any time during P70. The crew can use Mode I error display to monitor the DAP's ability to track automatic steering commands.
62 ENTR	Display Mode II total attitude errors.	Display on the FDAI error needles the total attitude error—(NOUN 22) desired ICDU angles, minus (NOUN 20), present ICDU angles.	This process can be selected by the crew any time during P70. The crew can use Mode II error display to assist them in manually maneuvering the LM.
65 ENTR	Disable U, V jets during DPS burns.	Inhibits U and V (pitch-roll) RCS jet firings during DPS powered flight.	The crew can select Extended VERB 65 at any time in P70, but VERB 65 is intended mainly for P40 use.
75 ENTR	Enable U, V jets during DPS burns.	Enables U and V (pitch-roll) RCS jet firings during DPS powered flight.	Extended VERB 75 as is Extended VERB 65 is mainly for P40 use, but is available to the crew in P70.
76 ENTR	Minimum Impulse Command Mode.	Enables the Minimum Impulse Mode of the DAP. The crew can then perform manual attitude control about all the vehicles axes with the ACA in the Minimum Impulse Mode.	Extended VERB 76 can be selected by the crew at any time. The crew must put the GUID CONT switch to PGNS and the MODE CONT switch to ATT HOLD.

TABLE 3.3.2-I

EXTENDED VERBS USED WITH DPS ABORT (P70) (SHEET 2 OF 3)

Verb	Identification	Purpose	Remarks
(76 cont)			The Minimum Impulse Mode will remain enabled until canceled by the rate command selection. (Extended VERB 77 or P63) or a fresh start. It is strongly recommended that no powered flight maneuver be attempted in this Minimum Impulse Mode. The Minimum Impulse Mode is also canceled when P70 is first entered.
77 ENTR	Rate Command and Attitude Hold Mode.	Enables the Rate Command Mode of the DAP and sets the desired ICDU angles equal to the actual ICDU angles. The crew can then perform manual attitude maneuvers about all vehicle axes with the ACA in the Rate Command Mode.	Extended VERB 77 can be selected by the crew at any time. The Rate Command Mode will remain enabled until canceled by the Minimum Impulse Mode (see Extended VERB 76). The GUID CONT and MODE CONT switches should be set in the same way as in Extended VERB 76. Note that the Rate Command Mode is established at DPS ignition in P63 and when P70 is first entered.

TABLE 3.3.2-I

EXTENDED VERBS USED WITH DPS ABORT (P70) (SHEET 3 OF 3)

Verb	Identification	Purpose	Remarks
82 ENTR	Orbital Parameter Display Routine (R30).	Provides the crew with pertinent orbital parameters computed by the LGC, updated every 2 seconds during AVERAGEG, to supplement orbital information provided by the ground.	Extended VERB 82 is manually selected by the crew after the engine is shut down in P70, and the LM has achieved an orbit. If TFF is not computable (perilune altitude is greater than 35,000 ft) the LGC will set TFF equal to -59B59 compute TF PER and store it in NOUN 32, which the crew can call also.

the vehicle dynamics must be related to the current mass. After the engine performance and thrust filter initialization, the target conditions are set up for the abort. The desired cutoff conditions are then transferred from fixed to erasable storage so that the target conditions may be updated. Finally t_{go} is established as being:

$$t_{go} = t_{abort} - t_{IG}\,(PDI)$$

Table 3.3.2-II lists the displays associated with P70. Figure 3.3.2-6 illustrates the logical flow of P70. Reference should be made to the table and flowchart while reading the computational sequence detailed below.

P70, the DPS Abort Program is called by depressing the ABORT pushbutton or by keying in VERB 37 ENTR 70 ENTR into the DSKY. If P70 is incorrectly selected for one of the following reasons, the OPR ERR light will be turned on informing the crew of the error:

a. P70 is already in progress.
b. The ABORT ENABLE flag is not set. *
c. P68, the Landing Confirmation Program, was called prohibiting any further calls to P70.
d. The AVERAGEG flag is not set.

If P70 is correctly selected, P70 is displayed on the DSKY indicating that the DPS Abort Program (P70) has started. After a few flags are appropriately set, the DPS engine is commanded on by P70. Note that if a total thrust failure has occurred, the crew would have to apply manual RCS translation until P70 automatically commands the DPS engine on.

Since the crew—before selecting the abort—was in the process of landing the LM, the LGC now removes the inertial data discrete from the CDUs and restarts R10, the Landing Analog Display Routine. In addition to the above, the LGC also controls the following processes:

a. Sets 1.0 degree deadband.
b. Terminates thrust vector control.
c. Holds inertial vehicle attitude.
d. Sets the Δv counter to 4 for use by R40, the Thrust Fail Routine.
e. Enables the current guidance displays.
f. Resets the IDLE and RCS flags.
g. Sets the 4 jet translation flag.

*P63 sets the ABORT ENABLE flag.
P71 resets the ABORT ENABLE flag.

TABLE 3. 3. 2-II

DESCENT PROPULSION ABORT DISPLAYS (P70) (SHEET 1 OF 3)

DSKY	Initiated by	Purpose	Condition	Register
FL V37	R00	Request Astronaut to select program (if ABORT push-button not used)	---	---
FL V50 N25	P70	Request desired modes for Guidance and attitude control for DPS abort be selected as follows: GUID CONT - PGNS ATT CONT - AUTO THROTTLE MODE - AUTO	ENTR - bypass request PRO - accept request by changing modes first	R1 00203_8 R2 Blank R3 Blank
V06 N63	P70	Display current velocity, rate of change of altitude, and altitude of the LM for monitoring DPS abort	Magnitude of the LM inertial velocity Present rate of change of altitude Present altitude of the LM above the LM position vector at the designated landing site, polarity is + for altitudes greater than the above radius.	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxxx ft
V05 N09 E	Astronaut (FINDCDUW routine)	Verify program alarm	00401 - desired middle gimbal angle exceeds 70 deg. 00402-FINDCDUW not controlling attitude.	R1 R2 R3 xxxxx*
FL V16 N63	P70	Informs crew of DPS engine shutdown	Same as V06 N63 data	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxxx ft

* Alarm code may appear in R1, R2, or R3

TABLE 3.3.2-II

DESCENT PROPULSION ABORT DISPLAYS (P70) (SHEET 2 of 3)

DSKY	Initiated by	Purpose	Condition	Register
FL V16 N85 or V16 N85 E**	P70 or Astronaut	To monitor v_G components remaining during the DPS burn and after DPS shutdown to monitor the v_G residuals during RCS trimming	Components of the present velocity to be gained vector along the LM X, Y, Z axis (VGX, VGY, VGZ)	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec
V06 N76 E	Astronaut	To display targeting information	Downrange velocity Radial velocity Crossrange	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x n. mi.
V16 N77 E	Astronaut	To display additional components to be used in monitoring DPS engine shutdown	Estimated time of flight from present time to ascent injection (i. e. TG). Magnitude of velocity component normal to the CSM orbital plane (i. e. V(Y))	R1 xxBxx min, sec (-polarity) R2 xxxx. x ft/sec R3 Blank ***
V 82 E†	Astronaut	To call R30 the orbital parameter display routine	---	---
FL V16 N44	R30	Displays orbital parameter information to supplement ground information	Apolune altitude of LM orbit Perilune altitude of LM orbit Time of free fall to 35, 000 ft.	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min, sec

** V16 N85 can be keyed in anytime during the DPS abort.

*** R3 would not be blank if N77 was keyed in over another display where R3 was not blank (i. e. N63)

† VERB 82 can be keyed in after DPS shutdown (i. e. FL V16 N63)

TABLE 3. 3. 2-II

DESCENT PROPULSION ABORT DISPLAYS (P70) (SHEET 3 OF 3)

DSKY	Initiated by	Purpose	Condition	Register
(FL) V06 N32 E[††] or (FL) V16 N32 E	Astronaut	Display time from perilune [†††]	TF perilune in hrs, mins, sec	R1 ooxxx hrs R2 oooxx mins R3 oxx. xx sec

[††] NOUN 32 display flashes if keyed in over a flashing display. V16 or V06 can be used to call the NOUN 32 display.

[†††] If TFF is not computable. i. e., perilune exceeds 35, 000 ft., the LGC sets TFF to -59B59 and computes TF perilune storing it in the NOUN 32 display

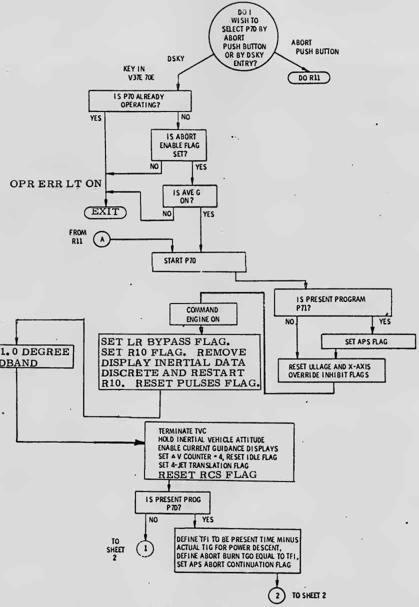

Figure 3.3.2-6. Descent Propulsion System Abort (P70) (Sheet 1 of 6)

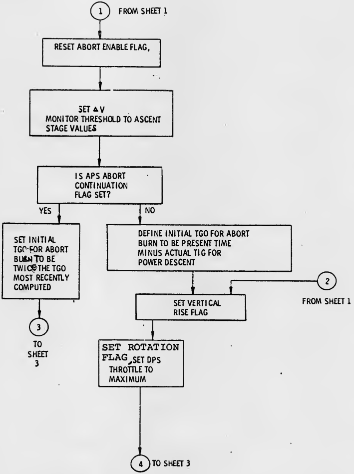

Figure 3.3.2-6. Descent Propulsion System Abort (P70) (Sheet 2 of 6)

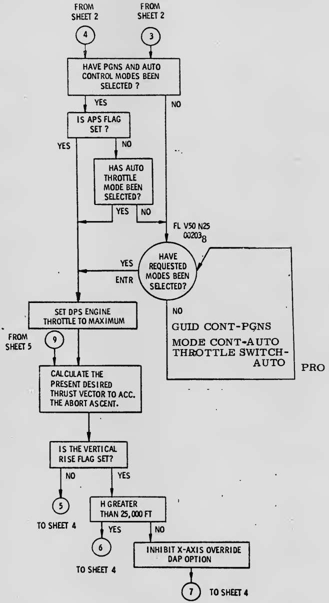

Figure 3.3.2-6. Descent Propulsion System Abort (P70) (Sheet 3 of 6)

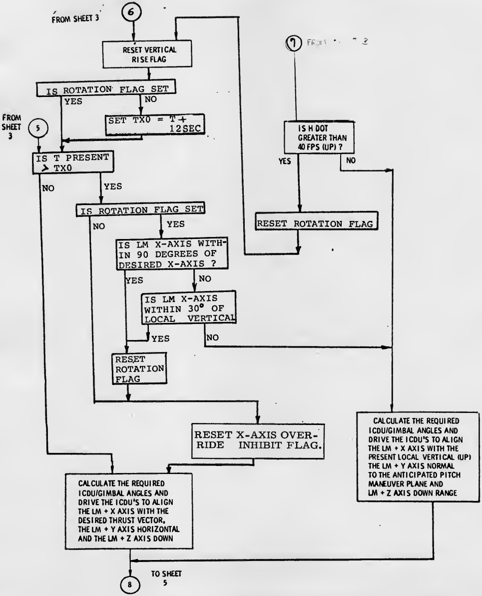

Figure 3.3.2-6. Descent Propulsion System Abort (P70) (Sheet 4 of 6)

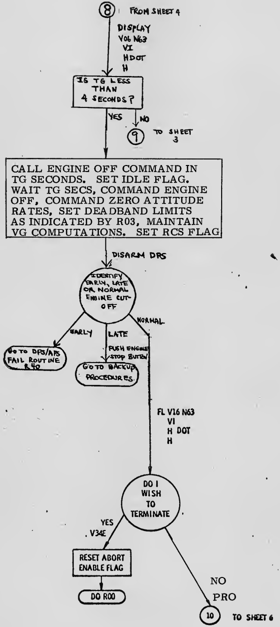

Figure 3.3.2-6. Descent Propulsion System Abort (P70) (Sheet 5 of 6)

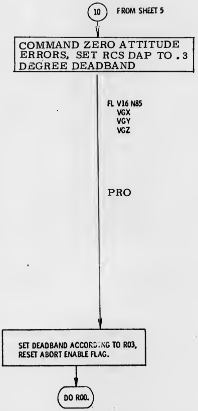

Figure 3.3.2-6. Descent Propulsion System Abort (P70) (Sheet 6 of 6)

Then the LGC calculates the initial t_{go} for the abort burn and sets a flag to allow P71, the APS Abort to be called as a follow-up to P70, the DPS Abort. (Note that if P71, the APS Abort Program is called as a follow-up to P70, the value of t_{go} will be twice that of the t_{go} that P70 has most recently computed.) The initial target conditions for the abort are then set up. See paragraph 3.3.2.1 for a description of the abort targets.

During the time when the above sequence of calculations is being carried out by the LGC, if desired, the crew could set the GUID CONT switch to PGNS, the THR CONT switch on the ENGINE THRUST CONT panel to AUTO and the PGNS MODE CONTROL switch to AUTO. The crew should then observe that the DPS comes to full thrust, since P70 has set the DPS engine throttle to the maximum value. This observation is made by monitoring the thrust indicator on the MAIN PROPULSION panel. If the crew have not selected the modes (as described above), a flashing VERB 50 NOUN 25 with R1 set to 00203 appears on the DSKY requesting that the crew "please perform" the selection of these modes. If the request is to be ignored, the crew key ENTR into the DSKY to continue. If the crew comply with the request by changing the modes, they key PRO into the DSKY to continue. Once again, the DPS engine throttle is set to maximum and, again, the crew should observe the maximum thrust, as described above.

The computer then calculates the present desired thrust vector to accomplish the abort ascent conditions and then determines if a vertical rise and pitchover maneuver is required. (An explanation of vertical rise and pitchover can be found in subsection 3.3.)

Regardless of whether the LM enters the vertical rise and pitchover phases or not, the LGC next calculates the required ICDU/gimbal angles and drives the ICDUs to align the LM + X-axis appropriately.

During the abort maneuver, the crew monitor the DSKY, FDAI, and look out the window. During the entire DPS burn, the DSKY displays VERB 06 NOUN 63 containing values of inertial velocity, HDOT, and present altitude. If the altitude is greater than 25,000 ft, the crew should observe that the PGNCS is maneuvering the LM to the correct attitude to perform the ascent abort. If the altitude is less than 25,000 ft, the crew must not use the X-axis override option. This X-axis override option is inhibited until completion of the pitch maneuver (i.e., present time plus 12 seconds). The PGNCS will maneuver the LM to local vertical and yaw the LM so that the windows are downrange. This local vertical attitude will be maintained until the altitude is greater than 25,000 ft or HDOT is greater than 40.0 ft/sec.

When either of these conditions is satisfied, the PGNCS will pitch the LM to the correct attitude to perform the ascent abort and once again restore the X-axis override option. The above maneuvers will be done with the RCS jets while the DPS is at full thrust.

While the crew are monitoring the DSKY, they should be observing the FDAI attitude errors and attitude rates as well as monitoring the thrust indicator for the DPS. They should then prepare for DPS engine shutdown, identifying early, late, or normal cutoff. If the target conditions are not met, and the DPS is shut down early, the crew see a flashing VERB 97 display from R40 on the DSKY indicating thrust failure. By replying appropriately to this flashing VERB 97 display (see paragraph 3.3.2.2.3), the crew return to P70 to attempt to re-ignite the DPS, complete the abort ascent using the RCS jets, or call the APS Abort Program (P71). Note that it is very likely that the DPS will run out of fuel in a long abort ascent. The crew determine engine shutdown by monitoring the inertial velocity of NOUN 63 or, optionally, keying in VERB 16 NOUN 77 ENTR into the DSKY to monitor the TG value in R1 of time to go to ascent injection conditions. When the DPS is shut down, the display changes to a flashing VERB 16 NOUN 63 on the DSKY.* In response to this flashing display, the crew disarm the DPS and, if desired, key PRO to display flashing VERB 16 NOUN 85 to observe the velocity residuals, VGX, VGY, VGZ—possibly nulling them out by an RCS trimming maneuver. (NOUN 85 can be called at anytime during the abort maneuver. See paragraph 3.3.2.6 on use of RCS jets in P70/P71 abort situations.) If the crew do not wish to observe the v_G values of NOUN 85, they can key in VERB 34 ENTR (terminate) into the DSKY to end P70. They can also key in VERB 82 ENTR to call R30, the Orbital Parameter Display Routine, to monitor continuous updated values of apolune, perilune, and TFF. The crew can also terminate P70 by keying in PRO or VERB 34 ENTR into the DSKY in response to the flashing VERB 16 NOUN 85 display when they are satisfied with the velocity residuals.

3.3.2.4 Alarms

In addition to the normal output expected from P70, alarms may occur calling for crew action. The crew can get a display of the alarm code by keying in VERB 05 NOUN 09 ENTR. The following are alarms that may occur during P70:

a. A 00401 alarm may occur as a warning to the crew of impending gimbal lock.

b. A 00402 alarm may occur if FINDCDUW is not controlling attitude.

---

* Note that if engine shutdown is identified by the crew as being later than desired, they should depress the engine STOP pushbutton.

If the 00401 alarm code is displayed, it indicates that the desired gimbal angle exceeds 70 degrees. Continuing the maneuver might result in gimbal lock. This alarm is unlikely to occur. Should it occur, it probably indicates that the PGNCS is not functioning properly and the crew should switch to AGS.

Alarm code 00402 is displayed if the FINDCDUW routine is not controlling attitude. The crew should either terminate thrust, or go to the Abort Guidance System (AGS) as backup. Refer to paragraph 3.3.1.8 for an explanation of the relation between the PGNCS and the AGS.

3.3.2.5 Restarts

P70 is restart protected. Should a software restart occur, and no other restart protection exists at the point of restart, the PROG alarm light is illuminated, and the program goes back to the last flashing display before the restart. Should a hardware restart occur, the RESTART light on DSKY is illuminated.

3.3.2.6 Engine Cutoff During Aborts

If P70 is called after t_{IG} + 300 sec, it is very likely that the DPS fuel will be depleted before insertion is accomplished. The crew must be aware of the v_G values at engine shutdown to be able to achieve target conditions. Based on the value of v_G, a decision must be made concerning overburn and minimum APS burntime constraints. The crew obtain the v_G display by keying VERB 16 NOUN 85 ENTR into the DSKY. The registers R1, R2 and R3 contain the components of v_G, VGX, VGY and VGZ, respectively.

When v_G is greater than 30 ft/sec, at DPS engine shutdown, the ABORT STAGE pushbutton must be depressed (i.e., P71, the APS Abort Program is called to accomplish insertion). As a result of the 2-second Ascent Guidance cycle, the minimum allowable APS burn is set at 3 seconds to avoid propellant freezing in the engine. The v_G in this 3-second APS burn is approximately 30 ft/sec, which is the overburn boundary value. If the value of v_G is less than 30 ft/sec at DPS shutdown, the RCS jets must be used to accomplish insertion since a large overburn will occur if the APS engine is used.

If an overburn occurs, the display would show v_G increasing after a decrease to some minimum value. If the DPS continues to thrust as v_G goes negative, the engine should be shut down by manual action. There is, however, a 2- to 4-second delay in the computation of v_G before it is displayed to the crew. Thus, before making the decision as to whether the LM is in an overburn or not, the crew must wait for the display to stabilize. Overburns with the DPS or APS are trimmed by RCS thrusting in a negative direction.

Before stabilization of the v_G display, if VGX is over 100 ft/sec, the ABORT STAGE pushbutton should be depressed. After stabilization of the v_G display (a delay of 6 seconds should be adequate), the crew is left with one of the three following choices:

a. If VGX is greater than 30 ft/sec the ABORT STAGE pushbutton must be depressed.
b. If VGX is less than 30 ft/sec, but greater than 5 ft/sec, the DPS must be manually staged and the RCS jets fired.
c. If VGX is less than or equal to 5 ft/sec, the RCS jets should be fired with the DPS attached. Note that the RCS jets should only be fired for approximately 15 seconds with the DPS attached. Firing for longer than 15 seconds will cause damage to the DPS and reflect on the APS stage structure.

BLANK

3.3.3 P71, Ascent Propulsion System Abort—LGC

P71, the Ascent Propulsion System (APS) Abort Program is an initialization program whose function is (1) to supply the targets for Ascent Guidance, and (2) to initialize the "engine parameters" needed by Ascent Guidance.* For P71 (as opposed to P70) these "engine parameters" are pre-loaded in the LM Guidance Computer (LGC). Note that when P71 is called after P70, no targeting initialization is done since P70 has continuously updated the targets for the Ascent Guidance.

P71 is used for APS aborts and can be called at any time from ignition at PDI until P68, the Landing Confirmation Program, is called. (For a detailed explanation of timing for aborts, abort criteria, and specific questions on aborting, refer to paragraph 3.3.2.) During the last part of the landing maneuver and surface stay—up to the entry of P68—the APS abort would have to be used since the DPS fuel is almost depleted.

The APS abort is called either by depressing the ABORT STAGE pushbutton or by keying VERB 37 ENTR 71 ENTR into the DSKY. The program is called when any of the following conditions arise:

a. The DPS engine fails during the landing sequence.
b. The DPS runs out of fuel or fails during a DPS abort maneuver (i.e., during P70).
c. A lunar surface abort is to be performed before P68 has been called.

If the DPS engine, in the abort maneuver, is cut off before orbit insertion, the crew are notified of the cutoff by a flashing VERB 97 display. (Refer to paragraph 3.3.3.1.1.) It is important that the crew be monitoring the v_G display during the DPS burn (called by keying VERB 16 NOUN 85 into the DSKY) because the following three decisions are based on v_G values at engine cutoff time:

a. Fire the RCS jets (with the DPS attached).
b. Manually stage the DPS and then fire the RCS jets.
c. Depress the ABORT STAGE pushbutton to call P71.

Refer to paragraph 3.3.2.6 for further information on engine cutoff during aborts.

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[*] Refer to subsection 3.3 for a complete description of the Ascent Guidance.

If the DPS runs out of fuel during P70, the LGC does not automatically select the APS Abort, P71. Therefore, the crew must anticipate fuel exhaustion and be prepared to select P71 either by keying VERB 37 ENTR 71 ENTR into the DSKY, or by depressing the ABORT STAGE pushbutton.

If a lunar surface abort is to be performed, the ABORT STAGE pushbutton is depressed before P68 has been called. The flight plan associated with the lunar surface abort is given below:

EVENT	TIME FROM IGNITION (PDI IGNITION)
Touchdown	690–775 sec
STAY/NO-STAY for lunar surface abort	810–895 sec
Preferred liftoff time	980 sec

If the crew cannot wait for the 980-second preferred liftoff time (for example, in the case of a probable tipover), the abort can be done immediately. The phasing, however, will not be as good as if the crew had waited the full 980 seconds.

Targets for a lunar-surface abort are the same as powered-descent-abort targets. But the ground supplies data for the crew to perform a P30–P41 boost maneuver at perilune in order to change the apolune from 30 to 45 n. mi., making this lunar-surface abort equivalent to a nominal ascent (P12) from the lunar surface. (Refer to paragraphs 3.3.1.1 and 3.3.1.2.)

Note that when P71 is called via VERB 37, the DPS will not be automatically staged. Thus, the crew must manually stage the DPS before using VERB 37 to enter P71. P71 has no way of determining if the DPS has been staged or not. As a result, if the DPS has not been manually staged, P71 will give the engine-on command to the DPS instead of the APS. If P71 is called by depressing the ABORT STAGE pushbutton, the DPS will be staged automatically.

Once P71 is called, the ABORT ENABLE flag is reset to zero, prohibiting any subsequent calls to P70 or P71. An operator error light will come on if an attempt is then made to call either P70 or P71.

3.3.3.1 Related Routines and Extended Verbs

The routines associated with P71 are listed below and briefly explained.

a. R11 is the Abort Discretes Monitor Routine. (Refer to paragraph 3.3.2.2.2.)
b. R10 is the Landing Analog Display Routine; however, R10 use of the rendezvous radar CDU's is inhibited by P71. (Refer to paragraph 3.3.2.2.1.)
c. R40 is the DPS/APS Thrust Fail Routine. (Refer to paragraph 3.3.3.1.1, below.)
d. R47 is the AGS Initialization Routine. (Refer to paragraph 3.3.2.2.4 for an explanation of R47.)

3.3.3.1.1 DPS/APS Thrust Fail Routine (R40).—The crew should follow procedures outlined for DPS thrust failure during the DPS Abort (P70), noting that the threshold value for the Δv comparison, set by P71, is 308 cm/sec. Also note that references to the throttle in the DPS thrust failure procedures do not apply to P71.

Table 3.3.3-I lists the extended verbs that may be used during P71.

3.3.3.2 Computational Sequence

The APS abort can be used either as a primary abort or as a follow-up to P70. The thrust filter initialization is the same for both uses of P71. But this initialization differs from P70 in that the engine performance parameters are prestored in the LGC. The initialization of t_{go}, however, differs in the two uses of P71. When P71 is used as a primary abort, the initial t_{go} calculation is the same as the t_{go} for P70. When P71 is used as a follow-up to P70, a working value of t_{go}, made available by P70, is used. This value must then be doubled to account for the lower acceleration of a full ascent stage during P71 as compared to the empty descent stage at termination of P70. Also, when P71 is used as a follow-up to P70, the target initialization is by-passed since it was previously done by P70.

Table 3.3.3-II lists the displays associated with P71. Figure 3.3.3-1 is a flowchart of P71. The flowchart and the tables should be referenced when reading the computational sequence detailed below.

TABLE 3.3.3-I

EXTENDED VERBS USED WITH APS ABORT (P71) (SHEET 1 OF 2)

VERB	Identification	Purpose	Remarks
61 ENTR	Display Mode I DAP attitude errors.	Display on the FDAI error needles the difference between the current CDU and the DAP command angles.	This process can be selected by the crew any time during P71. The crew can use Mode I error display to monitor the DAP's ability to track automatic steering commands.
62 ENTR	Display Mode II total attitude errors.	Display on the FDAI error needles the total attitude error— (NOUN 22) desired ICDU angles minus (NOUN 20) present ICDU angles.	This process can be selected by the crew any time during P71. The crew can use Mode II error display to assist them in manually maneuvering the LM.
76 ENTR	Minimum Impulse Command Mode.	Enables the Minimum Impulse Mode of the DAP. The crew can then perform manual attitude control about all the vehicles axes with the ACA in the Minimum Impulse Mode.	Extended VERB 76 can be selected by the crew at any time. The crew must put the GUID CONT switch to PGNS and the MODE COUNT switch to ATT HOLD. The Minimum Impulse Mode will remain enabled until canceled by the rate command selection (Extended VERB 77 or P63) or a fresh start. It is strongly recommended that no powered flight maneuver be attempted in this Minimum Impulse Mode. The Minimum Impulse Mode is also canceled when P71 is first entered.
77 ENTR	Rate Command and Attitude Hold Mode.	Enables the Rate Command Mode of the DAP and sets the desired ICDU angles equal to the actual ICDU angles. The crew can then perform manual attitude maneuvers about all vehicle axes with the ACA in the Rate Command Mode.	Extended VERB 77 can be selected by the crew at any time. The Rate Command Mode will remain enabled until canceled by the Minimum Impulse Mode (see Extended VERB 76). The GUID CONT and MODE CONT switches should be set in the same way as in Extended VERB 76. Note that the Rate Command Mode is established at DPS ignition in P63 and when P71 is first entered.

TABLE 3.3.3-I

EXTENDED VERBS USED WITH APS ABORT (P71) (SHEET 2 OF 2)

VERB	Identification	Purpose	Remarks
82 ENTR	Orbital Parameter Display Routine (R30)	Provides the crew with pertinent orbital parameters computed by the LGC, updated every 2 seconds during AVERAGEG, to supplement orbital information provided by the ground.	Extended VERB 82 is manually selected by the crew after the engine is shut down in P71, and the LM has achieved an orbit. If TFF is not computable (perilune altitude is greater than 35, 000 ft) the LGC will set TFF equal to -59B59, compute TF PER and store it in NOUN 32, which the crew can call also.

TABLE 3. 3. 3-II

ASCENT PROPULSION ABORT DISPLAYS (P71) (SHEET 1 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
FL V37	R00	Request astronaut to select program (if ABORT STAGE pushbutton not used)		
FL V50 N25	P71	Request desired modes for guidance and attitude control for APS abort be selected as follows: GUID CONT → PGNS ATT CONT → AUTO	ENTR - bypass request PRO - accept request by changing modes first	R1 00203_8 R2 Blank R3 Blank
V06 N63	P71	Display current velocity, rate of change of altitude, and altitude of the LM for monitoring APS abort	Magnitude of the LM inertial velocity Present rate of change of altitude Present altitude of the LM above the LM position vector at the designated landing site.	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxxx ft
V05 N09 E	Astronaut (FINDCDUW routine)	Verify program alarm	00401 - desired middle gimbal angle exceeds 70 deg. 00402 - FINDCDUW not controlling attitude	R1 R2 { xxxxx* R3
FL V16 N63	P71	Informs crew of APS engine shutdown	Same as V06 N63 data	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxxx ft
FL V16 N85 or V16 N85 E**	P71 or Astronaut	To monitor v_G components remaining during the APS burn and after APS shutdown to monitor the v_G residuals during RCS trimming.	Components of the present velocity to be gained vector along the LM X, Y, Z axis (VGX, VGY, VGZ)	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec

* Alarm code may appear in R1, R2, or R3

** V16 N85 can be keyed in anytime during the APS abort.

TABLE 3.3.3-II

ASCENT PROPULSION ABORT DISPLAYS (P71) (SHEET 2 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
V06 N76 E	Astronaut	To display targeting information	Downrange velocity Radial velocity Crossrange	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x n. mi.
V16 N77 E	Astronaut	To display additional components to be used in monitoring APS engine shutdown	Estimated time of flight from present time to ascent injection (i. e. TG) Magnitude of velocity component normal to the CSM orbital plane (i. e. V(Y))	R1 xxBxx min, sec (-polarity) R2 xxxx.x ft/sec R3 Blank***
V82 E †	Astronaut	To call R30, the Orbital Parameter Display Routine	- - -	- - -
FL V16 N44	R30	Displays orbital parameter information to supplement ground information	Apolune altitude of LM orbit Perilune altitude of LM orbit Time of free fall to 35,000 ft.	R1 xxxx.x n. mi. R2 xxxx.x n. mi. R3 xxBxx min, sec
(FL) V06 N32 E †† or (FL) V16 N32 E	Astronaut	Display time from perilune †††	TF perilune in hrs, mins, sec.	R1 ooxxx hrs. R2 oooxx min. R3 oxx.xx sec.

*** R3 would not be blank if N77 was keyed in over another display where R3 was not blank (i. e., N63)

† VERB 82 can be keyed in after APS shutdown (i. e. FL V16 N63)

†† NOUN 32 display flashes if keyed in over a flashing display. V16 or V06 can be used to call the NOUN 32 display.

††† If TFF is not computable, i. e., perilune exceeds 35,000 ft., the LGC sets TFF to - 59B59 and computes TF perilune storing it in the NOUN 32 display.

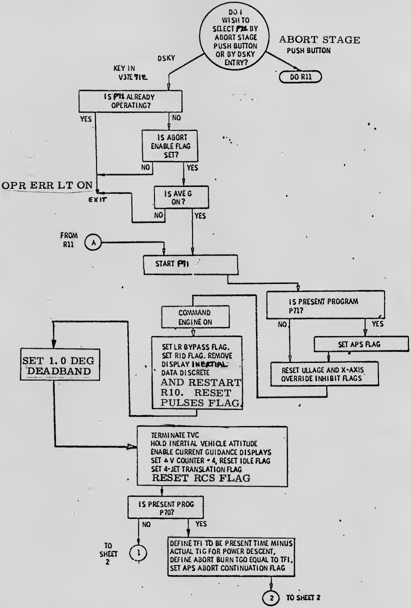

Figure 3.3.3-1. Ascent Propulsion System Abort (P71) (Sheet 1 of 6)

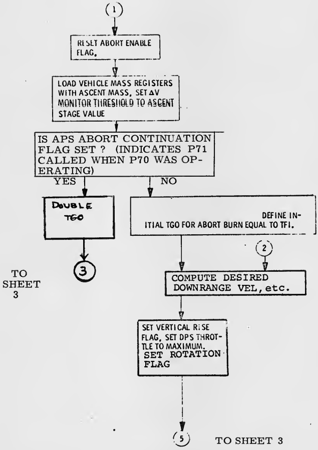

Figure 3.3.3-1. Ascent Propulsion System Abort (P71) (Sheet 2 of 6)

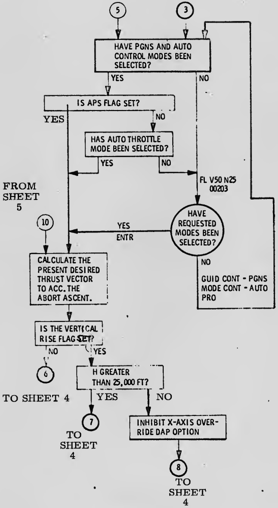

Figure 3.3.3-1. Ascent Propulsion System Abort (P71) (Sheet 3 of 6)

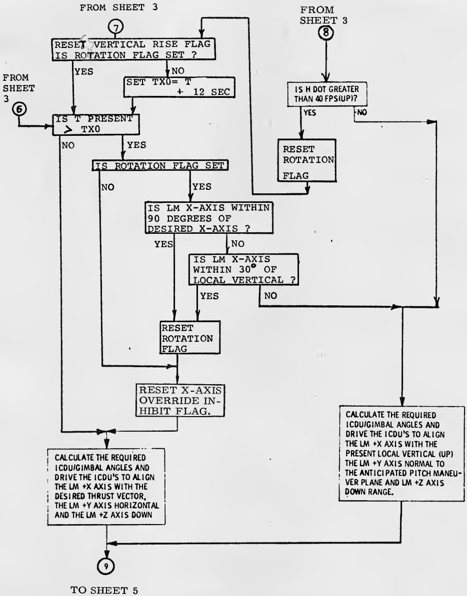

Figure 3.3.3-1. Ascent Propulsion System Abort (P71) (Sheet 4 of 6)

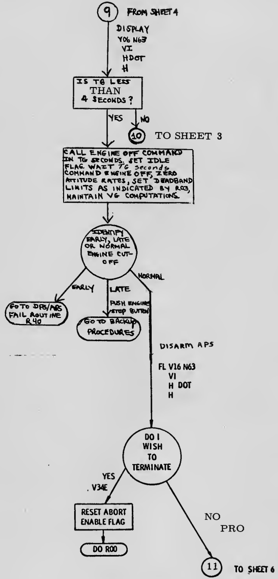

Figure 3.3.3-1. Ascent Propulsion System Abort (P71) (Sheet 5 of 6)

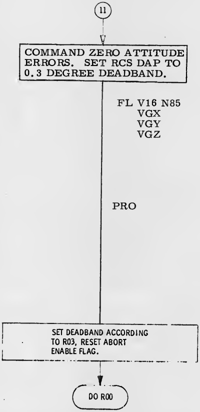

Figure 3.3.3-1. Ascent Propulsion System Abort (P71) (Sheet 6 of 6)

P71, the APS Abort Program, is called by depressing the ABORT STAGE pushbutton or by keying in VERB 37 ENTR 71 ENTR into the DSKY. If P71 is incorrectly selected because of one of the following reasons, the OPR ERR light will be turned on informing the crew of the error:

a. P71 is already in progress.
b. The ABORT ENABLE flag is not set. *
c. P68, the Landing Confirmation Program, was called prohibiting any further calls to P71.
d. The AVERAGEG flag is not set.

If P71 is correctly selected, 71 is displayed on the DSKY indicating that the APS Abort Program (P71) has started. After a few flags are appropriately set for the APS abort, the APS engine is commanded on by P71. Note that if a total thrust failure has occurred, the crew would have to apply manual RCS translation until P71 automatically commands the APS engine on. If the crew—before selecting the APS abort—was in the process of landing the LM, the LGC has to remove the inertial data discrete from the CDUs and restart R10, the Landing Analog Display Routine. In addition to the above, the LGC also controls the following processes:

a. Sets 1.0 degree deadband
b. Terminates thrust vector control
c. Holds inertial vehicle attitude
d. Sets the Δv counter to 4 for use by R40, the DPS/APS Thrust Fail Routine
e. Enables the current guidance displays
f. Reset IDLE and RCS flags
g. Sets the 4-jet translation flag
h. Sets the Δv monitor threshold to ascent stage values.

Then the LGC calculates the initial t_{go} for the APS abort and resets the ABORT ENABLE flag.** If P71 is called as a follow-up to the DPS Abort Program (P70), the value of t_{go} will be twice that of the t_{go} that P70 most recently calculated. The initial target conditions for the APS abort are set up if P71 has been called as a primary abort but the targeting initialization is bypassed if the APS abort (P71) is a follow-up to the DPS abort (P70). See paragraph 3.3.2.1 for a description of the abort targets.

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*P63 sets the ABORT ENABLE flag; P71 resets the flag.

**t_{go} is equal to the present time minus the actual t_{IG} for powered descent.

During the time the above sequence of calculations is being performed by the LGC, the crew, if desired, set the GUID CONT switch to PGNS and the PGNS MODE CONTROL switch to AUTO. As a follow-up to the DPS abort these switches should already be set as indicated above. If the crew have not selected these modes; that is, if P71 is being used as the primary abort, a flashing VERB 50 NOUN 25 with Rl set to 00203 appears on the DSKY requesting that the crew "please perform" the selection of these modes. If the desired modes have already been selected, the crew key ENTR to continue P71, bypassing the request. If the crew comply with the request by changing the modes, they key PRO to continue.

The LGC then calculates the present desired thrust vector to accomplish the abort ascent conditions and then determines if a vertical rise and pitchover maneuver is required. (An explanation of vertical rise and pitchover can be found in subsection 3.3.)

Regardless of whether the LM enters the vertical rise and pitchover phases or not, the LGC next calculates the required ICDU/gimbal angles and then drives the ICDUs to align the LM +X-axis appropriately.

During the APS abort, the crew monitor the DSKY, the FDAI and look out the window. During the entire APS burn, the DSKY displays VERB 06 NOUN 63 containing values of inertial velocity, HDOT, and present altitude. If the altitude is greater than 25,000 ft, the crew should observe that the PGNCS is maneuvering the LM to the correct attitude to perform the ascent abort. If the altitude is less than 25,000 ft, the crew must not use the X-axis override option. This X-axis override option is inhibited until completion of the pitch maneuver (i.e., present time +12 seconds). The PGNCS maneuvers the LM to local vertical, and yaws the LM so that the windows are downrange. This local vertical attitude is maintained until the altitude is greater than 25,000 ft or HDOT is greater than 40.0 ft/sec. When either of these conditions is satisfied, the PGNCS pitches the LM to the correct attitude to perform the ascent abort and once again restores the X-axis override option to the crew. The above maneuvers are done with the RCS jets.

While the crew are monitoring the DSKY display of VERB 06 NOUN 63, they should observe the FDAI attitude errors and attitude rates as well as monitoring the APS chamber pressure. They should then prepare for APS engine shutdown, identifying early, late, or normal cutoff.

If the target conditions are not met, and the APS is shut down early, the crew see a flashing VERB 97 display from R40 on the DSKY indicating thrust failure. By replying appropriately to the flashing VERB 99 display in R40 (see paragraph 3.3.3.1.1), the crew either attempt to re-ignite the APS, or complete the abort ascent using the RCS jets. The crew can get an approximation to APS engine shutdown by monitoring the inertial velocity of NOUN 63 or, optionally, by keying VERB 16 NOUN 77 into the DSKY to monitor the TG value in R1 (i.e., time to go to ascent injection). When the APS is shut down by P71, the VERB 06 NOUN 63 automatically changes to flashing VERB 16 NOUN 63 on the DSKY.* In response to this flashing display, the crew disarm the APS and, if desired, key PRO to display the flashing VERB 16 NOUN 85 on the DSKY to observe the velocity residuals, VGX, VGY, VGZ—possibly nulling them out by an RCS trimming maneuver. (NOUN 85 can be called anytime during the abort maneuver.) (See paragraph 3.3.2.6 on use of RCS jets in P70/P71 abort situations.) If the crew do not wish to observe the v_G values of NOUN 85, they can key in VERB 34 ENTR (terminate) into the DSKY to end P71. They can also key in VERB 82 ENTR into the DSKY to call R30, the Orbital Parameter Display Routine to monitor continuous updated values of apolune, perilune, and TFF. The crew can also terminate P71 by keying in PRO or VERB 34 ENTR into the DSKY, in response to the flashing VERB 16 NOUN 85 display, when they are satisfied with the velocity residuals.

3.3.3.3 Alarms

The alarms listed below may occur during P71.

a. Alarm 00401 may occur as a warning to the crew of impending gimbal lock.

b. Alarm 00402 may occur if FINDCDUW is not controlling attitude.

Refer to paragraph 3.3.2.4 for a detailed explanation of the above alarm codes.

3.3.3.4 Restarts

P71 is restart protected. Should a software restart occur, and no other restart protection exists at that point, the PROG alarm light would be illuminated and the program would go back to the last flashing display before the restart. Should a hardware restart occur, the RESTART light on the DSKY would be illuminated.

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* Note that if engine shutdown for the APS is identified by the crew as being later than desired, they should depress the engine STOP pushbutton.

SECTION 4.0

COASTING NAVIGATION

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4.1 INTRODUCTION TO COASTING FLIGHT NAVIGATION

Navigation during coasting flight is accomplished by onboard processing of optics and VHF data in the Command and Service Module (CSM), and of radar data in the Lunar Module (LM). The data contribute to maintaining current estimates of the CSM and LM state vectors.

The CSM coasting flight navigation programs are as follows:

P20	Rendezvous Navigation (paragraph 4.2.1)
P21	Ground-track Determination (paragraph 4.2.2)
P22	Orbital Navigation (paragraph 4.2.3)
P23	Cislunar Midcourse Navigation (paragraph 4.2.4).
P24	Rate-aided Optics (paragraph 4.2.5)

In the LM there is no need for cislunar navigation, and orbital navigation is replaced by lunar surface navigation. The LM navigation programs are the following:

P20	Rendezvous Navigation (paragraph 4.3.1)
P21	Ground-track Determination (paragraph 4.3.2)
P22	Lunar-surface Navigation (paragraph 4.3.3)
P25	Preferred Tracking Attitude (paragraph 4.3.4).

Although the two update programs (CSM P27 and LM P27) are included in this section, the navigation theory discussed in this introduction pertains to neither.

4.1.1 Mission Phases

Coasting flight navigation can be used during the following mission phases: cislunar (CSM), rendezvous, lunar prelaunch (LM), earth and lunar orbit (CSM).

4.1.1.1 Cislunar Navigation

Cislunar navigation is used to maintain state-vector estimates during translunar and transearth coast. The computed state-vector data provide the basis for onboard targeting of transearch trajectories outside the moon's sphere of influence. Cislunar navigation is used primarily as a backup mode since the trajectories are usually ground-targeted, using ground-computed state vectors.

Optical sightings of the angle between the directions to a star and to a planetary horizon or landmark supply data for modifying or updating the state vector. From the measured angle and the time of the sighting, the command module computer (CMC) determines the state-vector estimate. The CMC processes the angle-measurement data immediately after the measurement is made and displays the values for approval before the state vector is updated. Bad updates can be avoided by rejecting the values when they are displayed.

4.1.1.2 Rendezvous Navigation

During the rendezvous phase, estimates of both state vectors (LM and CSM) are stored in both vehicle computers (LGC and CMC). Rendezvous navigation is used to update one of the two state vectors (usually the LM's) in both vehicles. Only one state vector is updated because limited computer storage precludes updating both states. This, however, provides satisfactory rendezvous navigation since accurate knowledge of the relative state (knowledge of one state with respect to the other) is the primary concern in rendezvous.

The CSM-based sensors provide two types of tracking data: optical data, acquired manually with the sextant; VHF range-link data, acquired automatically. In the LM, tracking data are gathered from the rendezvous radar (RR). Either onboard system has the complete capability of providing the crew with the necessary data, computations, and control to perform the rendezvous without inflight assistance from the ground or the other vehicle's system.

4.1.1.3 Lunar-surface Navigation

During the final CSM orbits prior to launch from the lunar surface, the LM can use lunar-surface navigation to update its estimate of the CSM state vector.

Range and range-rate data[*] are obtained from the RR as the CSM passes in its orbit. A number of marks are taken before the state-vector updating process begins, since the CSM is within measurement range for a limited time. During the processing, the CSM is below the horizon and immediate repetition of the tracking is impossible.

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[*] RR angular data are not incorporated in the estimate due to uncertainties associated with the magnitude and nature of the RR angle biases.

The LGC establishes an estimate of the CSM state vector relative to the LM's known position and velocity as a prologue to LM rendezvous navigation, which begins after the LM'S ascent from the lunar surface.

4.1.1.4 Orbital Navigation

While the CSM is in earth or lunar orbit, orbital navigation can be used to maintain the CSM state-vector estimate or to refine knowledge of the location of a point on the surface. The state vector is expanded to nine dimensions during orbital navigation in order to include the estimated landmark position vector, the CSM position vector, and the CSM velocity vector.

Tracking data are obtained from optical measurements of the angles between the IMU stable member and lines of sight to a point on the surface. Processing of the data is done by the ground or, in some instances, onboard the spacecraft. Since the landmark remains visible to the orbiting vehicle for a limited time, a number of sets of optical angle data, or tracks, are acquired on each pass. These data are either directly telemetered for immediate processing (P24) or held for processing when the landmark is below the horizon (P22).

4.1.2 Recursive Navigation

Navigation in all these phases is accomplished by a procedure known as recursive navigation, a technique that uses the current state-vector estimate plus measurements to compute a new, updated estimate, then uses the new estimate and new measurements to compute another estimate, and so on. An essential part of recursive navigation is the use of a Kalman filter[*] to process the sensor data incorporated in each update. Kalman filtering is a technique for obtaining an optimum estimate by combining measured data with predicted data. When the difference between the measured and predicted values is multiplied by a weighting vector $(\underline{\omega})$, a correction is obtained for updating the state vector.

The four principal factors involved in this process are (1) extrapolation, (2) measurement geometry, (3) statistical weighting, and (4) error correlation. Levine[**] represents the interrelationship of these elements as an ellipsoid of six dimensions

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[*] Battin-Levine E-note 2401, "Application of Kalman Filtering Techniques to the APOLLO Program"

[**] SGA Memo No. 11-68 Gerald M. Levine, "Recursive Navigation Theory Explained"

(for three position components and three velocity components). The ellipsoid geometrically defines the area of one-sigma error probabilities. The changing size and shape of the idealized ellipsoid during navigation illustrate the dynamic behavior of the error matrix used in the Kalman filter computations.

To make a valid comparison of measured and predicted values, the AGC extrapolates the current state vector to the time of measurement, and a prediction is made as to the new estimate. (The statistical error ellipsoid associated with the state vector is also extrapolated. Between measurements, the error model should grow and rotate.) If the measured and predicted values agree, the extrapolated state vector is assumed correct; if the measured and predicted values do not agree, the extrapolated state vector is assumed to require some correction.

The role geometry plays is idealized one-dimensionally in Figure 4.1.2-1. Given perfect knowledge of the spacecraft orbit, a unique point P in that orbit can be inferred at time t by measuring the angle A between the fixed reference direction ($\overline{D}$) and the line of sight to a known point T. If the angle measurement were perfect, the point P would be the true orbital position.

Since it would be unrealistic to believe entirely in the measurement data and not at all in the predicted data, a <u>statistical</u> <u>weighting</u> model must be provided to determine the relative credibility of the two sets. Also, since in some instances data may be measured for only one dimension, a means must be provided for correlating the results to the unmeasured dimensions. The procedure for doing this can be visualized by considering an ellipse (Figure 4.1.2-2a) whose semi-major and semi-minor axes, respectively, lie along, and normal to, the line of sight to the target body; the size and shape of the ellipse E reflect the one-sigma error probability in the estimated position P.

Because state vector errors change with extrapolation, the size of E generally increases with time until a measurement is taken to restore confidence. New information causes E to shrink in the direction effected by the measurement (in Figure 4.1.2-2a, the direction normal to the line of sight). If there were no measurements, E would be continuously expanding. As a result of making measurements in a single direction, E becomes less circular. Without correlation, each measurement would cause E to become smaller in the direction normal to the measurement LOS, while E continued to grow in the direction of the LOS. The error model, however, rotates at a different rate than does the vehicle's state vector. After a period of extrapolation, the axes of an idealized ellipse would have rotated

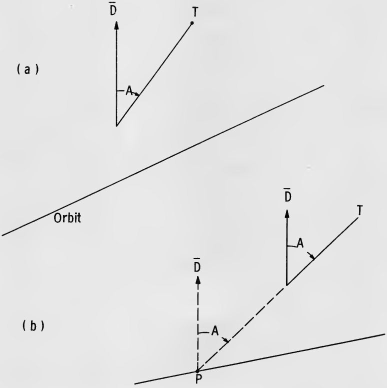
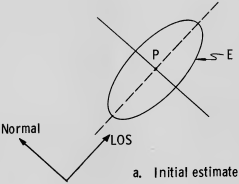
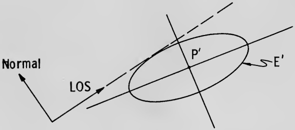


Figure 4.1.2-1. One-dimensional Example of Geometric Determination in Recursive Navigation



a. Initial estimate



b. Extrapolation of estimate

Figure 4.1.2-2. Two-dimensional Example of Extrapolation off the LOS, as shown in Figure 4.1.2-2b. A new measurement along the LOS would shrink both axes of the ellipse, thus the statistical error in the unmeasured direction is correlated to the measured direction. The amount of correlation depends on the amount of relative rotation between the state vector and the error model; the relative rotation depends on the eccentricity of the vehicle orbit. For example, at the end of transearth coast, correlation is very poor because the path of the vehicle is almost a straight line.

The interrelationship of the four principles of recursive navigation is presented in Figure 4.1.2-3. In Figure 4.1.2-3a, the point P represents the best estimate of spacecraft position at time t. The ellipse E circumscribes the one-sigma error probability associated with P. In Figure 4.1.2-3b, P' represents the spacecraft position extrapolated to time t'. As a result of the extrapolation, the error ellipse (E') associated with P' has enlarged slightly and rotated. A new measurement establishes the line of geometrical agreement (L_2). With perfect confidence in the measurement, P_2 would be assumed as the precise spacecraft location.

Statistical weighting of the difference between P_2 and P', however, results in the designation of Q as the most probable location—ignoring the unmeasured dimension. The measured and unmeasured dimensions are correlated by constructing L' parallel to L_2, through Q. The one point of L' that is tangent to the smallest ellipse of constant probability centered at P' is the new best estimate P_2'. Figure 4.1.2-3c shows the cycle completed with P_2', the new best estimate, and its reoriented and slightly smaller error ellipse E_2.

The statistical data describing the error ellipsoids are stored in the AGC as a six-dimensional matrix (nine-dimensional if the state vector is of nine dimensions) reflecting the covariances between the elements of the state vector inherent in the estimates. For computational convenience,* the error-transition matrix (W-matrix) is used rather than the covariance matrix (E-matrix); the W-matrix is essentially the square root of the E-matrix.

As the computational error ellipsoid, the W-matrix helps to provide correlation between errors in the direction of sensor measurements and errors in other directions not specifically measured. Over a period of time with several tracking measurements, the total correlation of errors in all directions will improve, as will the ability of the filter to reduce errors in unmeasured directions.

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*As explained in E-2401

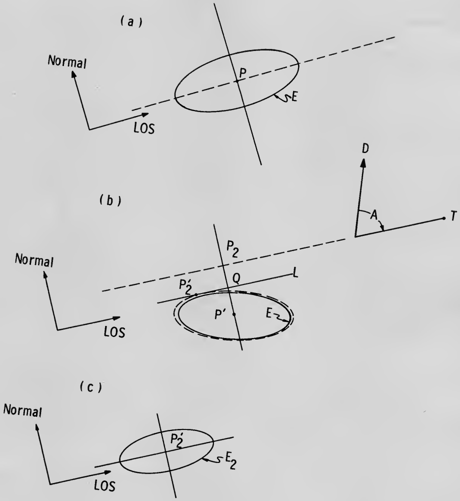

Figure 4.1.2-3. Two-dimensional Example of Correlation

Because of incomplete error modeling, as well as computer storage limitations and numerical problems of extrapolation, there is a gradual and inevitable decay of the elements of the W-matrix. Between measurements, the W-matrix tends to grow at too slow a rate, and then decreases as the result of incorporation of new data. Eventually, therefore, all new data would be ignored simply because they would be given a weighting factor of zero (thus giving the false impression that knowledge of the state vector could not be improved by new data). Consequently, the W-matrix must be periodically reinitialized (to predetermined expected values of position and velocity errors).* The timing of reinitialization is discussed in each program where applicable.

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*In cislunar navigation the modeling is more accurate (since there is only one vehicle), and reinitialization is unnecessary.

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SUBSECTION 4.2

CMC COASTING NAVIGATION PROGRAMS

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4.2.1 P20, Rendezvous Navigation—CMC

The Rendezvous Navigation Program (P20) is an onboard means of updating either of two state vectors (CSM or LM) carried in the Command Module Computer. The designated state vector is updated by incorporating measurements of line of sight (optics) and range (VHF) from the CSM to the LM. Except during the thrusting phases, P20 operates continuously throughout CSM-LM rendezvous, in conjunction with whichever is appropriate of the following targeting programs:

CSM Active

P30— External Δv

P32— Co-elliptic Sequence Initiation (CSI)
P33— Constant Delta Altitude (CDH)
P34— Transfer Phase Initiation (TPI)
P35— Transfer Phase Midcourse (TPM)

CSM—targeted LM Maneuvers

P72— LM Coelliptic Sequence Initiation
P73— LM Constant Delta Altitude
P74— LM Transfer Phase Initiation
P75— LM Transfer Phase Midcourse
P76— Target Δv

Ordinarily, rendezvous is effected using the concentric flight plan discussed in the Introduction to Targeting Programs (subsection 5.1). The rendezvous, GN&CS functional requirements are Navigation, Targeting, Powered-flight Control and Guidance, and IMU Alignment.

a. Navigation.—Optical, VHF ranging, and radar (LGC) data are continually incorporated to improve the estimate of the relative position and velocity of the two vehicles. This function is controlled by the Rendezvous Navigation Program (P20), which is described in this section (paragraph 4.2.1)—LGC P20, is described in paragraph 4.3.1. The Rendezvous Navigation Program also controls the spacecraft orientation during the coasting phase of rendezvous.

b. Targeting.—On the basis of the command-module computer (CMC) estimate of relative position and velocity, a required change in velocity is computed for each thrusting maneuver. This function is performed by the targeting programs described in Section 5.0.

c. Powered-flight Control and Guidance.—On the basis of targeting data and crew inputs, the CMC controls the reaction-control-system (RCS) and service-propulsion-system (SPS) thrusting maneuvers required for rendezvous. The powered-flight programs are discussed in Section 6.0.

d. IMU Alignment.—In addition to its knowledge of the relative position and velocity of the two vehicles, the CMC must know the spacecraft's orientation. Programs for aligning and determining the orientation of the inertial measurement unit (IMU) are described in Section 7.0.

Operating in the background throughout rendezvous, P20 becomes temporarily dormant upon the crew's requesting a final targeting computation, remains dormant during the powered-flight phase, and re-awakens only upon the crew's reselecting P20—VERB 37 ENTR 20 ENTR—or a compatible targeting program. (See Figure 4.2.1-1.) Should it become necessary to call any other program except P00, P06, P22, or P23 (e.g., IMU Alignment, P52), Rendezvous Navigation will similarly cease until P20 or a compatible targeting program is re-selected. Rendezvous Navigation, then, operates in conjunction with its complementary targeting programs (P30, P32, P33, P34, P35, P72, P73, P74, P75, and P76). Once P20 is entered, subsequent selection of a compatible targeting program changes the DSKY PROG number to reflect the program selected, but allows navigation to continue.

Accordingly, the crew can, upon a flashing display during one of the named programs, call either the Rendezvous Tracking Sighting Mark Routine (R21—VERB 57 ENTR) or the Backup Rendezvous Tracking Sighting Mark Routine (R23—VERB 54 ENTR), take the required optical measurements, and by depressing the PRO key, return to the point departed from in the major program in progress. Similarly, the crew can call for VHF range data to be incorporated by selecting VERB 87 ENTR, which will allow range data to be incorporated until the crew resets the VHF RANGE flag, either by keying VERB 88 ENTR or by executing a program change (VERB 37). For marks to be incorporated, the UPDATE flag must be set. The flag is automatically reset during prethrust computations in order to protect erasable memory. The essential concern to the crew is that—except during P76 and during recycle displays preceding the VERB 06 NOUN 59 display in P34—marks can be incorporated during targeting-program displays preceding the crew's request for final targeting computation (PRO response to flashing VERB 16 NOUN 45). A PRO to this display temporarily terminates navigation. (See Section 5.0.) Essentially, P20 provides the targeting programs with a continually updated state vector for one vehicle and the current state vector for the other vehicle. The appropriate targeting program, in turn, computes the Δv required to effect rendezvous.

Figure 4.2.1-2 is a simplified functional diagram of the logic for updating one of the two CMC state vectors—designated in Figure 4.2.1-2 as "passive vehicle orbit" and "active vehicle orbit."

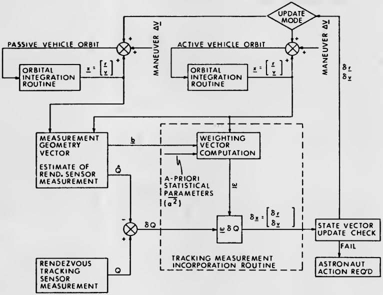
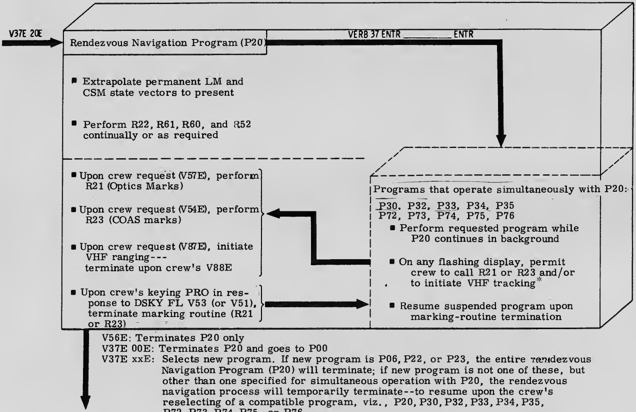


Figure 4.2.1-1. Simplified Rendezvous Navigation Diagram



V56E: Terminates P20 only
V37E 00E: Terminates P20 and goes to P00
V37E xxE: Selects new program. If new program is P06, P22, or P23, the entire rendezvous Navigation Program (P20) will terminate; if new program is not one of these, but other than one specified for simultaneous operation with P20, the rendezvous navigation process will temporarily terminate--to resume upon the crew's reselecting of a compatible program, viz., P20, P30, P32, P33, P34, P35, P72, P73, P74, P75, or P76.

*Navigation data are not incorporated, however, during the time that UPDATE flag is reset. See paragraph 4.2.1.5.

Figure 4.2.1-2. Simplified Flow Diagram Showing Relationship of P20 to Other CMC Programs

Extrapolating both state vectors to the time of measurement, P20 computes an estimated tracking quantity ($\hat{Q}$), which is compared with a measured tracking quantity (Q) to obtain a measurement deviation δQ. This is multiplied by a statistical weighting vector ($\underline{\omega}$) comprising an onboard computation of expected state-vector uncertainties, expected sensor performance ($\overline{\alpha}^2$), and the sensor geometry vector ($\underline{b}$). The resulting $\delta \underline{x}$ is a statistically optimum linear estimate of the state deviation to be added to the current estimate of the state vector selected to be updated.

Typically, tracking data are processed once every minute for VHF marks and as often as every 20 sec for optics; the selected state vector is automatically updated by the computed deviation $\delta \underline{x}$. If the magnitude of either the position-vector change ($\delta \underline{r}$) or the velocity-vector change ($\delta \underline{v}$) of the deviation $\delta \underline{x}$ is not less than preset values, however, the crew is alerted by a special display, and the update occurs only upon crew command, after verifying the tracking data.

4.2.1.1 Crew Options

The fundamental crew option is whether to update the CSM state vector or the LM state vector. Considerations affecting the decision are (1) the desire to update the state vector having the largest uncertainties, and (2) a desire to update the state vector of the vehicle that is to perform the rendezvous maneuver. Ordinarily, both considerations will favor updating the LM. Should the LM state-vector uncertainty be the smaller, however, updating the CSM would probably be preferred.

The second option regards the selection of sensors to be used in taking measurements. Ordinarily, the CSM optics will be used in conjunction with the VHF range link. If both sensor systems are not operational, however, or if, for example, the LM is not visible, P20 can be performed, with degraded accuracy, using only one of the sensors.

The third option is whether to use the preferred tracking attitude (sextant tracking) or the backup X-axis tracking attitude (COAS tracking). The "preferred" is the normal procedure.

4.2.1.2 Computational Sequence

Table 4.2.1-I is a summary of Rendezvous Navigation displays; Table 4.2.1-II gives the extended verbs; and Figures 4.2.1-3 through 4.2.1-12 are functional diagrams of P20 and the following, associated routines:

R02 — The IMU Status Check Routine (Figure 4.2.1-4) is called by programs requiring an aligned IMU. R02 checks the IMU orientation (REFSMMAT) flag and the IMU operate bit and initiates a PROG alarm if either is not set. The crew verifies the alarm by keying VERB 5 NOUN 9 ENTR. If IMU orientation is not known, but the inertial subsystem (ISS) is operating, alarm code 00220 will be displayed; if the ISS is not operating, alarm code 00210 will be displayed. For either alarm, keying RSET sends the program to the Final Automatic Request Terminate Routine (R00), where the crew turns on the ISS (if off) and calls either the primary or backup IMU Orientation Determination Program (P51 or P53).

R22 — The Rendezvous Tracking Data Processing Routine (Figure 4.2.1-5) is started by P20 and continues to run until P20 is terminated. R22 processes optical and VHF ranging data and updates the state vector designated by the state-vector flag. Incorporation of VHF data is enabled by VERB 87 ENTR and disabled by VERB 88 ENTR.

R61 — The Tracking Attitude Routine (Figure 4.2.1-6) is called either by P20 or R52. R52 calls R61 on every pass during rendezvous tracking. On every fourth pass (only), R61 extrapolates the CSM and LM state vectors to the present, calculates the LOS from the CSM to the LM, and computes the IMU gimbal angles required to keep the CSM properly oriented for tracking the LM. If the PREFERRED-ATTITUDE flag is set (automatically by P20 or by crew's VERB 76 ENTR), an appropriate attitude is held for SXT and VHF tracking; if the PREFERRED-ATTITUDE flag is reset (VERB 77 ENTR), an appropriate attitude is held (+X-axis pointed at LM) for COAS tracking. Comparing the required and present gimbal angles, R61 determines whether the required change in any gimbal angle is more than 10 deg. If all gimbal angles are within 10 deg of required, R61 computes the LOS angular velocity, resolves it into RCS control axes, and generates appropriate input to the RCS DAP. If, on the first pass through R61 after P20 entry (V50N18 flag set), any required gimbal-angle change is greater than 10 deg, R61 calls the Attitude Maneuver Routine (R60). If, on subsequent passes through R61 (V50N18 flag reset), any required gimbal-angle change is greater than 10 deg, R61 turns on the UPLINK ACTY light but does not call R60. Should the astronaut wish an R60 maneuver performed, he would key VERB 58 ENTR, setting the V50N18 flag (and resetting the STICK flag) and instructing R61 to call R60.

After commanding the maneuver or providing the appropriate RCS DAP input, R61 returns to the calling program.

R60 — The Attitude Maneuver Routine (Figure 4.2.1-7) maneuvers the spacecraft to an attitude specified by the calling program. The astronaut can choose to perform the maneuver manually or automatically. If manually, the maneuver is performed with the rotational hand controller (RHC) while the astronaut monitors the FDAI; if automatically, the maneuver is performed by CMC-commanded RCS jet firings.

R52 — During rendezvous navigation, the Automatic Optics Positioning Routine (Figure 4.2.1-8) keeps the CSM optics pointed at the LM. Calculating the LOS to the LM, with R61 maintaining tracking attitude, R52 drives the optics shaft and trunnion accordingly until the TRACK flag is reset.

R21 — The Rendezvous Tracking Sighting Mark Routine (Figure 4.2.1-9) is called by the crew's keying VERB 57 ENTR during R22. A flashing VERB 51 requests the astronaut to center SXT on LM and to mark. R21 is terminated by the crew's depressing the PRO key.

R23 — The Backup Rendezvous Tracking Sighting Mark Routine (Figure 4.2.1-10) is similar to R21 except that R23 uses the crew optical alignment sight (COAS) rather than the sextant (SXT). R23 is called by the crew's keying VERB 54 ENTR and is terminated by PRO.

R31/
R34 — The Rendezvous Parameter Display Routines (Figures 4.2.1-11 and -12) display range and range rate (between the CSM and LM) calculated from the stored LM and CSM state vectors. In addition, R31 displays the current angle (θ) between the CSM plus X-axis and the local-horizontal plane. R34 displays the current angle (ϕ) between the SXT SLOS and the local-horizontal plane.

Before entering P20, the crew performs the DAP Data Load Routine (R03).

Upon the crew's selection of P20 (VERB 37 ENTR 20 ENTR), the program performs the IMU Status Check Routine (R02, Figure 4.2.1-4) and illuminates the PROG alarm lamp should the ISS be off or the IMU orientation be unknown. Should the PROG lamp illuminate, the crew must key VERB 05 NOUN 09 ENTR in order to read the alarm code (00210, ISS not on; 00220, IMU orientation unknown). A flashing VERB

37 indicates that, as a result of the alarm, the program has entered the Final Automatic Request Terminate Routine (R00).

Next, the program automatically selects the preferred tracking-attitude option and LM state-vector option. The crew can change either of these by the following DSKY entries:

VERB 76 ENTR selects preferred tracking attitude.
VERB 77 ENTR selects plus X-axis track attitude.
VERB 80 ENTR selects LM state-vector update.
VERB 81 ENTR selects CSM state-vector update.

P20 next sets the following flags:

V50N18 Flag — enables R60 and the display of required gimbal angles for a maneuver to the desired tracking attitude.

TRACK FLAG — enables automatic maneuver, optics pointing, and state-vector update.

UPDATE FLAG — enables state-vector update.

RENDEZVOUS FLAG— enables total P20 operation.

The rendezvous-optics and VHF-ranging mark counters are next set to zero, and the CSM and LM state vectors are extrapolated to the present time. P20 then calls the Rendezvous Tracking Data Processing Routine (R22, Figure 4.2.1-5), which will continue to operate while P20 is active. The program then calls the Tracking Attitude Routine (R61, Figure 4.2.1-6), which uses VECPOINT to compute the CSM tracking attitude required for pointing the optics and radar transponder at the LM. VECPOINT is, basically, a method of taking the cross product of the present and desired LOS and computing the rotation angle required to align the two about the resulting cross-product vector. (See subsection 3.6 of the current CSM GSOP.) If attaining the preferred tracking attitude requires a gimbal-angle change of less than 10 deg, R61 will issue the command signals to the RCS DAP (SC CONT switch in CMC; CMC MODE switch in AUTO; STICK flag reset). If attaining the preferred tracking attitude requires a maneuver of 10 deg or larger, R61 calls the Attitude Maneuver Routine (R60, Figure 4.2.1-7). (NOTE: During P20 operation, R61 is called every 2 sec; only on every fourth pass, however, is R61 allowed to complete its cycle. After an initial pass has established a tracking attitude of less than 10 deg, R61 resets the V50N18 flag, disabling R60 on subsequent passes. Therefore, should, on a subsequent pass through R61, any required gimbal-angle change be found greater than 10 deg, R61 would illuminate the UPLINK ACTY light, and R60 would only be allowed to perform the required maneuver upon the astronaut's setting the V50N18 flag by keying VERB 58 ENTR.)

Entering R60, the program flashes VERB 50 NOUN 18 and displays the desired gimbal angles in 1/100 degree:

R1—OG, roll
R2—IG, pitch
R3—MG, yaw

Should the astronaut desire the maneuver to be performed by the autopilot, he would place the SC CONT switch in CMC, the CMC MODE switch in AUTO, and would then depress the PRO key on the DSKY, signaling the RCS DAP to begin the maneuver. (It is also assumed that VERB 46 ENTR has been keyed and that the RCS DAP is operating.)

During the maneuver, a non-flashing VERB 06 NOUN 18 displays the final gimbal angles, and the astronaut monitors the maneuver on the FDAI ball and needles. Should the maneuver approach gimbal lock, the astronaut would take over manually and complete the maneuver using the rotation hand controller (RHC).

At the completion of the maneuver—or its premature termination by the astronauts' use of the RHC—R60 recycles, and VERB 50 NOUN 18 again flashes the desired gimbal angles. If the displayed angles are within RCS deadband limits and no rotation about the pointing vector—to obtain wings level—is desired, the astronant would key ENTR, and R60 would exit. If further attitude adjustment were required, however, the astronaut would perform the adjustment with the RHC while referencing the FDAI needles and ball. Keying ENTR terminates R60 and allows R61 to continue computing and maintaining the pointing vector along the LM LOS as long as the SC CONT switch is in CMC AUTO.

The program next enters the Automatic Optics Positioning Routine (R52). R52 extrapolates the CSM and LM state vectors to the present plus 2.4 seconds, gets the CSM attitude from the ICDUs, computes the vector from the CSM to LM, and calculates the required optics angles to point the sextant line of sight at the LM.

If the required trunnion angle is less than 50 deg, R52 drives the shaft and trunnion CDUs to align the optics with the LM. The program then recycles through R61, and both routines (R61 and R52) continue to operate in approximately 2-second cycles.

When the astronaut wishes to take SXT marks on the LM, he keys VERB 57 ENTR, which calls the Rendezvous Tracking Sighting Mark Routine (R21, Figure 4.2.1-9). As described earlier, R61 will automatically maintain the preferred tracking attitude.

Once entered, R21 flashes VERB 51 on the DSKY, requesting the astronaut to "please mark." The astronaut then selects the manual optics mode, centers the LM in the reticle, and depresses the mark button. If the mark was satisfactory, the astronaut waits the prescribed time (based on geometry, timeline, etc.), recenters the LM in the reticle, and repeats the mark (if more marks are desired). If the mark was not satisfactory, the astronaut depresses the reject button and repeats the mark procedure. When sufficient marks have been taken, the astronaut keys in PRO to terminate R21. If any mark results in an excessive update (discussed in paragraph 4.2.1.5.1), a priority display (flashing VERB 06 NOUN 49) will automatically interrupt any program-initiated display and present the magnitude of the excessive update:

Flashing VERB 06 NOUN 49 — R1, ΔR (0.1 n. mi.); R2, Δv (0.1 ft/sec); R3, Source Code (00001, optics; 00002, VHF ranging).

Depressing the PRO key incorporates the update data; keying VERB 32 ENTR rejects the data. When rendezvous has been completed, the crew can exit P20 either by keying VERB 37 ENTR 00 ENTR, which discontinues all programs in progress, or by keying VERB 56 ENTR, which discontinues only P20.

For the plus X-axis tracking-attitude option, using the backup optics (COAS), the crew keys VERB 77 ENTR immediately after entering P20 and keys VERB 54 ENTR (rather than VERB 57 ENTR) after the attitude maneuver has been completed. VERB 54 calls the Backup Rendezvous Tracking Sighting Mark Routine (R23). The DSKY then flashes VERB 06 NOUN 94 and presents in registers 1 and 2 the equivalent shaft angle (SA) and equivalent trunnion angle (TA) for the alternate LOS in the NAVBASE Coordinate System. If the astronaut elects to use the COAS, the nominal values for these angles are 00000 in R1 and 57470 in R2. (Note: In-flight calibration of the COAS should be performed before use with rendezvous.) If the angles displayed are not correct for the selected LOS, the astronaut keys VERB 24 ENTR and loads the correct values. When the correct angles are displayed, the astronaut keys in PRO and will get a flashing VERB 53, "please perform alternate LOS sighting mark."

The astronaut will then use the RHC to align precisely the LM along the alternate LOS. He then depresses the ENTR key on the DSKY. When sufficient marks have been made, the astronaut depresses the PRO key. To reject a mark, the astronaut keys VERB 86 ENTR and repeats the mark procedure. Again, when rendezvous has been completed, VERB 37 ENTR 00 ENTR terminates all programs running; VERB 56 ENTR terminates only P20.

Although we have not mentioned how VHF range data are initiated, the crew procedure is simply to key VERB 87 ENTR whenever range data are desired; VHF range taking will then be continued automatically until terminated by the crew's selection of VERB 88 ENTR or by the execution of any program change, that is, any VERB 37.

4.2.1.3 Program Alarms

Viewing a PROG alarm light on the DSKY, the crew keys VERB 05 NOUN 09 ENTR for a display of the alarm code—if the code has not already been displayed by the CMC. After taking corrective action, the crew keys RSET to turn off the PROG light and alarm and continues with the program. Possible alarms encountered during rendezvous navigation are as follows:

a. Alarm 00110 indicates that the crew depressed the MARK REJECT button unnecessarily; no marks were taken yet. The astronaut should key RSET to extinguish the OP ERR light and continue normal operation.
b. Alarm 00112 indicates MARK REJECT was depressed while the CMC was not requesting marks. Key RSET and continue normal operation.
c. Alarm 00116 indicates the optics were switched to OFF from ZERO before the 15 sec optics zeroing time had elapsed. Set the Optics Zero switch to ZERO, key RSET, wait 15 sec and continue normal operation.
d. Alarm 00120 indicates optics not zeroed at the time of an optics torque request. Set Optics Zero switch to OFF, then to ZERO. Key RSET and wait 15 sec before continuing normal operation.
e. Alarm 00121 indicates a mark was made at the time of a CDU switching transient or vehicle rotation rate too high. Key RSET, MARK REJECT, and repeat mark.
f. Alarm 00122 indicates a mark was made while the CMC was not in a mark routine. Key RSET and continue normal operation.
g. Alarm 00210 indicates IMU not operating. It should be turned on and the stable member orientation determined before entering P20.
h. Alarm 00220 indicates IMU not aligned. No REFSMMAT is stored. Key RSET and execute P51.

i. Alarm 00401 indicates desired angles yield gimbal lock. Key RSET and either select new gimbal angles or maneuver spacecraft to avoid gimbal lock.

j. Alarm 00406 indicates that R21 or R23 has been called with P20 not operating: select P20 before calling the mark routine.

4.2.1.4 Restrictions and Limitations

When the CMC accepts an optics mark, three ICDUs, two OCDUs, and the time of the mark are stored in a buffer (position 1). When a second mark is taken, the data in position 1 are transferred to position 2, and the new data are stored in position 1. Should marks be taken faster than about one every 20 seconds, there is a chance that the data in position 2 will be lost. Also, there is a chance that one of the last two marks will be lost unless about 15 seconds are allowed before proceeding (PRO) after the last mark.

An additional restriction is that the W-matrix should never be re-initialized to values greater than 328 ft/sec and 51,647 ft. (The W-matrix is discussed in paragraph 4.2.1.5 and in the "Introduction to Coasting Flight Navigation," subsection 4.1.)

A limiting factor regarding VHF range data is that beyond 327.67 n. mi. the input counter to the CMC is saturated and VHF range data cannot be used. Also, depending upon scaling, there is a minimum range at which P20 is effective. Although it is difficult to establish definite limits, since scaling may differ for different missions (e.g., earth versus lunar), operation with current scaling is not recommended for ranges less than about 3 n. mi.

4.2.1.5 Tracking and W-Matrix Reinitialization Schedules

The Rendezvous Navigation Program (P20) can only solve for the relative position and velocity of one orbiting vehicle with respect to another. The extent to which the state vector updated by P20 conforms to actual position and velocity in inertial space will depend, therefore, upon how well the inertial position and velocity of the vehicle whose state vector is not updated are known. Since the primary concern in rendezvous navigation, however, is relative position and velocity, the limitations regarding inertial state-vector accuracy are of concern only as a factor to be considered in determining the relative state of the two vehicles. If there were no uncertainties in the direct measuring of range and LOS between the two vehicles, determining the relative state vector would be simply a matter of taking measurements, comparing the results with values predicted on the basis of the current best estimate of the two state vectors, and updating one of the estimated states such that the predicted and measured values agree. Measuring uncertainties do exist, however, calling for a statistical weighting matrix (W-matrix) and an a priori sensor variance for determining how much emphasis is to be given to the measured data, in updating the state, and how much is to be given to the current state estimate. Initially, the W-matrix is based on statistical studies to determine what the expected mean-square errors in position and velocity will be before any measurements are taken; as measurements are taken, however, and the confidence in the relative state vector increases, the W-matrix is itself updated such that statistical weighting becomes more and more in favor of the current estimate and less in favor of new measurements. Due to incomplete filter modeling and computational limitations of the computer, the weighting in favor of the measurements becomes, in time, too small. To prevent this, the W-matrix must be periodically re-initialized (WRI) to its padloaded or reloaded values.

Ordinarily, Mission Planning provides a schedule specifying when, what kind, and how many measurements should be taken, as well as when the W-Matrix should be reinitialized—and to what values. (Figure 4.2.1-13 is a typical tracking schedule provided by Mission Planning.) Such a schedule results from analyses of digital simulations of the actual computer operations for a particular mission. For inflight contingencies, however, requiring the crew to improvise a tracking and reinitialization strategy, an acceptable rule of thumb is to (a) reinitialize every 25 minutes, but allowing 10–15 minutes of tracking before a final targeting solution, (b) take several marks immediately before, immediatly after, and halfway between each reinitialization, and (c) reinitialize before taking marks after a maneuver if more than 45 minutes have elapsed since the last initialization.

The philosophy underlying the rule of thumb is to reinitialize more often than may be necessary but less often than would significantly degrade performance. In applying the rule, however, the crew should be aware of three other factors:

1. W-Matrix initial values are selected on the basis of anticipated state-vector error—the larger the expected error, the larger the initialization values. Typical reinitializing values during rendezvous are 2000 ft, 2 ft/sec, and (in the LGC) 5 m rad—corresponding to the RMS values of probable position, velocity, and radar-bias errors respectively. Immediately following lunar orbit insertion, however, when the large powered-flight maneuver may have produced large state-vector uncertainties, typical WRI values are 10,000 ft, 10 ft/sec, and 15 m rad (LGC).

2. The larger the WRI values, the more sensor data required to smooth the WRI transient. Even for the large initial values following lunar orbit insertion, however, an accurate state vector estimate is available for the final targeting computation if SXT marks are taken in batches of three or four marks each—typically, one batch immediately after WRI, a second batch halfway before a third batch immediately preceding the next WRI or the final targeting computation.
3. The two-sensor procedure following transfer-phase initiation (TPI)—when the tracking geometry is such as to rapidly decrease the size of the matrix with each mark—is to reinitialize before taking any marks following a maneuver. The single-sensor post-TPI procedure is (a) to take marks with no WRI between TPI and the first midcourse correction (MCC1) and (b) to take one batch and then reinitialize immediately after MCC1. Tracking then continues in the normal pattern.

Paragraphs 4.2.1.5.1—4.2.1.5.3 have been abstracted from E. Muller and P. Kachmar, Mission Simulation Memo 10-69, dated 12 May 1969. Some general recommendations are made on mark-reject and accept procedures, as well as recommended procedures when state-vector updates indicate a divergent navigation solution. Two graphs (Figures 4.2.1-14, -15) present actual state-vector updates (that exceed R_{MAX}, v_{MAX} values) for a CMC and LGC bit-by-bit simulation of the nominal Mission F rendezvous. (Note: R_{MAX} v_{MAX} limits were not exceeded after post-CSI V93.) Also shown are one-sigma state-vector updates.

The procedures here attempt to cover some off-nominal conditions. All off-nominal conditions, however, cannot be simply generalized; each case must be considered in the light of all information available; e.g., previous marking history may indicate a three-sigma radar, extremely large initial state errors that require a long tracking period to resolve, or degraded PIPA performance as evidenced by large state-vector updates after a burn.

4.2.1.5.1 State Vector Update.—The following are mission phases in which the largest state-vector updates can be expected:

a. Initial period of tracking after insertion
b. After maneuvers—either a burn for active vehicle or P76 for passive vehicle
c. Beginning of tracking after long period with no tracking
d. After W-matrix re-initialization.

Reasonable values for updates are a function of the phase in which they occur. Typically, a δr of 12000 ft and a δv of 12 ft/sec (before CSI), 5000 ft and 5 ft/sec after CSI, can be expected during phases of expected large updates. Should the update value seem excessive, the crew should reject the first mark, ensure that the sextant is actually tracking the LM, check VHF range against nominal, and repeat the mark. If the second mark yields a similar, or slightly larger, update, accept the mark and look for a decrease in the size of the update as marks continue. If update values do not become smaller, apply divergence procedure (paragraph 4.2.1.5.2 below).

Anomalous updates during "steady-state" conditions, i.e., not during phases of expected large updates, are those that are larger than the preset R_{MAX}, v_{MAX}. For this condition, the follows the same procedure described for larger-than-reasonable updates during expected-large-update phases. One bad mark could be the result of poor sighting technique or large random error. If anomalous updates continue, use divergence procedure (paragraph 4.2.1.5.2).

4.2.1.5.2 Divergence Procedures. — There are six categories of anomalous conditions requiring special procedures:

1. Condition. State-vector updates are not decreasing (and are near the 12000 ft, 12 fps limits) after 10 accepted marks after insertion. Procedure. Re-initialize W-matrix; zero out bias estimates (not W-matrix bias loads). (Bias estimates apply only to the LGC.)

   Implication. Initial relative errors were too large for initial W-matrix to handle; repeat entire procedure and if same results occur, assume system failure unless other vehicle is experiencing same difficulty. (This indicates ground uplink yielded relative errors of such a magnitude that system cannot resolve them.)

2. Condition. State-vector updates exceed R_{MAX}, v_{MAX} for three unaccepted marks during steady-state operation (where it is assumed a period of acceptable tracking precedes these marks). Procedure. Re-initialize W-matrix and accept first mark. If updates do not decrease after four or five accepted marks, system has failed.

3. Condition. State-vector updates exceed 5000 ft, 5 ft/sec for three unaccepted marks during steady-state operation (no excessive updates preceding as above). Procedure. Re-initialize W-matrix and accept first

mark. If updates continue to exceed 5000 ft or 5 ft/sec, or do not decrease after four or five accepted marks, system has failed. If updates converge, realize that you may be operating with a sensor that has bias and that a state-vector error will exist. (The value of this error should be approximately the size of the first update after W-matrix re-initialization.)

4. Condition. Last mark before a maneuver exceeds R_{MAX}, v_{MAX}. Procedure. If you were in steady-state conditions before this, reject last mark. If updates were exceeding R_{MAX}, v_{MAX} before last mark, but were decreasing, accept mark.

5. Condition. Unreasonably large Position Update. Procedure. Reject; anything larger than $\frac{\text{range}}{5}$ can cause system to be unstable.

6. Condition. Unreasonably large update is accepted and is known to have been incorrect (system malfunction discovered; bad P76, bad ground uplink, etc.) Procedure. (a) Fix malfunction; (b) get new ground uplink, if possible, and start again; (c) if uplink not possible, re-initialize W-matrix to approximate position value of update, velocity value 0.001 x position value, zero out bias estimates (not in W-matrix load) and proceed. (Bias estimates apply only to the LGC.)

4.2.1.5.3—Summary of Correction Procedures for Anomalous Updates During Steady State Tracking.

1. Always check out sextant first—after a VHF mark and V88.
2. If both sensors fail procedure—V93 and start over.
3. If only one sensor fails procedure—proceed with other sensor only.

Sensor Verification
(assumes first mark rejected)

ΔR, Δv(N49) < 1 n. mi., 5 fps	ΔR, Δv(N49) > 1 n. mi., 5 fps
accept second and third marks (PRO) if fourth mark under limit -- sensor data OK if fourth mark over limit-- sensor data bad	- reject three consecutive marks that exceed above limits (including first mark) (sensor data bad)

Recovery procedure after extremely large update known to be incorrect

- Record N49 value of ΔR (xxxx. x n. mi.)
- Terminate updates (V88)
- V67E, load N99 with

  R1 = ΔR times 6000 (xxxxx. ft)
  R2 = ΔR times 6 (xxxx. x fps)
  R3 = + 00001
- RESUME updates (V87)

TABLE 4.2.1-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH RENDEZVOUS NAVIGATION (P20) (SHEET 1 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
V05 N09 E	Astronaut	Verify PROG alarm	00210 = ISS not on 00220 = IMU orientation unknown 00406 = P20 not in progress	Rn xxxxx
FL V37	R00	Request astronaut to select program	– – –	– – –
FL V50 N18	R60	Priority* display of required gimbal angles	OGA (roll) IGA (pitch) MGA (yaw)	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
V06 N18	R60	Priority* display of required gimbal angles	OGA IGA MGA	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
FL V51 N45	R21	Request "Please Mark" and display MARK CTRS, TFI and MGA.	MARK CTRS TFI MGA	R1 xxBxx R2 xxBxx min, sec R3 xxx.xx deg
FL V06 N94	R23	Display backup (COAS) optics shaft and trunnion angles	00000 = Shaft angle (SA), nominal 57470 = Trunnion angle (TA), nominal	R1 xxx.xx deg R2 xx.xxx deg
V24E	Astronaut	Load desired SA and TA	– – –	R1 xxx.xx deg R2 xx.xxx deg

*Priority display is an internally generated display that will override any other internally generated display. Display cannot be responded to for 2 seconds.

TABLE 4.2.1-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH RENDEZVOUS NAVIGATION (P20) (SHEET 2 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
FL V53 N45	R23	Perform alternate LOS mark and display MARK CTRS, TFI and MGA.	MARK CTRS TFI MGA	R1 xxBxx R2 xxBxx min, sec R3 xxx.xx deg
FL V06 N49	R22	Priority* display of state-vector data for crew approval	ΔR Δv Source code	R1: xxxx.x n.mi. R2: xxxx.x ft/sec R3: oooox
FL V06 N99	V67	Display W-matrix RMS Error	Position error Velocity error Option code (Rendezvous)	R1: xxxxx. ft R2: xxxx.x ft/sec R3: 00001
V16 N22E	Astronaut	Monitor desired gimbal angles	OGA IGA MGA	R1: xxx.xx deg R2: xxx.xx deg R3: xxx.xx deg
V16 N92E	Astronaut	Monitor desired optics angles	shaft trunnion	R1: xxx.xx deg R2: xx.xxx deg
FL V16 N54	R31	Monitor range data	range range rate theta	R1: xxx.xx n.mi. R2: xxxx.x ft/sec R3: xxx.xx deg
FL V16 N53	R34	Monitor range data	range range rate phi	R1: xxx.xx n.mi. R2: xxxx.x ft/sec R3: xxx.xx deg

TABLE 4.2.1-II

EXTENDED VERBS USED WITH RENDEZVOUS NAVIGATION (SHEET 1 OF 3)

VERB	Identification	Purpose	Remarks
32 ENTR*	Recycle	Reject R22 Update data when displayed by N49	See discussion of excessive update parameters, paragraphs 4.2.1.5.1 – 4.2.1.5.3
44 ENTR 45 ENTR	Set Surface Flag Reset Surface Flag	Indicates LM on lunar surface Indicates LM not on lunar surface	This flag must be in the proper configuration before the Tracking-attitude Routine (R61) is performed.
54 ENTR 57 ENTR	Do R23 Do R21	Perform LM markings using the backup (COAS) optics Perform LM markings using the SXT	With P20 running in the background and with R61 and R52 maintaining attitude and optics positioning (preferred-attitude flag set), the marking routine (R21 or R23) can be called whenever required by the mission marking schedule.
56 ENTR	Reset Rendezvous Flag	Terminate P20 without terminating other major programs	Resetting this flag terminates the entire rendezvous-navigation process. Also, reset by P00 selection (VERB 37 ENTR 00 ENTR). Set by P20 selection.
58 ENTR	Reset Stick Flag and set V50N18 Flag	Allow RCS DAP to resume automatic attitude control, and R61 to call R60.	The stick flag is set whenever RHC is taken out of detent and the CMC CONT switch is in the CMC position. Once set, the flag can only be reset by a selection of a new Program or by VERB 58 ENTR. The V50N18 Flag is initially set by VERB 37 ENTR 20 ENTR and is reset during each pass through R61. After the initial pass, R61 can call R60 only after the crew's VERB 58 ENTR.
62 ENTR	Select Mode 2	Provide FDAI reference for manual attitude maneuver	Displays total attitude error (NOUN22 - NOUN20) on FDAI error needles

* Though, strictly speaking, Verb 32 is not an extended verb, it is included here for convenience in summarizing special-purpose verbs associated with this program.

TABLE 4.2.1-II

EXTENDED VERBS USED WITH RENDEZVOUS NAVIGATION (SHEET 2 OF 3)

VERB	Identification	Purpose	Remarks
67 ENTR	W-Matrix RMS Display	To display W-Matrix and to provide a means of changing and reinitializing the preset values.	When reinitialization of the W-Matrix to a value other than the preset value is desired, the crew keys VERB 67 ENTR and enters the new values into NOUN 99. The W-Matrix will then reinitialize to the new values when the next mark is incorporated by R22.
76 ENTR	Set Preferred-Attitude Flag	Cause R61 to drive CSM attitude to align SXT LOS with LM	The Preferred-Attitude Flag is automatically set when P20 is entered. Therefore, if +X-axis alignment with LM is desired, VERB 77 ENTR should be keyed before R61 begins the attitude maneuver.
77 ENTR	Reset Preferred-Attitude Flag	Cause R61 to drive CSM attitude to align +X-axis with LM	
80 ENTR	Set State-Vector Flag to LM	Cause the LM state vector to be updated	The State-Vector Flag is automatically set to LM when P20 is entered. Therefore, if the CSM state vector is that intended for update, VERB 81 ENTR must be keyed before the marking routine is called.
81 ENTR	Set State-Vector Flag to CSM	Cause the CSM state vector to be updated	
83 ENTR	Do R31	Display first set of rendezvous parameters	DSKY displays range, range rate, and theta, the angle between local horizontal and the spacecraft X-axis (FL VERB 16 NOUN 54)
85 ENTR	Do R34	Display second set of rendezvous parameters	DSKY displays range, range rate, and phi, the angle between local horizontal and the trunnion SLOS (FL VERB 16 NOUN 53)
86 ENTR	---	Reject R23 mark	Erases sighting data in position 1 and recycles to permit new mark

TABLE 4.2.1-II

EXTENDED VERBS USED WITH RENDEZVOUS NAVIGATION (SHEET 3 OF 3)

VERB	Identification	Purpose	Remarks
87 ENTR	Set VHF Range Flag	Allow R22 to accept range data	This flag is not set automatically. Therefore, if VHF range data are to be incorporated in the state-vector update, VERB 87 ENTR must be keyed.
88 ENTR	Reset VHF Flag	Stops R22 from accepting range data	VHF ranging will then continue automatically until the crew either keys VERB 88 ENTR or any VERB 37.
93 ENTR	Reset RENDWFLAG	Reinitialize W-Matrix	If reinitializing without changing the preset values, the crew need only key VERB 93 ENTR.

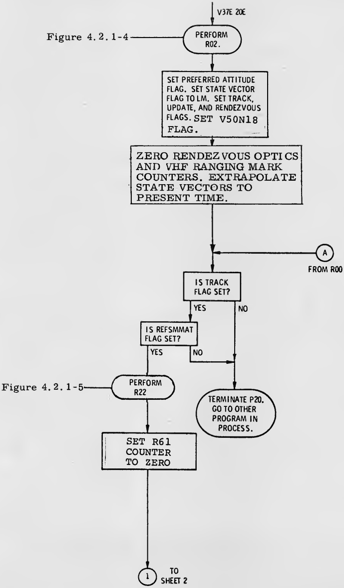


Figure 4.2.1-3 Rendezvous Navigation Program (P20) (Sheet 1 of 2)

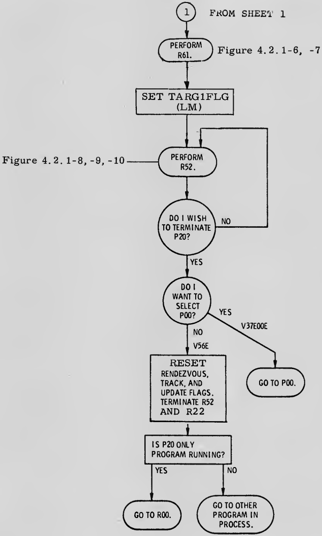


Figure 4.2.1-3 Rendezvous Navigation Program (P20) (Sheet 2 of 2)

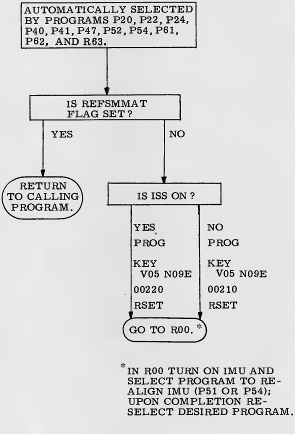


Figure 4.2.1-4. IMU Status Check Routine (R02)

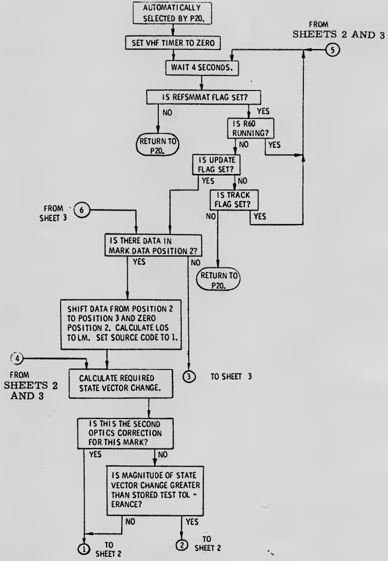


Figure 4. 2. 1-5. Rendezvous Tracking Data Processing Routine (R22) (Sheet 1 of 3)

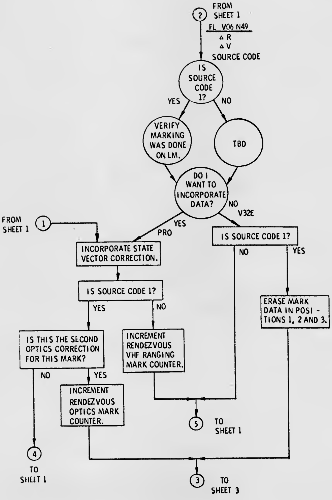


Figure 4. 2. 1-5. Rendezvous Tracking Data Processing Routine (R22) (Sheet 2 of 3)

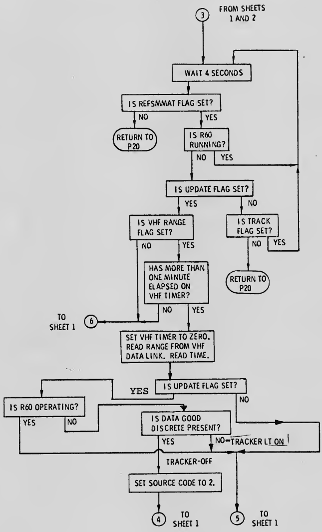


Figure 4. 2. 1- 5. Rendezvous Tracking Data Processing Routine (R22) (Sheet 3 of 3)

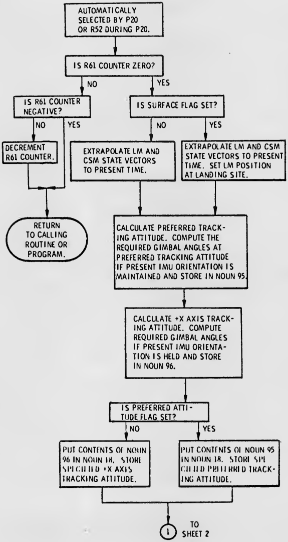


Figure 4.2.1-6. Tracking Attitude Routine (R61) (Sheet 1 of 2)

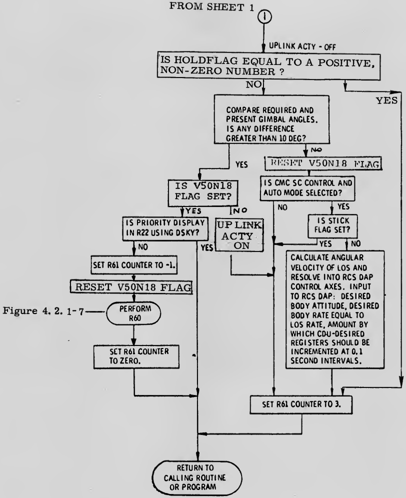


Figure 4. 2. 1-6. Tracking Attitude Routine (R61) (Sheet 2 of 2)

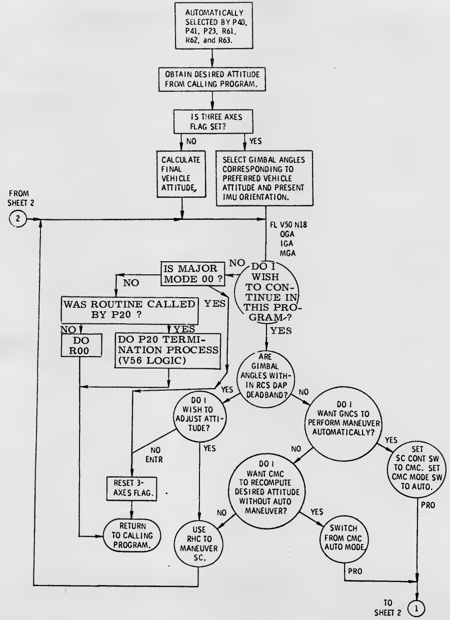


Figure 4.2.1-7. Attitude Maneuver Routine (R60) (Sheet 1 of 2)

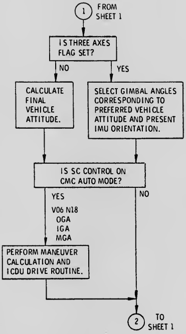


Figure 4. 2. 1-7. Attitude Maneuver Routine (R60) (Sheet 2 of 2)

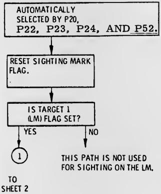


Figure 4. 2. 1- 8. Automatic Optics Positioning Routine (R52) (Rendezvous) (Sheet 1 of 2)

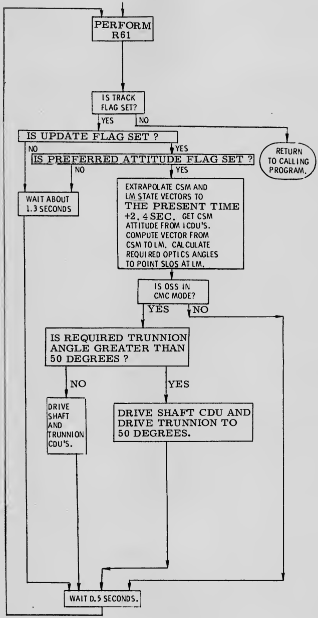


Figure 4. 2. 1-8. Automatic Optics Positioning Routine (R52) (Rendezvous) (Sheet 2 of 2)

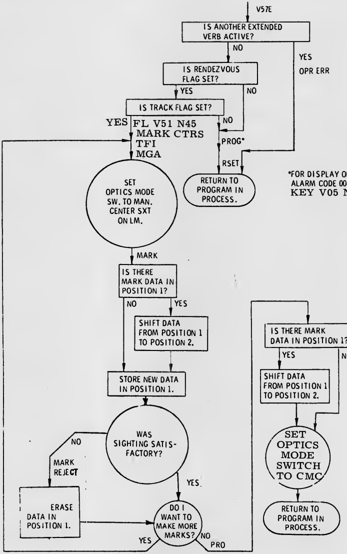
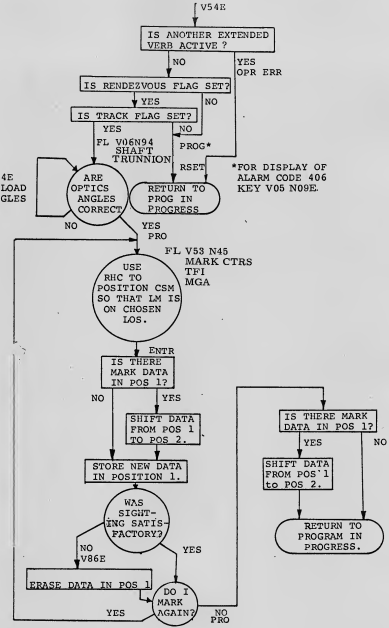


Figure 4. 2. 1-9. Rendezvous Tracking Sighting Mark Routine (R21)



*FOR DISPLAY OF ALARM CODE 406 KEY V05 N09E.

Figure 4. 2. 1-10. Backup Rendezvous Tracking Sighting Mark Routine (R23)

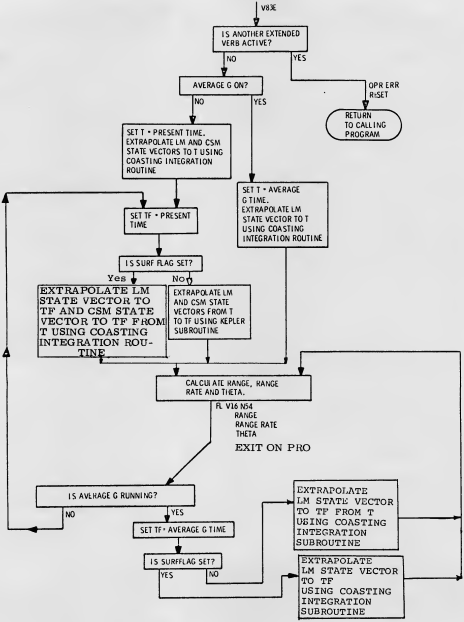


Figure 4. 2. 1-11. Rendezvous Parameter Display Routine No. 1 (R31)

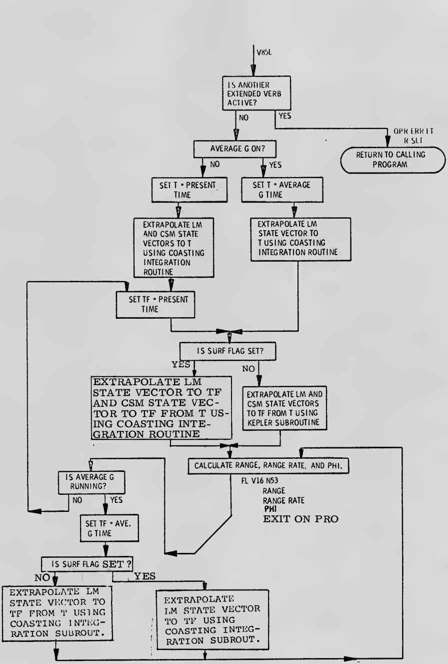


Figure 4.2.1-12. Rendezvous Parameter Display Routine No. 2 (R34)

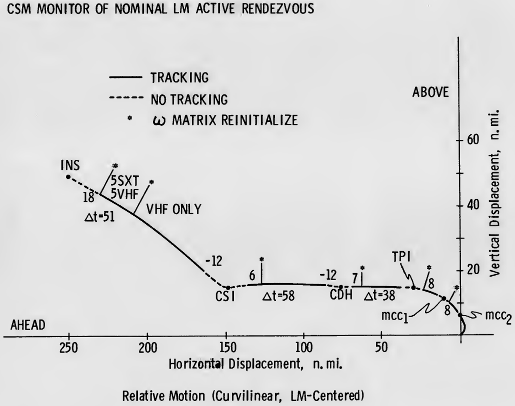


Figure 4.2.1-13. Typical Tracking Schedule for a CSM-monitored — LM-active Rendezvous

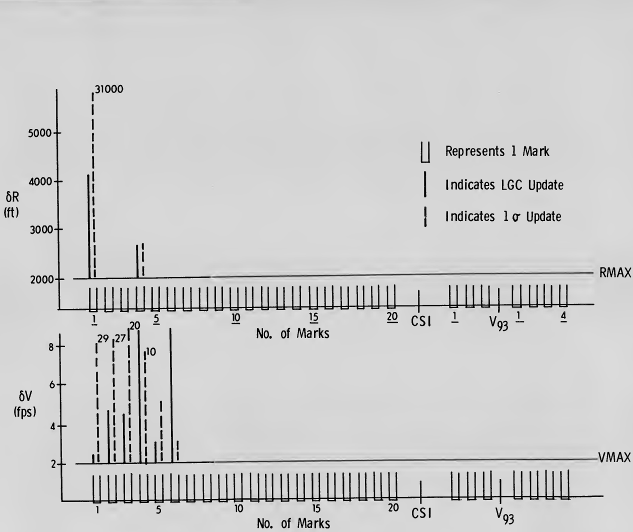


Figure 4.2.1-14. Typical RR δR, δv Updates

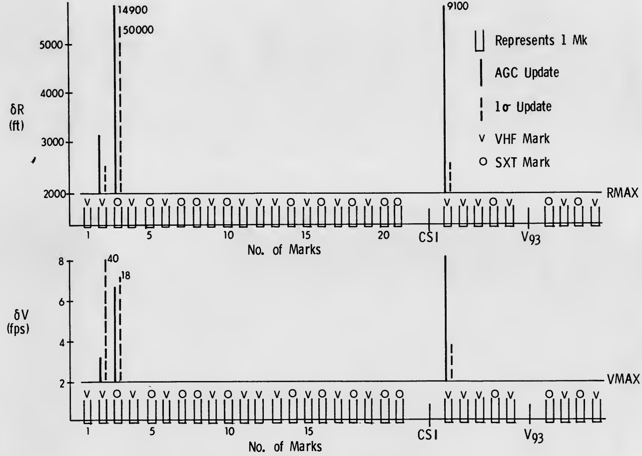


Figure 4.2.1-15. Typical VHF and SXT δR, δv Updates

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4.2.2 P21, Ground-track Determination—CMC

P21 has two distinct uses. First, as P21 ground track determination, it can be used to predict marktaking opportunities for P22 orbital navigation. The astronaut specifies a time (GET) and vehicle (CSM or LM). The program integrates the appropriate vehicle state vector to that time, converts it into latitude, longitude and altitude, and displays the result. Second, with the latitude-longitude information returned by P21 and charts of the lunar terrain, landmarks can be identified in advance for marktaking. The altitude effectively determines the duration of the marktaking window.

An optional trajectory parameter display can also be obtained in P21 by using NOUN 73, which is useful during P23 cislunar coast and, in certain conditions in the vicinity of the moon, to determine the flight path angle (γ), at t_{IG} when using P37. (See paragraph 5.2.6.8.) NOUN 73 displays the altitude (range), velocity, and flight-path angle of the trajectory that results from extrapolating the current state vector of the CSM to some future time; e.g., LOI during the translunar phase and reentry time during the return.

Table 4.2.2-I lists the displays that occur in P21 with descriptions of the associated program features. Figure 4.2.2-1 is the program flowchart.

4.2.2.1 Options

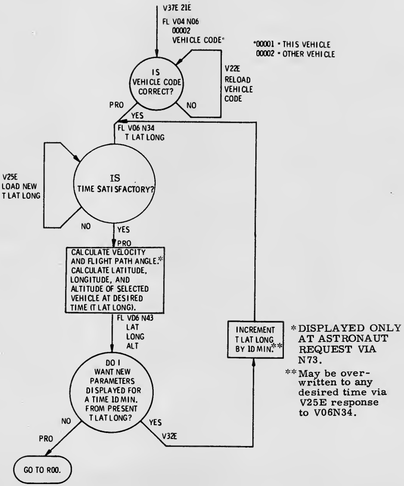
The latitude, longitude and altitude predictions of future vehicle positions produced by the advanced ground tracking option in P21 can be used: 1) to select relevant portions of the lunar landscape on maps preliminary to making out-the-window landmark identification, and 2) to designate unknown landmark coordinates in P22 for auto optics acquisition. In lunar orbit, sufficient uncertainty is introduced into the vehicle state vectors by the current onboard potential model during extrapolation that coordinate predictions may contain errors of 1 or 2 n. mi. This presents no problem for option 1, but requires that probable state vector errors be taken into account for option 2. Variations in lunar gravity have a negligible effect at cislunar distances, so that the NOUN 73 option is accurate enough.

4.2.2.1.1 Advanced Ground Track Determination.—In near-earth or near-moon orbit, the astronaut can specify a future time to the program and have his coordinates (latitude, longitude, altitude) for that time returned. An optional recycle on the final latitude-longitude-altitude display will cause the program to return to the second display where the desired time was input (VERB 06 NOUN 34) and return the time originally specified incremented by ten minutes. The astronaut can then PRO to obtain the LAT-LONG-ALT corresponding to the original GET plus ten minutes, or

TABLE 4. 2. 2-I

P21 GROUND TRACK DETERMINATION PROCEDURES

DSKY	Register	Comments
Key V37 E21E	DSKY P21	Only requirement for P21 is an up-to-date state vector. ISS not required.
FL V04 N06	R1 00002 R2 00001 R3 Blank	Vehicle code in R1=00002 R2=00001 indicates this vehicle; R2=00002 indicates other vehicle: Key PRO if correct; keying V22E will blank R2, permitting vehicle code to be changed.
FL V06 N34	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec	Request load desired GET (T-LAT-LONG) in hours, minutes, and seconds to nearest 0. 01 sec. For present time set R1, R2 and R3 to all zeros. PRO to compute latitude, longitude, altitude for specified GET; V25E to change time.
FL V06 N43	R1 xxx. xx deg R2 xxx. xx deg R3 xxxx. x n. i.	Program displays vehicle latitude and longitude in degrees to nearest 0. 01 deg in R1 and R2 (+is North or East, respectively) for specified GET. R3 contains altitude in nautical miles to nearest 0. 1 n. mi. measured from launch pad radius (earth) or latest landing site radius (moon). V32E will increment T-LAT-LONG GET initially specified by 10 minutes; recycle to V06N34 display. T-LAT-LONG may then be overwritten via V25E to any desired time.
FL V37		Keying PRO will terminate P21.
Key N73E	R1 xxxxB n. mi. R2 xxxxx. fps R3 xxx. xx deg	Altitude to nearest 10 n. mi. Inertial velocity to nearest 1 fps. Flight path angle to nearest 0. 01 deg. This display may be obtained in P21 any time after integration is complete.



*DISPLAYED ONLY AT ASTRONAUT REQUEST VIA N73.

**May be overwritten to any desired time via V25E response to V06N34.

Figure 4.2.2-1. Ground Track Determination Program (P21) reject it by keying VERB 25 ENTR and overwrite any desired T-LAT LONG. In this way he can identify particular landmarks available for P22 in advance and anticipate promising marktaking opportunities.

4.2.2.1.2 Orbital Parameter.—The P21 NOUN 73 option is primarily used after a P23 navigation sequence to determine whether the trajectory produced by the spacecraft's newly-updated state vector results in satisfactory terminal conditions at the target planet. Alternatively, the VERB 82 orbital parameters display (see P23, paragraph 4.2.4) can be called after the latitude-longitude-altitude display; i.e., after state-vector integration is complete. VERB 82 displays apogee and perigee height and time of free fall; this trajectory information supplements NOUN 73 and P37. (NOUN 73 is also used—in rare situations—to determine the value of γ for P37. See paragraph 5.2.6.8.)

4.2.2.2 Limitations

To predict the future orbital position of a vehicle (LM or CSM), P21 must obtain a precision integration of its state vector over the specified time interval. The further in advance the request is made (i.e., the larger the extrapolation interval), the less precise is the coordinate information returned. In earth or lunar orbit, the quality of the precision integration—and therefore the predictions—is determined primarily by the quality of the potential model used in the integration routine for the earth or moon gravitation.

On the first pass through P21, the program uses precision integration to compute the desired vehicle state vector at the specified T-LAT LONG. Computations for subsequent T-LAT LONGS via the VERB 32 ENTR option are conic and are based on the initial precision output. The CMC requires approximately 30 seconds to integrate one full revolution in lunar orbit. The recycle option will, therefore, perform quickly and precisely if the times chosen are close to the initial T-LAT LONG. If times input via VERB 32 ENTR differ significantly from the initial precision-integration value, the accuracy of the conic solutions obtained will degrade accordingly.

4.2.3 P22, Orbital Navigation—CMC

Table 4.2.3-I lists the purposes P22 was designed to achieve.

TABLE 4.2.3-I

PURPOSES OF P22 ORBITAL NAVIGATION

1. Locate and track a landmark suitable for navigation
2. Obtain sighting marks on the chosen landmark
3. Calculate the orbital parameter changes generated by the landmark sighting marks
4. Display the orbital parameter changes generated by the first sighting mark on a landmark, for decision by the navigator/ground on the validity of the landmark and navigation process prior to incorporation of state vector changes resulting from the sighting marks
5. Provide updated coordinates of the known landmarks
6. Provide coordinates of unknown landmarks
7. Track a preloaded landing site
8. Provide coordinates of a new landing site (treated as an unknown landmark)
9. Provide coordinates of an offset landing site
10. Point the optics along an advanced orbit ground track for tracking and mapping a new landing site.

The onboard navigation and landmark mapping capabilities of P22 are not yet being used in the way originally intended, as optical marks are not processed onboard.[*] Items 2 and 7 are the only applications authorized. Optical marks are taken on the landing site and nearby known landmarks using state vector values and landmark coordinates supplied by the ground. A zero W-matrix is used and marks taken are not incorporated onboard but are downlinked for use in ground computations. Primary ground track data, together with downlinked optics marks are used to compute the spacecraft's state vector and acquisition orientation for the next marktaking sequence; these computations are uplinked shortly before they are required.

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[*] This statement applies to the G and H missions and will probably remain valid until an adequate lunar potential model is obtained.

The program flowchart, Figure 4.2.3-1 delineates the decision points in P22; however, many of the optional paths are not significant at present.

Procedures that ensure proper landmark acquisition and marktaking are a precondition to successful landmark navigation using P22, whether marks are processed onboard or not. Because of the restricted use currently made of P22, the procedures in Table 4.2.3-II and the accompanying discussion (see paragraph 4.2.3.6) are concerned mainly with correct landmark acquisition and marktaking technique and not with evaluation of onboard updates, navigation, or mapping.

4.2.3.1 Program Options

The only live option in P22 at present is the choice between designating a known landmark which has its coordinates stored in the CMC (e.g., R2 equals 10001 for the landing site), or an unstored known landmark (R2 equals 10000), whose latitude, longitude, and altitude must be input by the astronaut. The latter option affords some flexibility in pointing the optics if there is any uncertainty in the landmark's true location. The IMU must be up and recently aligned since optics CDU angles recorded for each mark are referred to platform CDU angles. The quality of navigation data therefore depends directly on IMU alignment.

The program options that permit marks to be processed onboard, unknown landmarks to be mapped, and offset landing sites to be designated are not used.

4.2.3.2 Landmark Tracking Geometry

Figure 4.2.3-2 shows the geometry for tracking a landmark in a 60 n. mi. circular lunar orbit. Recommended marktaking technique requires that five marks be taken equally spaced over the plus-55- to minus-55-degree marktaking window. The advantage of oblique lines-of-sight on the first and last marks diminishes rapidly beyond ± 45 degrees. Consequently, marks taken symmetrically and at equally spaced intervals are preferred to marks taken asymmetrically at the extremes of the marktaking window. The interval between marks for the 76-degree (100-second) minimum marktaking window is 19 degrees (25 seconds); for the 110-degree (180-second) maximum window, the interval between marks is 27.5 degrees (45 seconds).*

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*Illustrations and numerical data, MSC Internal Note No. 69-FM-81, "Lunar Landmark Tracking Attitude Studies," C. R. Hunt, TRW Systems, April 11, 1969.

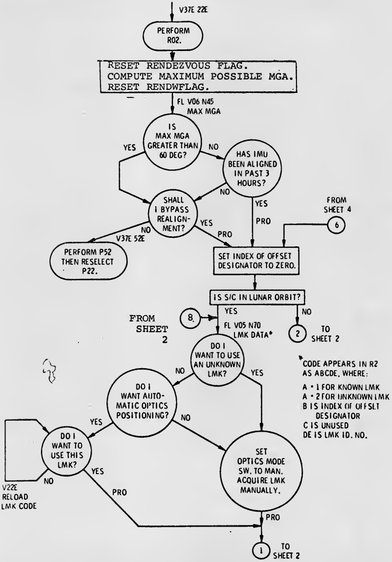

Figure 4.2.3 -1. Orbital Navigation Program (P22) (Sheet 1 of 4)

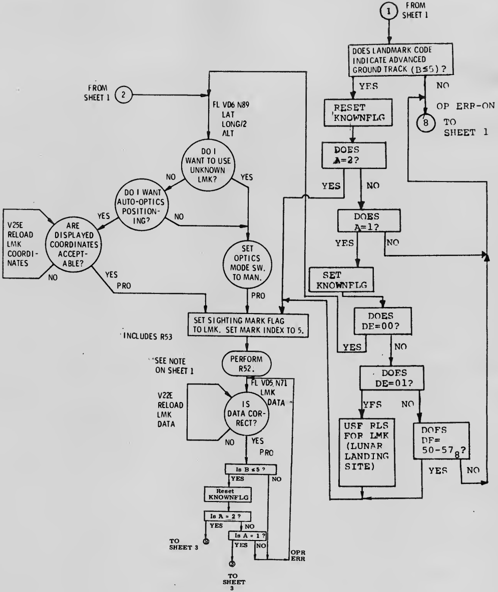

Figure 4.2.3 -1. Orbital Navigation Program (P22) (Sheet 2 of 4)

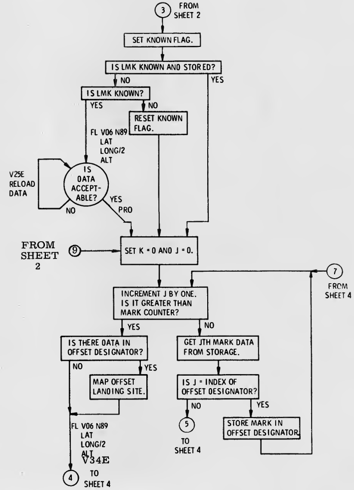

Figure 4.2.3 -1. Orbital Navigation Program (P22) (Sheet 3 of 4)

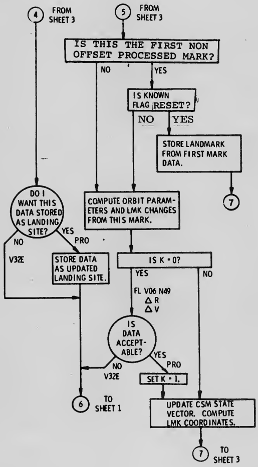

Figure 4.2.3-1. Orbital Navigation Program (P22) (Sheet 4 of 4)

TABLE 4.2.3-II

P22 PROCEDURES (SHEET 1 OF 3)

Step	DSKY Activity	Registers	Comments
1.	Key V37 E22E		P22 entered 5 to 10 minutes prior to point of closest approach. Note: Before entering P22, the SC will have been maneuvered to the acquisition attitude via VERB 49E. Optics may be driven to acquisition shaft and trunnion angles by keying VERB 41 NOUN 91E loading R1 and R2 with 00000°/45.000°.
2.	FL V06 N45	R1 Blank R2 Blank R3 oxx.xx	Maximum possible MGA to nearest 0.01 degrees (angle between Y_{SM} and $\underline{V} \times \underline{R}$) is displayed. If angle is acceptable, PRO.
3.	FL V05 N70	R1 Blank R2 ABCDE R3 Blank	Key VERB 22E to select R52 auto optics option, load R2 with 10000 or 10001 and ENTR. A 1 signifies known landmark A 2 signifies unknown landmark B index of offset designator C not used DE landmark ID number PRO when correct values loaded. If optics were not driven to 0 degrees shaft and ~ 45 degrees trunnion before (See step 1), they can be positioned manually as follows: OPTICS ZERO - OFF OPTICS MODE - MANUAL Drive optics to 45 degrees with OHC and return OPTICS MODE switch to CMC
4.	FL V06 N89	R1 xx.xxx R2 xx.xxx R3 xxx.xx	Only appears if R2 = 10000, (step 3) or in earth orbit. Latitude to nearest 0.001 deg, + is North. Longitude divided by 2 to nearest 0.001 degree, + is East. Altitude above Fischer Ellipsoid or mean lunar radius to nearest 0.01 n.mi. Load DAP via V25N79E (step 5) in preparation for maneuver in step 6. PRO on re-appearance of N89 when DAP is loaded.

TABLE 4.2.3-II
P22 PROCEDURES (SHEET 2 OF 3)

Step	DSKY Activity	Registers	Comments
5.	FL V25 N79	R1 x.xxxx R2 xxx.xx R3 xxxxx	SC rate in deg/sec to nearest 0.0001 deg/sec. + for increasing CDU angles. SC deadband to nearest 0.01 deg. Axis code 00000 = X-axis (roll) non-zero = Y-axis (pitch). Key VERB 25E and reload DAP data. Recommended loads are: R1 = -00500E for -0.05 deg/sec pitch rate (-02000 or -03000 for -0.2 or -0.3 deg/sec rates). R2 = +01500E for 15 deg deadband R3 = +00001E to pitch about Y control axis (any non-zero number).
	FL V06 N89		Reappears when N79 data ENTR keyed. PRO to step 6.
6.	V06 N92	R1 xxx.xx R2 xx.xxx R3 Blank	Shaft angle to nearest 0.01 degree. Trunnion angle to nearest 0.001 degree. R52 will drive optics angles to point at landmark. (Although unlikely, 00404 alarm will flash if T angle exceeds 90°). S and T angles will continue to be displayed though, and the alarm can be reset when the trunnion comes within 49.775°. Optics will then track automatically. The VERB 06 NOUN 92 display will not appear unless the OPTICS ZERO switch is OFF and the OPTICS MODE switch is in the CMC position. Landmark should be acquired and confirmed before pitch down point. At CPA -90 sec, key VERB 79E to obtain FL VERB 06 NOUN 79. If DAP loads are correct, PRO to initiate pitch rate. When marktaking window is entered and astronaut is ready to track manually switch Optics Mode to MAN and initiate manual tracking with OHC.

TABLE 4.2.3-II

P22 PROCEDURES (SHEET 3 OF 3)

Step	DSKY Activity	Registers	Comments
7.	FL V51		R53 Sighting Marks Routine is selected by switch to MAN and VERB 51 Please Mark request will flash until 5 marks are taken. Mark Reject button will erase last mark data and decrement mark counter.
8.	FL V50 N25	R1 00016 R2 Blank R3 Blank	Terminate mark sequence flashes after fifth mark. PRO will return to P22.
9.	FL V05 N71	R1 Blank R2 ABCDE R3 Blank	Same as V05 N70 measurement ID, confirm and PRO.
10.	FL V06 N49	R1 xxxx.x R2 xxxx.x R3 Blank	DELTA R DELTA V } In n.mi. to nearest 0.1 n.mi.; in fps to nearest 0.1 fps Hold for 11 seconds and PRO (W-matrix is zero so both DELTA R and DELTA V will be zero).
11.	FL V06 N89	R1 xx.xxx R2 xx.xxx R3 xxx.xx	Same as step 4, confirm and V34E Latitude to nearest 0.001 degree; + is North Longitude divided by 2 to nearest 0.001 degree;+ is East Altitude above Fischer Ellipsoid or mean lunar radius to nearest 0.01 n.mi.
12.	FL V37		Return to CMC auto. V34E keyed above terminates P22 and causes V37 to flash after processing delay.
13.	00E		00E response to FLV37 transfers to R00

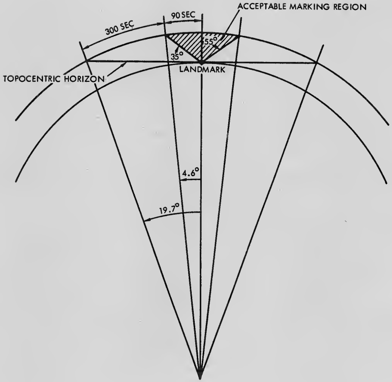

Figure 4.2.3 -2. Landmark Tracking Geometry for a 60-Nautical Mile Circular Lunar Orbit

4.2.3.2.1 Landmark Tracking Modes.—Two landmark tracking modes have been defined which, with variations and in combination, suffice to define all practicable landmark tracking possibilities.[*] Mode I is used for landmark tracking in the CSM/LM docked configuration when the LM blocks portions of the CSM SCT and SXT FOV. (See Figure 4.2.3-3.) An area of diminished brightness, similar to the one shown for the SCT, also exists for the SXT. However, the lunar landscape is sufficiently bright that the total FOV of both instruments is assumed to be useful for landmark tracking. Mode I requires that the CSM/LM combination be maneuvered—well before marks are taken—to an inertial attitude that becomes -2 degrees nosedown with respect to the local horizontal at the 55-degree start of the marktaking window. This position affords a good angle of forward vision for acquisition.

Figure 4.2.3-4 illustrates the geometry for Mode I landmark tracking. The landmark enters the SCT FOV 148 seconds before the closest point of approach (CPA) to the landmark at an elevation angle of 21 degrees; it enters the SXT FOV 112 seconds before the CPA at an elevation angle of 28.2 degrees. At 90 seconds before CPA and 35 degrees elevation angle, the spacecraft X-axis reaches the predetermined -2.1-degree attitude with respect to the local horizontal, and a -0.3 deg/sec pitch rate is started.[**] This causes the vehicle and the optics shaft axis to rotate through -54 degrees while traversing the 180-second (110 degree) marktaking window.

The -2.1-degree attitude allows 58 seconds and 22 seconds for acquisition in the SCT and SXT, respectively, before the pitchdown rate is initiated. The landmark will remain in the SXT FOV throughout the acceptable marking region, even if the pitch rate is slightly less than 0.3 deg/sec or if its initiation is slightly delayed.

A variant of Mode I calls for an 8-degree nosedown attitude at the 90-sec/35 degree pitch down point, plus a -0.2 deg/sec rate. With this version, the landmark enters the SCT FOV 38 seconds before the pitch is initiated, and enters and leaves the SXT FOV at almost exactly the 55-degree boundaries of the marktaking window, leaving almost no margin for error.

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[*] Actually four modes were defined in the Hunt Study but Mode II is a combination of Modes I and III and Mode IV is a roll mode not currently practiced for P22.

[**] This same inertial attitude is equivalent to +2.5 degrees at the landmark local vertical.

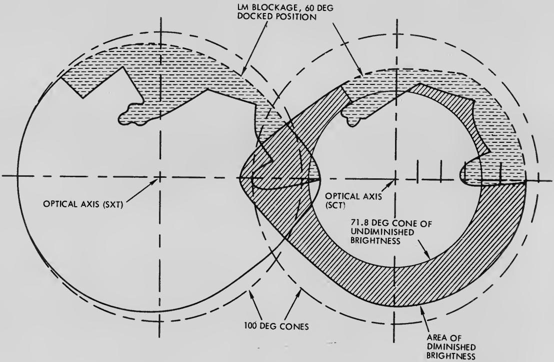

Figure 4.2.3 -3. SXT and SCT Fields of Coverage

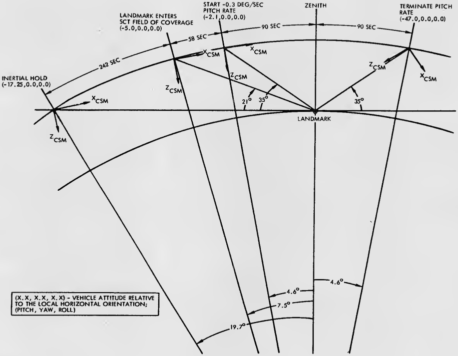

Figure 4.2.3 -4. Tracking Geometry for Mode I Landmark Tracking

Mode III is used after separation when the LM no longer blocks the CSM optical FOV. This mode consists of a -22-degree nosedown local attitude hold, accomplished by maneuvering the spacecraft X-axis 22 degrees below the local vertical and immediately initiating a 0.05 deg/sec negative (orbrate) pitch rate, which effectively maintains the spacecraft attitude constant at 22 degrees below the local horizontal. Figure 4.2.3-5 shows the elevation angles and times a landmark will enter the SXT and SCT FOV and exit the SXT. In Mode III, 5 or 10 degrees of the marktaking window after CPA is traded for 30 to 60 seconds of acquisition time, i.e., pre-mark tracking of the landmark. Mode III orbrate tracking is the standard undocked landmark tracking method because it requires the minimum feasible pitchdown rate and, therefore, minimizes RCS fuel use. The important variable in Mode III is the choice of an optimum amount of nosedown attitude.

In the G-mission, visual acquisition and identification of landmarks through the spacecraft windows proved relatively easy. It is still a problem, however, to find landmarks using the SXT—with its narrow field of view—when auto optics pointing information contains significant errors. An appreciable noseup acquisition attitude seems necessary if time is required to scan large areas using the SXT with its 1.8-degree FOV. In situations where the target is a terrain feature and not the LM, optical acquisition in the SCT would appear to be a good possibility. If feasible, acquisition via the SCT might allow a few degrees more negative acquisition attitude, so that 30 seconds of acquisition time could be exchanged for a full post-zenith marktaking window.

4.2.3.2.2 Optical Tracking Rate Limitations.—Implicit in the foregoing discussion of acquisition attitudes and tracking rates is the assumption that both the spacecraft X–Z plane and the landmark are in the orbital plane. This is not so. If the landmark is in the orbital plane, the spacecraft must be rolled out of the orbital plane to prevent excessive shaft rates that would result if the LOS to the landmark were permitted to pass within a few degrees of the shaft.

At the closest point of approach, the trunnion rate goes to zero for an instant and the shaft must rotate at the actual LOS rate times the cosecant (1/sine) of the roll angle. If the roll angle is small, the cosecant may be very large and the maximum shaft rate correspondingly high, e.g., the shaft rate approaches infinity as the off-axis angle approaches zero. A 10-degree roll angle gives about six times the approximately 5/6-deg/sec LOS rate. At 60 n. mi., this produces a shaft rate of 5 deg/sec, well within the 15 deg/sec shaft drive rate limit.

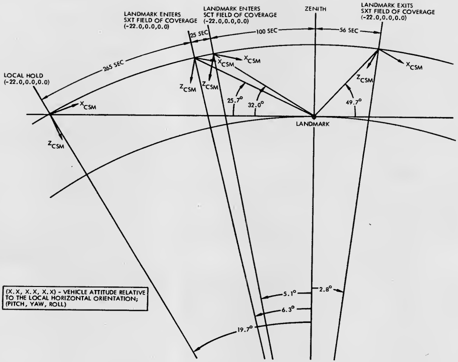

Figure 4.2.3 -5. Tracking Geometry for Mode III Undocked Landmark Tracking

The 10-deg roll is positive (right) since this rotates the optics FOV into the less obstructed quadrant of the CSM FOV occulted by the LM before separation (see Figure 4.2.3-3), and more nearly conforms with the 7.25 degree X CDU constraint for the Barbecue Mode Routine. (See paragraph 4.2.3.3.) If the landmark is off the ground track appreciably (particularly between 4 degrees and 16 degrees to the left at the groundtrack), the roll angle must be modified accordingly. The resulting roll angle must compromise the requirement that the shaft axis be more than 6 degrees from the landmark LOS at CPA with the yaw that will result from rolls other than 7.25 degrees.

4.2.3.3 Acquisition Attitudes and Marktaking Pitch Rates

The principal decisions that must be made in P22, as it is currently used, are the selection of the extended verbs and routines required to obtain the desired attitude and pitch rate—with particular emphasis on the timing and magnitude of rates and maneuvers. The two fundamental tracking modes, with several variations, involve various combinations of vehicle attitude and pitch rate, depending on whether marks are to be taken in the docked or undocked configuration and on the size of the acquisition and marktaking windows required.

Maneuvers to inertial acquisition and tracking attitudes can be performed using the Crew Defined Maneuver Routine, R62, obtained by keying VERB 49.

Pitch rates can also be applied using the RHC in the acceleration command mode. Alternatively, after the landmark has been acquired, the Minimum Impulse Controller can be used, in the CMC FREE position to impose a pitch rate prior to marktaking.

Attitude rates can be obtained by a number of alternative methods. Orbrate (-0.05 deg/sec) can be attained by loading a minimum rate into the DAP and commanding a maneuver to an attitude sufficiently far (e.g., 45 degrees) from the initial attitude that it will not be reached during the marktaking interval, so that the vehicle will continue to pitch at orbrate while the landmark is acquired and marks are taken.

The Barbecue Mode Routine (R64) which is called by VERB 79 ENTR is now available and permits pitch rates to be applied automatically. However, the use of this routine is limited. The major limitation is that the roll angle must be approximately 7.25 degrees to align $\underline{Y}_{SC}$ with $\underline{Y}_{SM}$. [To the extent that a roll angle other than 7.25 degrees is required (viz., 10 degrees; see paragraph 4.2.3.2.2), any pitch rate applied with VERB 79 will couple a component of the pitch rate proportional to the sine of the difference angle (e.g., 10 deg - 7.25 deg = 2.75 deg) into a yaw maneuver. For landmarks within a few degrees of the groundtrack this effect is negligible.]

Another limitation is that R64 must be called after initiation of P22 because new program initiation stops the orbital rate.

4.2.3.4 Preliminary Procedures

The IMU is aligned via P52 as near to the time landmark tracking begins as is convenient—usually about 1 hour before P22 is entered. The landing site alignment used is that in which the stable member X-axis is aligned to the landing site local vertical. To obtain the 22-degree nosedown, 10-degree left roll acquisition attitude defined above, key VERB 49E and load R1, R2 and R3 in the NOUN 22 display with 10 degrees, 248 degrees and 0 degrees, respectively (248 degrees represents a 112-degree pitch down from the landmark local vertical).

In the H1-mission, the attitude required for acquisition was computed and the P22 PAD voiced up immediately before the VERB 49 maneuver to the acquisition attitude. In the G-mission the maneuver PAD was transmitted 45 minutes to an hour ahead because the landing site was farther east and there was insufficient time for tracking and computation of new PAD values before the maneuver. For westerly landing sites, the CSM can be tracked through the period after communication is reestablished, less than an hour before the maneuver. In this way state vector information with the smallest possible extrapolation and potential modeling errors can be incorporated into the computed VERB 49 roll, pitch and yaw values.

4.2.3.5 P22 Acquisition and Marktaking Procedures

The VERB 49 manuever to the inertial hold attitude that produces the -2.1-degree attitude specified at the -90-second pitchdown point (Figure 4.2.3-4), can be performed 10 minutes or more in advance.* This allows time to enter P22 early, proceed to the NOUN 89 LAT-LONG display, set up the automatic pitch maneuver with NOUN 79, and return to P22 to monitor auto optics tracking of the landmark via the VERB 06 NOUN 92 shaft and trunnion displays. At 90 seconds before CPA, or before, if visual acquisition has occurred, VERB 79 is recalled and the pitch maneuver initiated using a 6-keystroke sequence. The landmark is being tracked

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* The convention in the illustrations (pitch, roll, yaw) is not consistent with the roll, pitch, yaw convention used in loading R1, R2 and R3 in VERB 49, and also omits the 10-degree roll, and the use of inertial landmark local vertical coordinates.

meanwhile by auto optics and monitored with the SXT by the astronaut. With a -0.3 deg/sec pitch rate, the vehicle angular rate very nearly matches the LOS rate at +55 deg (0.34 deg/sec) so that a switch to the MANUAL optics mode at this time requires relatively little initial intervention with the OHC by the astronaut.

4.2.3.6 Restrictions and Limitations

Two incompatible combinations must be avoided when using VERB 49 and VERB 79 with P22. An erasable location is shared by VERB 49 and VERB 79, so that any attempt to set up a pitch rate in VERB 79, and then to perform a maneuver using VERB 49 and return to VERB 79 will find the desired DAP data overwritten by VERB 49. Any maneuver using VERB 49 after setting up the VERB 79 pitch rate, therefore, requires that the VERB 79 DAP data be reinitialized. The pilot must always verify that NOUN 79 is properly loaded before initiating the pitch rate.

Ideally, NOUN 79 would be loaded prior to entering P22, and the order of performance would be: maneuver to acquisition attitude (VERB 49); initiate orbrate (VERB 79); and enter P22. However, in Mode I (where the inertial attitude is held until the landmark is acquired before the pitch rate is initiated), P22 will perform R00 which will overwrite the VERB 79 DAP data. And in Mode III, R00 will kill the orbrate if it is initiated prior to P22. The procedure outlined in Table 4.2.3-II is therefore recommended for both modes. The shaft and trunnion acquisition angles and alarm limits are different for the two tracking modes and the timing and amount of the pitchdown rates change.

4.2.3.7 Alarms

A list of alarms that may be encountered in P22 and an explanation of each follows:

00210 Alarm — IMU not on
00220 Alarm — IMU orientation not known
00120 Alarm — Optics not zeroed
00116 Alarm — Optics taken out of zero before 15 seconds elapse
00115 Alarm — Optics torque request with mode switch not at CMC
00404 Alarm — Trunnion angle exceeds 90 degrees. (See Table 4. 2. 3-II.)
31211 Alarm — Illegal interrupt of extended verb which occurs if optics MODE switch is switched to MAN when VERB 79 has been called, but not executed.

4.2.4 P23, Cislunar Navigation—CMC

Program P23 permits navigation fixes to be made during translunar and transearth coast. These fixes are made through updating the spacecraft state vector by measuring the angle between a suitable star and an earth or lunar horizon or lunar landmark. (See Figures 4.2.4-1a and b.) The resulting position and velocity data provide the basis for onboard targeting of nominal translunar and transearth trajectories, time-critical aborts, and free returns should communications fail. Navigation using P23 is feasible within either the earth or the lunar gravitational sphere.*

Figure 4.2.4-2 shows the schedule of P23 activity for the G-mission plotted on a diagram of the translunar and transearth trajectories. Fifteen state vector updates were scheduled in all—two early in translunar coast and thirteen at intervals throughout the transearth return. Three marks were specified on each of three to five stars for each update, each mark requiring an individual P23 entry. In all, cislunar navigation during G-mission transearth coast entailed 177 performances of P23, producing a total of 177 marks on 59 stars. (Notice that one star in each sequence was usually marked on twice.) The figure gives the nominal time of each sequence of P23 activity, the decimal star code of each 3-mark star-horizon measurement in the sequence, three initials (e.g., NEH, FEH, signifying near-earth horizon and far-earth horizon, respectively; NMH, FMH, signifying near-moon horizon and far-moon horizon) and the times of the three midcourse corrections that would have been computed onboard using P37 had communications failed. (Note that before taking measurement marks and at half-hour intervals while marks are being taken, it is necessary to calibrate the SXT optics to compensate for measurement errors due to trunnion bias.)

Nominally, sets of three marks are taken on successive stars at 10-minute intervals, allowing ample time for maneuver and optics pointing. The three redundant marks made on each star provide a sounder statistical basis for measurement incorporation than single marks. Two marks will work almost as well if three are inconvenient; five are recommended on the first star marked after a sleep period or after TEI when errors may be large.

The two sequences of P23 activity at 06:30 GET and 24:30 GET during the translunar phase are, in effect, rehearsals that obtain data on the consistency of the navigator's

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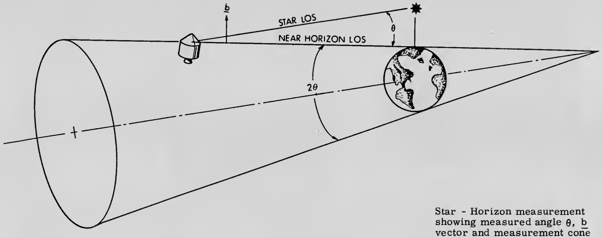
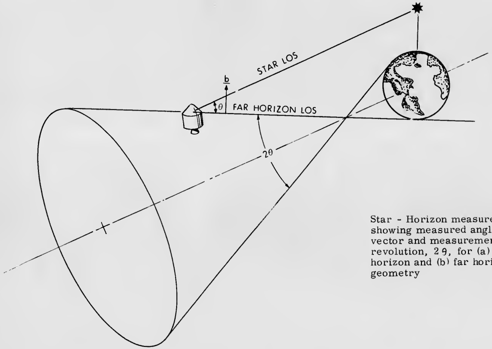
* Since P37 makes use of the state vector data compiled by P23, it is noteworthy that P37 requires a t_{IG} outside the lunar sphere.



Star - Horizon measurement showing measured angle θ, $\underline{b}$ vector and measurement cone of revolution, 2θ, for (a) near-horizon and (b) far horizon geometry

Figure 4.2.4-1a. Star Horizon Measurement Geometry (Near-Horizon)



Star - Horizon measurement showing measured angle θ, $\underline{b}$ vector and measurement cone of revolution, 2θ, for (a) near-horizon and (b) far horizon geometry

Figure 4.2.4-1b. Star Horizon Measurement Geometry (Far-Horizon)

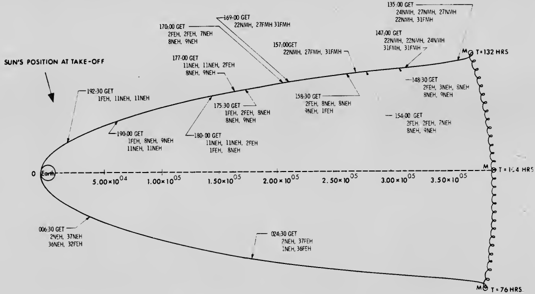


Figure 4.2.4-2. P23 Activity for G-Mission Translunar and Transearth Trajectories

subjective perception of the earth horizon (i.e., its variance and any bias as a function of range) and star visibility thresholds. These preliminary translunar P23 data are downlinked and analyzed to refine a priori statistical variance which is subsequently stored in the CMC via uplink for use during the transearth cislunar-navigation phase.

Figures 4.2.4-3a and b show two views of earth that illustrate the available measurement stars visible in the 60-deg FOV of the SCT at the respective 148:30 GET and 192:30 GET P23 sequences of Figure 4.2.4-2. The 148:30 GET measurement sequence was the first (maximum range) measurement made during the transearth return after leaving the lunar sphere; the 192:30 GET sequence was the last navigation before reentry.

4.2.4.1 Options

Experience with P23 in initial APOLLO flights has dictated that certain options, originally considered nominal, be de-emphasized in favor of others or supplemented with alternative procedures.

The original P23 procedure specified manual maneuvers and optics pointing because the ISS was to have been powered down during cislunar coast to conserve power. Thus IMU-derived REFSMMAT information necessary for auto maneuver and optics would have been unavailable. The IMU is now left on, and automatic maneuver (R60) and optics pointing (R52) are therefore nominal procedure in P23 to minimize RCS fuel use.

4.2.4.1.1 Landmark Option.—The option to designate earth and lunar landmarks for marktaking by specifying the latitude, longitude, and altitude of each, though available in P23, is little used. The star-horizon measurement option has largely supplanted star-landmark sightings because adequate landmarks are not always available, and star image visibility is usually marginal against a bright earth image. (See the visibility criteria discussion in paragraph 4.2.4.3.)

4.2.4.1.2 Planet Option.—Another P23 option is the capability of selecting planets (e.g., Mars, Venus) for navigation by specifying the x, y, and z basic-reference components of their locations at a particular GET to the CMC via the DSKY. Unlike stars, whose inertial coordinates are fixed and may be stored in the CMC by star code, planet ephemerides are time-varying and must be obtained from tables for the desired measurement time.

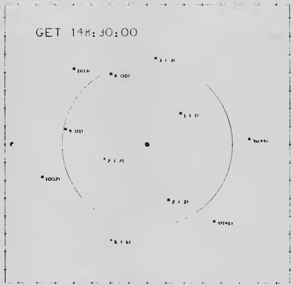


Figure 4.2.4-3a.

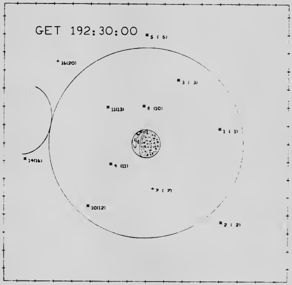


Figure 4.2.4-3b.

Figure 4.2.4-3. Available Measurement Stars Visible in SCT FOV at 148:30 GET and 192:30 GET during APOLLO 11

4.2.4.1.3 Landmark Calibration.—A differential visibility problem similar to the one mentioned under "Landmark Option" has caused the landmark calibration procedure to be de-emphasized in favor of star calibration.* Procedures for accomplishing minimum RCS maneuvers to point the LLOS at calibration stars have therefore been devised; calibration stars will henceforth be included in the measurement series. Optimum calibration stars can be pre-selected and identified in the checklist by star code. Factors that influence star selection and landmark visibility are discussed in paragraph 4.2.4.3.

4.2.4.1.4 Star Calibration.—P23 does not now facilitate maneuvers to calibration stars. Beginning with APOLLO 14, an option will be provided in P23 to automatically (via R60) point the SXT LLOS at a star for calibration (as distinguished from pointing it at the star's substellar point on the measurement planet, the only current option). The interim calibration procedure requires that P52 be entered before P23 to perform a minimum RCS-fuel maneuver to the attitude necessary to acquire the calibration star. P23 is then entered and R57, the calibration subroutine, is called to record the trunnion bias. If trunnion bias (VERB 06 NOUN 87) is normal, the astronaut keys VERB 94 ENTR in response to the VERB 06 NOUN 92 in R52, causing P23 to recycle to R60. R60 then maneuvers the spacecraft to the substellar point for the first measurement star, after which P23 measurement marktaking proceeds normally. Three-mark iterations of P23 follow for each of the remaining stars in the measurement sequence.

A number of other options exist, some internal to the program, others external. An example of the former is the VERB 94 ENTR option, which permits the program to be recycled if the vehicle or the optics are improperly aimed. Examples of external options are the routines and options (e.g., R30, R31, and NOUN 73) available to assist in evaluating the effects of navigation marks on the state vector and the trajectories that result. Refer to paragraph 4.2.2 for an explanation of the NOUN 73 option in P21 and to paragraph 4.2.4.5 for a discussion of post-measurement evaluation.

4.2.4.2 Procedures

Nominal P23 operation assumes automatic maneuver and optics pointing. The IMU must, therefore, be up and aligned to compute vehicle and optics pointing vectors.

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* Applies mainly to earth-landmark-navigation; high-contrast lunar landmarks are plentiful so that measurements and calibration should still be feasible for moon-oriented navigation.

Similarly, appropriate DAP parameters (vehicle mass, DAP deadband and rate) must be loaded via R03 to obtain correct tracking dynamics.

4.2.4.2.1 Calibration Procedure.—To obtain optimum results from P23, angle measurements that achieve the full 10-arc-sec precision inherent in the OSS design are necessary. Trunnion biases in the 10–30-arc-sec range are caused by thermal gradients produced by heat sources within the OSS and, less importantly, by differential heating due to incident solar radiation. One-half hour must elapse after optics turn-on to achieve thermal equilibrium before the OSS is calibrated and used to obtain star-sight navigation marks in P23. The optics are often left on, so this will usually not be a problem. Spacecraft attitude during calibration should be consistent with measurement orientation to prevent gross changes (daylight-to-dark or vice versa) in the spacecraft-OSS solar-thermal environment. A SXT trunnion bias calibration should be performed before each P23 sequence and at half-hour intervals during the course of the update.

Current calibration procedure involves superimposing a star image obtained via the SLOS on the image of the same star obtained via the LLOS. This procedure requires that the spacecraft first be maneuvered to acquire the calibration star in the SXT LLOS FOV. Image superimposition is then accomplished by switching the OPTICS ZERO switch to ZERO, which drives the trunnion CDUs to zero, thus aligning the SLOS with LLOS. The trunnion is then adjusted via the OHC until the images coincide and a mark is taken; this records the trunnion CDU angle necessary to superimpose the images and compensate for trunnion bias.

The P23 calibration procedure occurs in the two phases outlined below, which correspond to steps 1–5 and 6–10, respectively of Table 4.2.4-I:

a. An abridged pass through P52 is performed to obtain the optics shaft and trunnion angles of the calibration star in R1 and R2. This display provides the basis for a pure roll maneuver to null R1 (i.e., until R1 equals 0 or 180 deg) followed by a pure pitch maneuver to null R2, thus expending the minimum, feasible RCS fuel to obtain the desired orientation.

b. A partial pass through P23 obtains the calibration routine R57 in which trunnion bias is recorded. If the trunnion bias displayed in VERB 06 NOUN 87 is acceptable, a VERB 94 ENTR response to the trunnion angle display (VERB 06 NOUN 92) causes P23 to recycle and call R60 for an automatic maneuver to the substellar point of the first measurement

TABLE 4.2.4-I

P23 CALIBRATION PROCEDURE (SHEET 1 OF 3)

Step	DSKY Display	Register Contents	Remarks
1.	Key V37 E52E		Select P52 for P23 calibration (IMU is already realigned).
2.	FL V04 N06	R1 00001 R2 oooox R3 Blank	Program requests IMU orientation. Set R2 = 3 (REFSMMAT) and PRO.
3.	FL V50 N25	R1 00015 R2 Blank R3 Blank	Is CMC to select two alignment stars ? ENTR (No)
4.	FL V01 N70	R1 000xx R2 Blank R3 Blank	Request Response Display Celestial Body Code. Astronaut should load star code for calibration star, switch optics to CMC and PRO. Program calls R52 auto optics position routine. If star code is $01-45_8$ and the trunnion angle is not excessive ($T>90^o$ = 00404 alarm code), SXT shaft and trunnion angles will be displayed.
5.	V06 N92 or FL V51	R1 xxx.xx deg R2 xx.xxx deg R3 Blank	Shaft angle to nearest 0.01 degree. Trunnion angle to nearest 0.001 degree. If OPTICS MODE switch has been switched to MANUAL in R52, R53 will be selected and flash V51 (Please mark). Keying V16 N92E will display shaft and trunnion angle. With optics at CMC, the procedure is to initiate a pure roll maneuver with the RHC (roll left if R1 = 0 - 180°, roll right if R1 = 180° - 360°) until R1 = 0 or 180°. Then perform a pure pitch maneuver (up if R1 reads 0, down if R1 = 180°) until R2 = 0.

TABLE 4.2.4-I

P23 CALIBRATION PROCEDURE (SHEET 2 OF 3)

Step	DSKY Display	Register Contents	Remarks
6.	V37 E23E FL V05 N70	R1 000DE Star ID R2 00C00 LMK ID R3 00CD0 HOR ID	Enter P23 for calibration. Request measurement identification R1 = 000xx where xx is star code of measurement star. R2 = 00C00 where C = 1 for earth landmark, C = 2 for moon landmark. R2 = 00000 for horizon measurement. R3 = 00CD0 where C = 1 for earth horizon, C = 2 for moon horizon, D = 1 for near horizon, D = 2 for far horizon. R3 = 00000 for landmark measurement On calibration pass, load R2 = 0, R1 with star code of first measurement star (not calibration star) and R3 with appropriate code for earth or moon near or far horizon and PRO.
7.	FL V50 N25	R1 = 202 R2 = Blank R3 = Blank	Do I want GNCS auto maneuver to star ID via R60 ? No, Key ENTR.
8.	FL V59		R57 please mark; to calibrate: 1. Set OPTICS ZERO switch to ZERO. 2. Slave SCT to SXT. 3. Perform MIC minimum impulse maneuver to center star in SCT FOV. 4. Set OPTICS ZERO switch to OFF. 5. Set OPTICS MODE switch to MAN. 6. Superimpose SLOS and LLOS images using OHC. 7. Mark.

TABLE 4.2.4-I

P23 CALIBRATION PROCEDURE (SHEET 3 OF 3)

Step	DSKY Display	Register Contents	Remarks
9.	FL V06 N87 NOTE:	R1 Blank R2 xx.xxx deg R3 Blank Bias value may be loaded directly using V22N94E instead of repeating measurement.	R2 contains trunnion bias to nearest 0.001 degrees. Trunnion CDU granularity ≈ 0.003° = 10 arc-seconds. Max trunnion bias 0.010° - 0.015°, typically. RECAL if excessive. Make at least 3 calibration marks to ensure marking consistency. A consistency of ±1 bit (.003 deg) should be obtainable. Incorporate the last mark if it meets the above criterion; if not, make another mark and repeat until consistency is achieved. Set OPTICS MODE switch to CMC if acceptable and PRO to incorporate.
10.	V06 N92 FL V51 or FL V05 N 09 00404 in Rn (T > 90°)	R1 xxx.xx deg R2 xx.xxx deg R3 Blank	FL V51 will appear if OPTICS MODE is not in CMC position. Key V94E when V06 N92 appears causing P23 to recycle. End of calibration, recycle to perform first star-horizon marks. Go to Table 4.2.4-II, step 6 (R60) after V94E recycle. Shaft and trunnion values displayed in R1 and R2 are angles between calibration star and measurement substellar point. If T > 50°, maneuver manually to reduce before recycle.

star, after which P23 proceeds normally; that is, being entered again for each mark, unless another calibration maneuver is necessary, one-half hour later.

Table 4.2.4-I lists the displays in the P23 calibration procedure in the order in which they occur. The premaneuver P52 procedures require little comment beyond the remarks in the table. A 90-deg 00404 alarm should not occur unless a gross error is made in nulling PTC rotation.* Using the shaft and trunnion angle VERB 06 NOUN 92 displays, the astronaut can perform the pure roll and pure pitch maneuver procedure in the table to align the SXT LLOS on the calibration star, after which calibration can be performed.

After P23 is entered, the information loaded at the measurement ID display relates not to the calibration pass currently underway, but to the measurement star that will be marked on during the measurement made when P23 is recycled following calibration. R1 must contain the code of the first measurement star; R2 must equal all zeros, and R3 must be loaded with the appropriate planet and horizon codes.

After a PRO response at the VERB 50 NOUN 25 (R1 equals 00202) display, P23 will select R60. The astronaut may allow an automatic maneuver if the gimbal angles are acceptable. The astronaut must monitor the FDAI ball gimbal angle display to prevent gimbal lock. After R60 has driven to the substellar point, transfer of control to R52 is made by keying ENTR. R60 drives directly to the substellar point without regard to the measurement plane.

It is desirable to have the spacecraft aligned such that the spacecraft Y-axis is normal to the plane defined by the star-planet-spacecraft plane (i.e., parallel to the substellar horizon). This alignment will allow adjustment of the substellar point (making it parallel to the M-lines) by pure spacecraft roll. If the LM is attached, LM occultation will be prevented if the preceding condition is met along with the additional constraint of placing heads toward the planet (with a resultant shaft angle of 180 deg).

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* At the standard 0.03-deg Barbecue Mode rate, the spacecraft angular momentum will be nulled within 5 or 10 deg of the orientation at RCS firing.

If the trunnion angle is within limits (no VERB 05 NOUN 09 alarms), the optics shaft and trunnion angles of the measurement star will be displayed, and R52 will drive optics to acquire it in the SLOS. A switch to manual optics will then permit the optics to be maneuvered to register the star image on the horizon substellar point and to take marks in response to the flashing VERB 51.

After each mark is taken and confirmed, P23 will compute and display Δr and Δv changes which will be made in the state vector—if the mark is incorporated. The nominal incorporation criterion is that Δr and Δv not exceed 50 n. mi., 50 fps, respectively. Keying a PRO will incorporate the mark; keying a VERB 32 ENTR will reject it. Keying a 23 ENTR response to the VERB 37 that flashes after the mark is accepted, followed by the PRO, ENTR and PRO responses to the measurement ID, auto maneuver, and calibration displays, respectively, will obtain the flashing VERB 51 which requests the next mark on the same star.

4.2.4.2.2 Measurement Procedure.—If the IMU has not been aligned, P23 goes directly to the calibration routine, R57 (see Figure 4.2.4-4), and the astronaut must set the Optics Mode switch to MAN and manually maneuver the spacecraft to a calibration star. (See Figure 4.2.4-5.)

The computation of desired gimbal angles makes use of the VECPOINT routine which effectively rotates the LLOS into the substellar LOS vector (without constraining the rotation about the LLOS). This allows the astronaut to rotate the spacecraft and have the desired gimbal angle recomputed as often as desired by proper switch selection and response to the VERB 50 NOUN 18 display. (See step 6 of Table 4.2.4-II.) Unless the next substellar point is within the DAP deadband, the PRO response to select an auto maneuver is nominal. Subsequent procedures are similar to the nominal measurement performed after calibration described above and detailed in Table 4.2.4-II.

In the nominal procedure, the astronaut loads star-horizon data during the first flashing VERB 05 NOUN 70 display; flashing VERB 50 NOUN 25 (R1 equals 00202) appears next for the auto maneuver (R60) decision. (Refer to Table 4.2.4-II.)

The VERB 06 NOUN 89 landmark latitude-longitude- altitude display appears only if the unstored known landmark option is loaded in the target ID display.

The VERB 06 NOUN 88 display permits a planet to be identified by specifying its unit vector. The 37 stars in the star table have the x, y, and z components of their respective unit vectors permanently stored in the CMC according to star code.

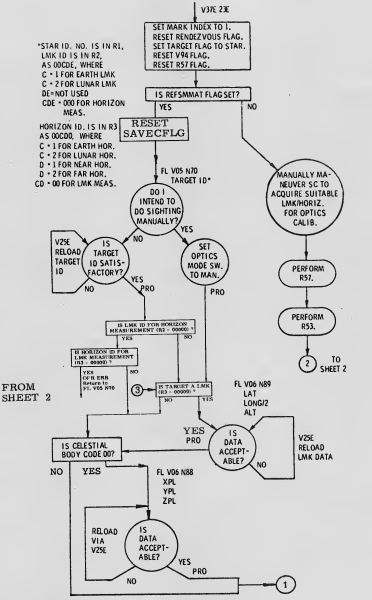


Figure 4.2.4-4. Cislunar Navigation Program (P23) (Sheet 1 of 3)

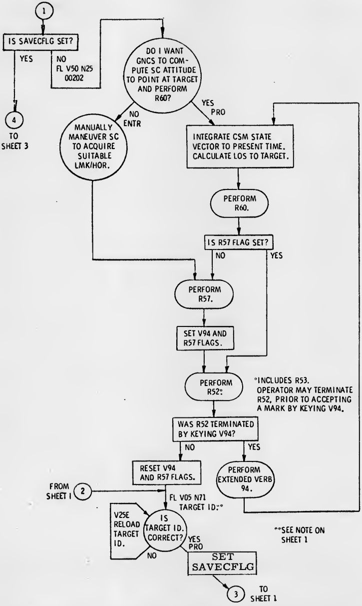


Figure 4. 2. 4-4. Cislunar Navigation Program (P23) (Sheet 2 of 3)

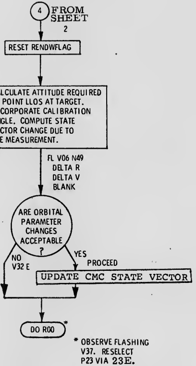
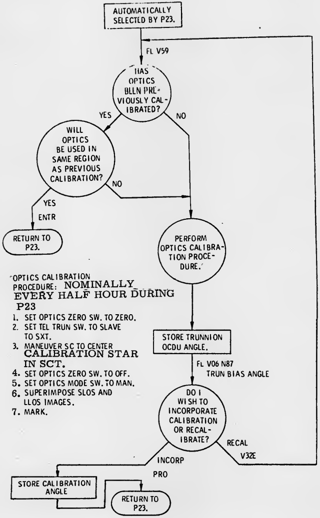


Figure 4.2.4-4. Cislunar Navigation Program (P23) (Sheet 3 of 3)



OPTICS CALIBRATION PROCEDURE: NOMINALLY EVERY HALF HOUR DURING P23

1. SET OPTICS ZERO SW. TO ZERO.
2. SET TEL TRUN SW. TO SLAVE TO SXT.
3. MANEUVER SC TO CENTER CALIBRATION STAR IN SCT.
4. SET OPTICS ZERO SW. TO OFF.
5. SET OPTICS MODE SW. TO MAN.
6. SUPERIMPOSE SLOS AND LLOS IMAGES.
7. MARK.

Figure 4.2.4-5. Optics Calibration Routine (R57)

TABLE 4.2.4-II

P23 DSKY INPUT OUTPUT ACTIVITY (SHEET 1 OF 4)

Step	DSKY Display	Register Contents	Remarks
1.	V37 E23E		Astronaut keys P23 major mode.
2.	FL V05 N70	R1 oooxx	Star ID 00-45_8
		R2 00C00	Landmark ID C = 1 for earth landmark C = 2 for moon landmark R2=00000 for horizon measurement
		R3 00CD0	Horizon ID C = 1 for earth horizon C = 2 for moon horizon D = 1 for near horizon D = 2 for far horizon R3 = 00000 for landmark measurement PRO if correct. V25E to load
3.	FL V06 N89	R1 xx.xxx R2 xx.xxx R3 xxx.xx	Appears when R3 = 00000 in previous display. R1 = Latitude of landmark in degrees to nearest 0.001 degree. (+ = North). R2 = Longitude of landmark divided by 2 in degrees to nearest 0.001 degree (+ = East). R3 = Altitude of landmark in n. mi. to nearest 0.01 n. mi. above Fischer Ellipsoid (earth) or mean lunar radius (moon)
4.	FL V06 N88	R1 .xxxxx R2 .xxxxx R3 .xxxxx	Appears when R1 = 00000 in N70 of step 2. R1 = XPL X component of the unit position vector of the planet/star at GET. R2 = YPL Y component, same as XPL. ZPL Z component, same as XPL. All three in basic reference coordinates as 5-digit decimal fractions.

TABLE 4.2.4-II

P23 DSKY INPUT OUTPUT ACTIVITY (SHEET 2 OF 4)

Step	DSKY Display	Register Contents	Remarks
5.	FL V50 N25	R1 00202 R2 BLANK R3 BLANK	Requests astronaut decisions: auto maneuver to target LOS via R60 prior to calibration ? Or manual maneuver to calibration attitude ? PRO response selects auto maneuver, ENTR requires manual maneuver prior to performance of R57.
6.	FL V50 N18	R1 xxx.xx OGA R2 xxx.xx IGA R3 xxx.xx MGA	First display in R60. Display gimbal angles for desired maneuver to substellar point for measurement star. During AUTO maneuver, monitor FDAI for possible impending gimbal lock. If necessary, assume manual control via RHC. After a manual take-over, the astronaut can have the resulting gimbal angles displayed by returning to CMC-AUTO and keying PRO. A PRO response always results in a VECPOINT computation of desired gimbal angles followed by a check to determine if an AUTO maneuver is allowed (SC CONT SW = CMC and MODE SW in AUTO). If allowed, the CMC displays V06 N18 and initiates the maneuver; if not allowed, the CMC redisplays V50 N18. ENTR will call R57.
7.	V06 N18	R1 xxx.xx OGA R2 xxx.xx IGA R3 xxx.xx MGA	Final gimbal angles will be displayed nonflashing during maneuver. V50 N18 resumes flashing when maneuver is complete (substellar point is within DAP deadband) or interrupted by astronaut.

TABLE 4.2.4-II

P23 DSKY INPUT OUTPUT ACTIVITY (SHEET 3 OF 4)

Step	DSKY Display	Register Contents	Remarks
8.	FL V59 FL V06 N87		Calibration Mark Request R57. Does maneuver calibration optics history indicate calibration required ? If so, mark, otherwise go to step 9 (R52) via ENTR or PRO. If trunnion bias angle resulting from calibration differs from previous value by more than 10-arc-seconds, incorporate (PRO) or recalibrate via (RECAL) and compare second biases prior to incorporation.
9.	V06 N92	R1 xxx.xx R2 xx.xxx R3 Blank	R52 auto optics shaft and trunnion angles. If trunnion <50° (no 404 PROG alarm) and OSS is in CMC mode, optics CDUs will drive until SLOS optics achieve star-horizon superimposition. Recycle via V94E returns to step 6.
10.	FL V51		R53 sighting mark routine selected by setting OPTICS MODE SW to MAN. When star appears in SXT FOV, astronaut must maneuver SC with RHC so that star image is aligned with earth/moon horizon at substellar point. FL V51 Please Mark Request is terminated by pressing optics MARK button. V94E prior to ACCEPT or REJECT erases mark data and returns to step 6.

TABLE 4.2.4-II

P23 DSKY INPUT OUTPUT ACTIVITY (SHEET 4 OF 4)

Step	DSKY Display	Register Contents	Remarks
11.	FL V50 N25	R1 00016 R2 Blank R3 Blank	Appears after MARK is taken. MARK REJECT will erase mark and return to step 10. PRO reponse will terminate R53 and return to P23.
12.	FL V05 N71	R1 oooxx R2 00C00 R3 00CD0	Confirm measurement ID. Must conform to correct star, landmark and horizon codes. R1 - 00 if planet was used, 01 to 45 (octal) if one of 37 coded stars. If ID is correct (V05 N70), PRO. If not, load correct data (V2 x E), then PRO.
13.	FL V06 N89	R1 xx.xxx R2 xx.xxx R3 xxx.xx	Appears when R3 = 00000 in previous display. R1 = Latitude of landmark in degrees to nearest 0.001 degree. (+ = North). R2 = Longitude of landmark divided by 2 in degrees to nearest 0.001 degree (+ = East). R3 = Altitude of landmark in n.mi to nearest 0.01 n.mi. above Fischer Ellipsoid (earth) or mean lunar radius (moon).
14.	FL V06 N88	R1 .xxxxx R2 .xxxxx R3 .xxxxx	Appears when R1 = 00000 in N71 of step 12. R1 = XPL X component of the unit position vector of the planet/star at GET. R2 = YPL Y component, same as XPL. ZPL Z component, same as XPL. All three in basic reference coordinates as 5-digit decimal fractions.
15.	FL V06 N49	R1 xxxx.x R2 xxxx.x R3 Blank	Display orbital parameter changes R1 = ΔR, position change due to last mark in n.mi. to nearest 0.1 n.mi. R2 = Δv, velocity change due to last mark in fps to nearest 0.1 fps. PRO will cause mark to be incorporated, updating CMC state vector. V32E will cause recycle. Incorporation criterion is: $\Delta R < 50$ n.mi. and $\Delta v < 50$ fps.
16.	FL V37		In either case, V37 will flash. P23 can be reselected by 23E response if necessary. PRO, ENTR and PRO responses at steps 2, 5 and 8 will return flashing VERB 51 (step 10) for next mark on same star.

The unit vectors of planets (which are time-varying) may be precalculated and written into the checklist for use in particular mission situations. Tables are provided that give the unit vectors of the planets on which measurements might be made as a function of GET. The VERB 06 NOUN 88 display following a 00 star code is provided to permit celestial bodies other than the ones identified by prestored star codes to be marked.

After the automatic-maneuver (R60) and optics-positioning routines (R52) have caused the optics to acquire the measurement star and its associated substellar horizon, it is possible for the astronaut to use the SCT to verify from star charts of nearby celestial bodies that the star in the SXT FOV is indeed the one desired. If the ΔR, Δv display is greater than expected, the astronaut should consider rejecting the update and repeating the measurement with special concern for the input data (e.g., near versus far horizon and star ID) and a careful review of the star background. If all checks confirm a proper measurement, the ΔR,Δv should be accepted.

4.2.4.3 OSS Performance and Visibility Criteria

Near the earth, earth light scattered in the optics tends to obscure stars in its vicinity. This may reduce the population of stars available for navigation angle measurements to three or four situated more than 30 deg from the earth horizon LOS; i.e., in the outer periphery of the 100-deg cone covered by the SXT trunnion. Because the earth's image is much brighter than that of a star, the optics LLOS was designed to transmit only 3.2 percent of incident light and the SLOS to transmit about 25 percent to ensure appropriate differential visibility for star-horizon superimposition. Because of the 25-fold incident light attenuation through the LLOS and the fact that earthshine tends to swamp star images near the earth, calibration may require maneuvers to attitudes that point the LLOS 20 or 30 deg from the earth. At the 0.2-deg/sec DAP rate, calibration maneuvers may require several minutes. Thus a trade must be made between frequent calibration (which ensures low-measurement bias and precise navigation), time, and RCS fuel consumption.

4.2.4.4 Influence of Measurement Geometry on State Vector

Figures 4.2.4-1a and b show the locus of spacecraft position determined by a single star-horizon measurement to be a cone of revolution about the horizon line of sight, with its apex angle (2θ) twice the angle formed by the star LOS and the horizon LOS. The onboard measurement technique used is not deterministic as the illustration tends to imply, but employs a statistical-filtering technique to produce an optimum linear combination of weighted increments from each angle measurement. Each star-horizon angle measurement provides position information primarily in the plane of the measurement and orthogonal to the horizon LOS. A geometry vector b (Figures 4.2.4-1a and b) associated with each star-angle measurement characterizes its information content. The statistical uncertainty of vehicle position is reduced primarily along a dimension parallel to the b vector for each measurement star. Therefore, angle measurements should be made on stars located in different measurement planes. However, stars with a large b vector component in the orbital plane are preferred.

A sequence of P23 angle measurements processed through the W-matrix to produce statistically optimum weighted updates to the onboard state vector differs fundamentally from a simultaneous 3-dimensional fix on three well-separated (ideally orthogonal) stars. P23-derived position information efficiently minimizes state-vector uncertainties in a plane orthogonal to the horizon LOS, but is somewhat less effective in reducing R and $\dot{R}$ uncertainty along the LOS. The dominant consideration in providing position and velocity inputs to P37 is minimizing uncertainty in the radial miss-distance in the orbital plane of the ±20 n. mi. reentry window. The effect of this on P23 procedure is to dictate that, whenever possible, star measurements be made on stars whose measurement planes are near the orbital plane.

Notice that in the two sets of measurement stars in Figures 4.2.4-3a and b (corresponding to No. 9 at 148:30 and No. 11 at 192:30 in Figure 4.2.4-2), the last star marked on is nearest the (horizontal) orbital plane, consistent with the above discussion. This principle should be borne in mind if deviations from prescribed measurement schedules are necessary.

Note that the measurement schedule for each sequence of P23 activity on the mission flight plan is designed to minimize RCS fuel consumed by vehicle maneuvers necessary to orient the LLOS toward the substellar points of the successive measurement stars in each sequence. Any unscheduled P23 activity should also be carefully planned to minimize RCS maneuvers.

4.2.4.5 Post-Measurement Evaluation

Figure 4.2.4-6 shows the change in perigee that resulted from a group of 15 sightings made on the lunar horizon at a distance of 45,000 n. mi. during the translunar leg of APOLLO 8. At the end of this group of measurements, the indicated perilune was 67.1 n. mi., about 1.8 n. mi. less than the value later reconstructed from MSFN groundtrack data. Perigees computed onboard using either P37 or R30 (obtainable

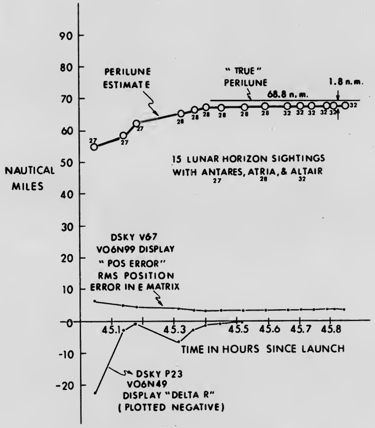


Figure 4. 2. 4-6. APOLLO 8 Translunar Midcourse Navigation

with VERB 82) should converge in the manner shown during a sequence of P23 star-horizon measurements, whether earth- or moon-centered.

4.2.4.6 Effects of Calibration and Substeller Errors

Frequent calibration is recommended to compensate for optical biases caused by thermal effects (both internal and external). An uncalibrated 20-arc-sec bias will cause a 20-km position error at a 100,000-mile range. Another potential source of error is bad marktaking technique, which results when the measurement star image is allowed to wander from the substellar point by more than 1 deg. The 1/2-deg DAP deadband limit will, at long ranges where the earth may subtend as little as 2 deg, bring the star image only within 15 or 20 deg of the substellar point. The astronaut must therefore ensure that the image is properly registered on the substellar point before marking.

At maximum range, the angle subtended by the earth's image is comparable to the SXT FOV so that the curvature of the earth gives a good visual cue as to whether a star image is at the substellar point or not. Nearer the earth, the DAP will achieve acceptable pointing accuracy but the reduced curvature of the terrestrial limb gives somewhat vague clues as to where the star image bisects the earth image. Consequently, there is a tendency to allow the star image to slide off to one side. The effect on angle measurement accuracy of an aiming error in substellar alignment increases as the square of the error: a 4-deg substellar alignment error produces an acceptable 2-arc-sec horizon error, but accuracy rapidly degrades beyond a few degrees.

4.2.4.7 Marking on the Horizon

Two factors must be considered in aligning the measurement plane. The first is determining the substellar point on the horizon. The cue for making this determination is the reticle pattern. The star image should be moved to the point on the horizon where a line tangent to that point is parallel to the horizontal axis of the reticle pattern. Figure 4.2.4-7 illustrates this alignment. The second is orienting the spacecraft so the star image and substellar point fall in the center two-thirds of the field of view. Judging the parallelism of the reticle to the tangent at the substellar point correctly is the most critical alignment operation. If the substellar point is found to lie near the side of the field of view, the spacecraft should be maneuvered to move this point near the center. The vertical location of the field of view is not critical.

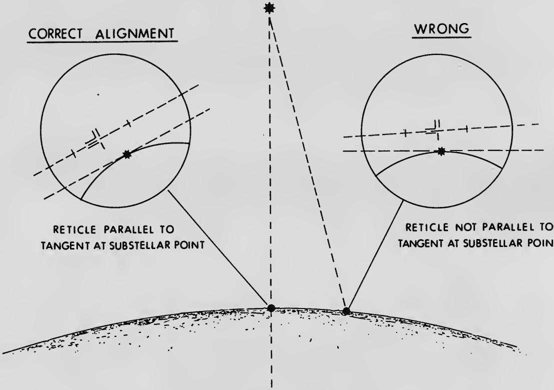


Figure 4.2.4-7. Correct Reticle Alignment with Substellar Tangent for Marktaking

To define the location of the earth's horizon, the center of the star image should be placed on the upper threshold of the atmosphere. The center, not the edge, of the star image should be used since focus and star magnitude affect the size of the image. The upper threshold of the earth's atmosphere does not appear as a sharp boundary.

Considerable variation exists in where different people perceive the threshold to be; each person, however, can accurately repeat his original selection. For this reason, APOLLO flight plans call for a series of marks to be made as close to the earth as possible to determine the horizon altitude that the navigator on each mission prefers to use.

4.2.4.8 Influence of W-Matrix on ΔR, Δv Mark Accept/Reject

Current policy is to reinitialize the W-matrix only once at the beginning of P23 takeover to a large diagonal value provided in a contingency table. (See Table 4.2.4-III.) The large W-matrix initialization for the first transearth navigation measurements (30,000 feet and 30 fps) is to allow for the possibility of errors in the TEI burn. The large W-matrix does not adversely affect nominal performance, but it will cause a state vector with large errors to converge where a small one might not. The W-matrix is only initialized once during the transearth return. P23 is not used during transearth coast unless communications are lost prior to entry-minus-30 hours. Table 4.2.4-III gives W-initialization values for the G-mission. The growth of the W-matrix with extrapolation over the intervals between measurements is expected to provide adequate gain for subsequent P23 measurements. Since the size of the W increases exponentially with time, the size of the first $\Delta\underline{R}$, $\Delta\underline{v}$ in a sequence of P23 measurements will vary predictably with time. A good check on W growth prior to P23 measurement activity can be had using the W-matrix position component display, VERB 67 ENTR. Knowing the size of the W to be nominal before marktaking ensures that marks taken will in fact have the desired effect on the state vector.

The prime criterion for accepting or rejecting ΔR and Δv updates to the state vector is a fairly crude 50-n. mi./50-fps GO/NO-GO test. If ΔR or Δv is greater than 50, reject the update and repeat the mark, making sure it is accurate and on the correct star. If the second ΔR, Δv is close to the first, accept it unless it is truly excessive—in which case consider recalibrating. If very large values persist, the SXT may be broken; try the SCT.

TABLE 4.2.4-III

RECOMMENDED PROCEDURE IN CASE OF COMMUNICATION LOSS

Communication Loss Time (hr from TEI)	W-Matrix To Be Input at 1st Mark	Batches of Data To Be Taken
0 - 1.5	30,000/30	All
1.5 - 10	73,000/5.0	2nd through end of schedule
10 - 35	30,000/0.5	1st beginning after loss through end of schedule
35 - Entry*	None	None

* This assumes a MSFN update at TEI +35 hours.

The only guarantees of state vector quality using P23 are an adequate W-matrix, a plausible $\Delta R, \Delta v$ for the first mark, and convergent $\Delta R, \Delta v$ over a P23 sequence. The best guarantee of success is to adhere to the flight plan and utilize the contingency procedures in the checklist.

4.2.4.9 Alarms

A list of alarms that may be encountered in P23 and a brief explanation of each follows:

a. Alarm code 00120 is displayed if the optics are not zeroed.

b. Alarm code 00116 is displayed if the optics are taken out of zero before 15 seconds has elapsed.

c. Alarm code 00115 is displayed if an optics torque request is made and the mode switch is not at CMC.

d. Alarm code 00404 is displayed if the trunnion angle exceeds 90 deg.

4.2.5 P27, CMC Update

The CMC Update Program, P27, is used to insert update data into the CMC by digital uplink or by DSKY entry. P27 is entered via one of four extended verbs uplinked by the ground or keyed in by the crew; each verb designates a different type of input:

a. VERB 70 ENTR—provides ground capability to update the liftoff time.
b. VERB 71 ENTR—provides ground capability to update from 1 to 18 consecutive erasable memory locations whose address is specified as part of the input.
c. VERB 72 ENTR—provides ground capability to update from 1 to 9 individually specified erasable locations, which are not necessarily consecutive.
d. VERB 73 ENTR—provides ground capability to increment or decrement the CMC clock only.

Any ground command sequence normally transmitted via the uplink can be done by the crew instead via the DSKY. It is possible (though it is unlikely) for the ground to transmit input data by voice communications and for the crew to key in the update (manual-input option). A more likely use of the crew manual-input option is for correction of uplinked data. Tables 4.2.5-I and -II show the P27 DSKY displays and extended verbs, respectively.

4.2.5.1 Extended Verbs

The four extended verbs used for entry to P27 are functionally different. The verbs and the procedures associated with each are explained below.

4.2.5.1.1 VERB 70 ENTR.—VERB 70 allows the ground or crew to update the time of liftoff. The crew load the time as xxxxx ENTR xxxxx ENTR, i.e., two pieces of data appear successively in R1 of the DSKY. After the crew have keyed the second ENTR—to give the crew an opportunity to correct the data—P27 displays a flashing VERB 21 NOUN 02 with the following registers:

R1 = Blank
R2 = Unchanged
R3 = xxxxx, the address in memory where the identifier will be loaded if a correction is to be made.

TABLE 4.2.5-I

DSKY DISPLAYS ASSOCIATED WITH P27

DSKY	Initiated by	Purpose	Condition	Register
FL V21 N01	P27	Request load of index	R3 contains ECADR* where index is to be loaded; R1 displays data as loaded	R1 Blank (xxxxx) R2 Unchanged R3 xxxxx
FL V21 N01	P27	Request load of data	R3 contains address where data are to be loaded; R1 displays data as it is loaded	R1 Blank (xxxxx) R2 Unchanged R3 xxxxx
FL V21 N02	P27	Request load of octal identifier	R3 contains address where identifier is to be loaded	R1 Blank R2 Unchanged R3 xxxxx

*ECADR is an erasable memory constant.

TABLE 4.2.5-II

EXTENDED VERBS USED WITH P27

VERB	Identification	Purpose	Remarks
70 ENTR	Liftoff time update	Select P27 for liftoff time update	Refer to paragraph 4.2.5.1.1
71 ENTR	Contiguous block update	Select P27 to update from 1_8 to 22_8 consecutive erasable memory locations in the same EBANK*.	Refer to paragraph 4.2.5.1.2
72 ENTR	Scatter update	Select P27 to update from 1_8 to 11_8 not necessarily consecutive erasable memory locations.	Refer to paragraph 4.2.5.1.3
73 ENTR	Octal clock increment	Select P27 to increment or decrement the CMC clock	Refer to paragraph 4.2.5.1.4

* EBANK is an erasable memory bank.

Should the crew wish to correct some of the update data, they can respond to the flashing VERB 21 NOUN 02 by keying in a 2-digit octal identifier followed by ENTR. The octal identifier specifies which piece of data (01 or 02) is to be changed. The DSKY then flashes VERB 21 NOUN 01 to request the new value. If an unacceptable octal identifier is entered, the program disregards the entry and continues to flash VERB 21 NOUN 02.

P27 verifies that the double precision octal time (i.e., the 10-digit number entered above) can be subtracted from the CMC clock without causing overflow. If the subtraction can be made, P27 proceeds to increment TEPHEM and decrement the CMC clock, the CSM state vector time, and the LM state vector time.*

4.2.5.1.2 VERB 71 ENTR.—VERB 71 allows the ground or the crew to initiate a contiguous erasable-memory update. VERB 71 can be used to load any contiguous block of erasable memory; but it is usually used to perform the following updates:

a. CMC CSM/LM state vector update
b. CMC desired REFSMMAT update
c. CMC REFSMMAT update
d. CMC External $\Delta \underline{v}$ update
e. CMC retrofire External $\Delta \underline{v}$ update
f. CMC entry update
g. CMC Lambert target update
h. CMC landing site vector update.**

The VERB 71 data are entered according to the following format:

II ENTR
AAAA ENTR
xxxxx ENTR
xxxxx ENTR
.
.
.
xxxxx ENTR

---

* TEPHEM is ephemeris time.

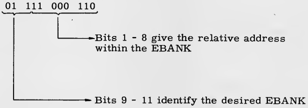
** Refer to Section 2, GSOP, paragraph 2.1.5, for a definition of each of these updates.

where:

<u>II</u> is a 2-digit octal number between 3_8 and 24_8—the index value representing the total octal number of numeric quantites to be loaded.

<u>AAAA</u> is the erasable memory address of the first data word of the update data block to be processed. For one data load operation, all update parameters must ultimately be stored in the same EBANK (erasable memory bank). Therefore, the starting address and the length of the block must be chosen so that the complete load can be contained in the same EBANK. Bits 1−8 of AAAA indicate the relative address ($0-377_8$) within the selected EBANK and bits 9−11 identify the desired EBANK (0−7). The format just described is the format of an erasable memory constant called an ECADR. The relative address plus the index minus 3 must be less than or equal to 377_8. The example below illustrates this explanation.

If the EBANK equals 3 and the relative address equals 306_8, AAAA would have the following bit configuration:



The crew would key in the octal value 1706.

<u>xxxxx</u> is octal data to be loaded.

The crew respond to the first request for data (flashing VERB 21 NOUN 01) by keying in the 2-digit octal index and visually verifying it (as displayed in R1) before keying ENTR. The program will flash VERB 21 NOUN 01 until a legal value is entered—as indicated by a change in the contents of R3. An incorrect index value perceived before ENTR has been keyed can be altered by keying CLR and keying in the correct value. Once an incorrect index value has been entered, the only means of recovering is to terminate the update (VERB 34 ENTR) and to re-initiate the update verb.

The second octal data word the crew enter must be the erasable memory address of the first word of the update block. The crew then load the update parameters to be stored in sequential memory locations.

As each data word is loaded, a counter is incremented so that the last ENTR of the update sequence causes P27 to flash VERB 21 NOUN 02 to request acceptance, or modification, of the data. Keying in VERB 33 ENTR (data accepted) causes P27 to transfer the data to the specified block.

4.2.5.1.3 VERB 72 ENTR.—VERB 72 allows the ground or the crew to initiate an erasable memory update in not necessarily contiguous locations. The VERB 72 data format is as follows:

II ENTR
AAAA ENTR
xxxxx ENTR
AAAA ENTR
xxxxx ENTR
.
.
.
AAAA ENTR
xxxxx ENTR

where:

II is a 2-digit octal number between 3_8 and 23_8. The index II must always be odd since it includes the index and the address data pairs (i.e., AAAA and xxxxx). If the index entered is even when it is checked after VERB 33 ENTR, P27 will reject all the data and terminate.

AAAA is the erasable memory address of the location to be loaded with the xxxxx immediately following.

xxxxx is octal data to be loaded.

Except for the format, VERB 72 is operationally similar to VERB 71.

4.2.5.1.4 VERB 73 ENTR.—The crew key VERB 73 ENTR to initiate a double-precision octal time increment. The loading procedure for this update is identical to the VERB 70 update defined in paragraph 4.2.5.1.1. If the update data are acceptable, the data are used to increment the clock. No delay is encountered if the Orbital Integration Routine is in use, since the information used by that routine cannot be changed by the CMC clock update.

4.2.5.2 P27 Procedure

Figure 4.2.5-1 gives the logical flow of P27. Figure 4.2.5-2 gives two examples of manual data loads.

Before entering P27, the CMC major mode must be P00 or P02 and the DSKY must be available.

P27 can be manually selected by the astronaut's keying in one of the four extended verbs on the DSKY. The program can also be selected by the ground via uplink transmission. If the latter is done, the crew must place the UP TLM ACCEPT/BLOCK switch to ACCEPT. The manual update is described in the following program procedures. Uplink update is done in the same way, except that the crew functions are performed from the ground.

P27 is entered by keying VERB 70 ENTR, VERB 71 ENTR, VERB 72 ENTR, or VERB 73 ENTR. If another extended verb is active when one of the four verbs is keyed in, the DSKY will not be available, and P27 will illuminate the OPR ERR light. The crew should restart the program when the DSKY is free.

If the program being interrupted is not P00 or P02, P27 will turn the OPR ERR light on and the UPLINK ACTY light off. The crew should place the UP TLM ACCEPT/BLOCK switch in BLOCK; CMC control will automatically return to the interrupted program.

If VERB 71 or VERB 72 is entered, the DSKY flashes VERB 21 NOUN 01 to request the loading of the index in the specified machine address. (R3 contains the machine address.) The index is the total number (in octal) of numeric values to be loaded—a minimum of 3_8 and a maximum of 24_8. The registers will appear as follows:

R1 = Blank
R2 = Unchanged
R3 = ECADR, the address at which the index will be loaded.

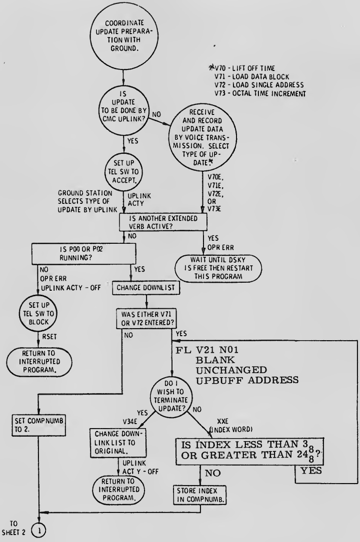


Figure 4.2.5-1. CMC Update Program (P27) (Sheet 1 of 3)

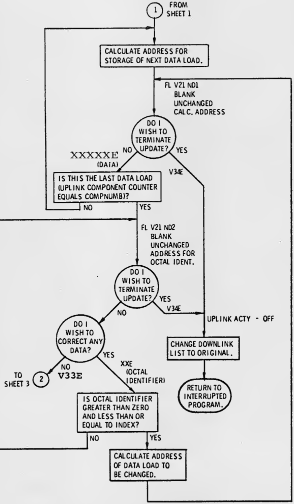


Figure 4.2.5-1. CMC Update Program (P27) (Sheet 2 of 3)

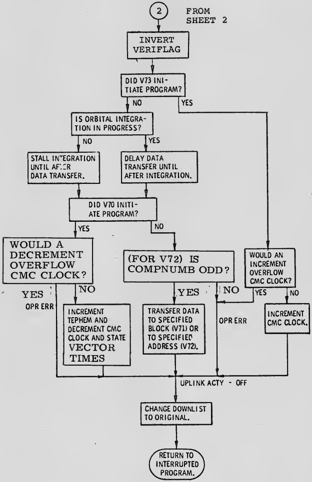


Figure 4.2.5-1. CMC Update Program (P27) (Sheet 3 of 3)

EXAMPLE 1: Load REFSMMAT (CM)

ENTRY	CMC RESPONSE	EXPLANATION
VERB 71 ENTR	→ FL VERB 21 NOUN 01	
24 ENTR		Octal number of numeric values to be loaded (including this one)
1735 ENTR		First erasable location
xxxxx ENTR		Data
⋮		
xxxxx ENTR	→ FL VERB 21 NOUN 02	Last data point
VERB 33 ENTR	→ P00	

EXAMPLE 2: Load CSM state vector in earth orbit

ENTRY	CMC RESPONSE	EXPLANATION
VERB 71 ENTR	→ FL VERB 21 NOUN 01	
21 ENTR		Octal number of numeric values to be loaded (including this one)
1501 ENTR		Code for state vector load
1 ENTR		Code for CSM state vector in earth orbit
xxxxx ENTR		Data
⋮		
xxxxx ENTR	→ FL VERB 21 NOUN 02	Last data point
VERB 33 ENTR	→ P00	

Figure 4.2.5-2. Examples of Manual Data Loads

The crew have the option of terminating the update at this point by keying in VERB 34 ENTR. If the crew terminate, the UPLINK ACTY light will go out and control will return to the program running at the time the update was initiated.

If the crew do not terminate, they load the index value, which is then displayed in R1 of the DSKY. If the index value is not within the limits (3_8 through 24_8), the flashing VERB 21 NOUN 01 display will return to the DSKY, requesting the load of the index value. If the index value is within the specified limits, the program stores the index.

P27 next increments UPBUFF for storage of the next data load. (UPBUFF contains the address of the temporary storage location of the data word.) The DSKY flashes VERB 21 NOUN 01 to request load of data into the UPBUFF address displayed in R3. The crew have the option of terminating the update at this point by keying in VERB 34 ENTR. (The UPLINK ACTY light would go off.) If the crew load data into UPBUFF, the data loaded will be displayed in R1. P27 will continue to flash VERB 21 NOUN 01 and display loaded data in R1 until all of the data has been loaded, i.e., until the number of items entered equals the index value.

Next the DSKY displays a flashing VERB 21 NOUN 02 to request response. The crew have three possible responses:

a. To accept all the data by keying in VERB 33 ENTR*
b. To terminate the update by keying in VERB 34 ENTR
c. To correct an item by keying in the octal identifier to specify which of the data words will be corrected.

In the last case, if an illegal octal identifier (less than zero or greater than the index) is keyed in, the flashing VERB 21 NOUN 02 display will return. Otherwise, the program will calculate the address of the data word to be changed and will return to the second flashing VERB 21 NOUN 01 display.

After all the data have been corrected and VERB 33 ENTR has been keyed in, P27 makes the actual data transfer.

---

* Although VERB 33 ENTR is usually the equivalent of PRO, for VERB 21–23 PRO is not accepted even for a manual load. VERB PRO is accepted, however.

If P27 is entered by using extended VERB 73, the program increments the CMC clock. Illumination of the OPR ERR light indicates that an increment would have caused an overflow.

If P27 is entered by using the other three extended verbs, the program determines if the state vector data are being used by the Orbital Integration Routine. If so, further P27 instruction executions are delayed until the integration is complete. A DSKY display of 27 as the major mode, a ground verification that BIT3 of FLAGWRD7 (VERIFLAG) has been inverted, and the absence of an OPR ERR notification should indicate to the crew that the completion of P27 is temporarily delayed. After P27 is reactivated, or if the Orbital Integration Routine is not in use, P27 will inhibit other routines from using state vector data.

If entered via VERB 70, P27 increments TEPHEM and decrements the CMC clock and state vector times. Illumination of the OPR ERR light indicates that decrement of the CMC clock would cause overflow.

If entered via VERB 71 or VERB 72, P27 transfers the data to the specified block (VERB 70) or address (VERB 72).

When transfer of data is complete, P27 turns the UPLINK ACTY light off, releases the state vector data for other routines, and reinstates the interrupted program.

4.2.5.3 Alarms

No program alarms are associated with P27. The OPR ERR light is illuminated if the crew attempts to enter P27 while another extended verb is active, if the CMC is not in P00 or P02, or if incrementing in VERB 73 (or decrementing in VERB 70) would cause the CMC clock to overflow. The program then turns off the UPLINK ACTY light and terminates.

4.2.5.4 Restrictions and Limitations

P27 is allowed to enter only when the CMC is in P00 or P02 and no other extended verbs are active.

The number of numeric quantities which can be loaded is restricted as follows:

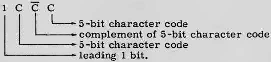
a. To 22_8 for VERB 71, because the capacity of the temporary storage buffer for input data is 24_8 words, and this must include the index count and the starting address

b. To 11_8 for VERB 72, because the maximum 24_8 data words must include an address for each data word and the index.

If the Orbital Integration Routine is running when P27 is ready to transfer data to permanent locations and if the update is other than VERB 73, P27 will be delayed until the Orbital Integration Routine is terminated. While the transfer of data is taking place, use of the state vector data is inhibited. This restriction was made to avoid use of partially updated state vector information.

4.2.5.5 Ground Uplink Format

Information received by the CMC from the uplink is in the form of keyboard characters. Each character is assigned a character code number (C). Each character code transmitted to the CMC is sent as a triply redundant uplink word with a leading 1 bit. Thus, the 16-bit uplink word has the form:



where $\overline{C}$ denotes the bit-by-bit complement of the 5-bit C. To these 16 bits of information, the ground adds a 3-bit code specifying the system aboard the spacecraft that is to be the final recipient of the data and a 3-bit code indicating the spacecraft that should receive the information. The 22 total bits are further encoded bit-by-bit (i.e., each bit is replaced with a 5-bit code for transmission). If the message is received and successfully decoded, the on-board receiver will send back an 8-bit-message-accepted pulse to the ground and shift the original 16 bits of the uplink word to the CMC. The leading 1 bit causes an interrupt within the CMC after all 16 bits have been shifted from the uplink receiver. It is good operational procedure to end every uplink message with KEY RELEASE. (Table 4.2.5-III gives the uplink words for all legal input characters.)

If the CMC receives an improperly coded word from the uplink receiver during the load, it notifies the ground by setting BIT4 of FLAGWRD7 to 1 and transmitting it

TABLE 4.2.5-III

LEGAL INPUT CHARACTERS AND ASSOCIATED UPLINK WORDS

Character	Uplink Word (Binary)			
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

via downlink. When this occurs, the ground station should correct the transmission by sending the following uplink word:

1 00000 00000 00000

and follow this by transmitting ERROR RESET. (Keying RSET on the DSKY would have no effect.) If CLEAR is transmitted immediately following ERROR RESET, the ground can then begin the corrected transmission with the first digit of the 5 octal digits that were being sent when the condition occurred. CLEAR is used after ERROR RESET to blank the data display register (R1). The ground station should then resume the update function by retransmitting the word beginning with the first octal character. If the ground wishes to continue loading without transmitting CLEAR, it must determine which character was in error when failure occurred, and resume uplink transmission from the point of failure. The determination can be made by monitoring the display in R1.

4.2.5.6 Restart

P27 is restart protected after data are verified by ground except for (1) a small window (place) in the clock updates (VERB 70 and VERB 73) and (2) a small window immediately after verification. Should a restart occur during a clock update, the crew should check the clock carefully, upon completion of P27, to see that it has been correctly updated. Should a restart occur before data have been verified, the crew must reselect P27. Should a restart occur immediately after ground verification, the crew should check that the uplink data have been processed.

SUBSECTION 4.3

LGC COASTING NAVIGATION PROGRAMS

BLANK

4.3.1 P20, Rendezvous Navigation (LGC)

The Rendezvous Navigation Program (P20) controls the LM attitude and the rendezvous radar (RR) to acquire and track the CSM with the RR during rendezvous. The program processes RR tracking data to permit updates of either the LM or the CSM state vector maintained in the LM Guidance Computer (LGC). P20 can also track the CSM with the RR without updating either state vector, for example after DOI, when the RR may be used to track the CSM without updating as an abort contingency measure. P20 control of the LM attitude also points the LM optical beacon at the CSM.

Radar range, range rate, and tracking angle data are used by the LGC to update the state vector of the active vehicle relative to the passive vehicle. P20 maintains estimates of the LM and CSM state vectors during the navigation portion of each rendezvous phase: CSI, CDH, TPI, and TPM. Based on the updated estimates thus obtained, the appropriate targeting program (P32, P33, P34, P35 respectively) computes the Δv required to effect each rendezvous maneuver in turn.

Figure 4.3.1-1 is a simplified functional diagram of the rendezvous navigation logic for the successive phases of the rendezvous (CSI, CDH, TPI, TPM) respectively used both in the LGC and the CMC. Normally, the LM is the active vehicle, and the CSM is the passive vehicle.

Extrapolating both state vectors to the time of measurement, P20 computes an estimate of one of the parameters the RR measures (e.g., range) ($\hat{Q}$), which is compared with the measured range (Q) to obtain a measurement deviation δQ. This is multiplied by a statistical weighting vector ($\underline{\omega}$), which is computed from an onboard statistical estimate of (1) state-vector uncertainties (W-matrix), (2) radar range measurement error (α^2), and (3) a measurement geometry vector ($\underline{b}$). The resulting $\delta\underline{x}$ is a statistically optimum linear estimate of deviation to be added to the current estimate of the state vector to be updated. The same procedure is carried out for the other radar parameters (range rate and two tracking angles).

4.3.1.1 Program Options

A fundamental P20 option is whether to update the CSM state vector or the LM state vector. Considerations affecting the decision are (1) the desire to update the state vector having the larger uncertainties, and (2) the desire to update the state vector of the vehicle that is to perform the rendezvous maneuvers. Almost always, both considerations will favor updating the LM since the CSM state will have benefited

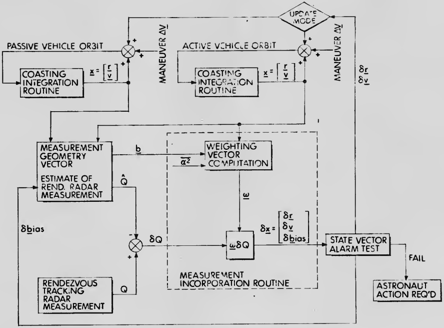


Figure 4.3.1-1. Simplified Rendezvous Navigation Diagram

from MSFN tracking prior to and during the ascent, while the LM state is degraded by maneuver uncertainties. Should the LM state-vector uncertainty be smaller, however, updating the CSM would be preferred. The state vector to be updated can be changed at any time during P20 operation by keying in VERB 80 ENTR (LM update), VERB 81 ENTR (CSM update), or VERB 95 ENTR (no-update mode).

> NOTE: After VERB 95 E is keyed in to prevent updating either state vector, VERB 80 or VERB 81 must be keyed in to allow state vector updating; reselection of P20 will not automatically cause state vector updating to resume.

Another option is the choice between manual or automatic acquisition of the CSM by the LM RR. Normally, the RR mode select switch is put in the LGC position for automatic target acquisition when the astronaut turns on the RR heaters before entering P20. However, the astronaut may elect to use the manual mode (SLEW switch position) for acquisition. If he does, he places the mode control switch in the SLEW position before entering P20. R23 is used to perform the manual acquisition. (Note, however, that R23 can be performed only if P20 is the only program running.)

4.3.1.2 Procedures

The procedures employed in the operation of P20 are discussed in this paragraph; the routines involved in its operation, and referenced herein, are discussed in detail in numerical order in paragraph 4.3.1.4. Figure 4.3.1-2 charts the logical flow of P20; Table 4.3.1-I summarizes P20 verbs and displays, and Table 4.3.1-II gives the extended verbs.

The IMU Orientation Determination Program (P51) or the Lunar Surface Alignment Program (P57) should be completed before the selection of P20. If this is not done, the LGC may not have a satisfactory inertial reference and a program alarm will occur. Both the LM and CSM must maneuver to their respective preferred tracking attitudes, which correctly orient the LM RR and CSM radar transponder before RR tracking, using P20, is initiated by the LM. For both vehicles, P20 maintains the preferred tracking attitude automatically once it is achieved; however both vehicles must maneuver to burn attitudes and then return to the preferred tracking attitude for the first three rendezvous burns. The rendezvous radar must be on and warmed up to operating condition, and preliminary checkout should be completed via R04 (see paragraph 4.3.1.4) before entering P20. Before entering P20, the astronaut places the RR mode control switch (1753 on the RADAR panel) in the LGC position,

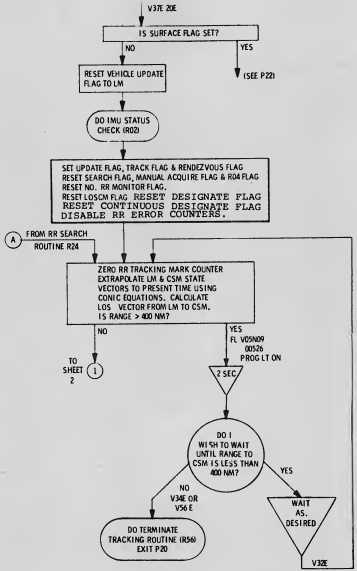


Figure 4.3.1-2. Rendezvous Navigation Program (P20) (Sheet 1 of 3)

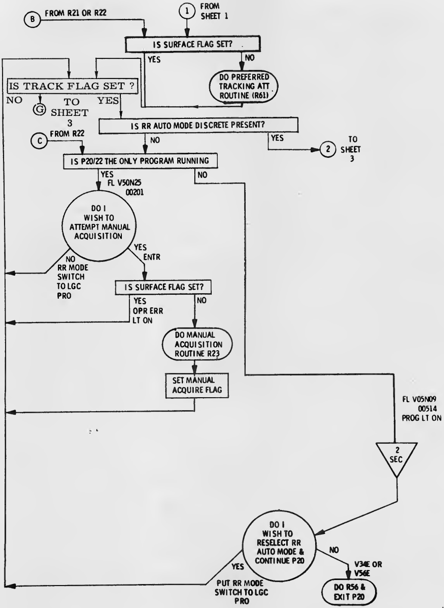


Figure 4.3.1-2. Rendezvous Navigation Program (P20) (Sheet 2 of 3)

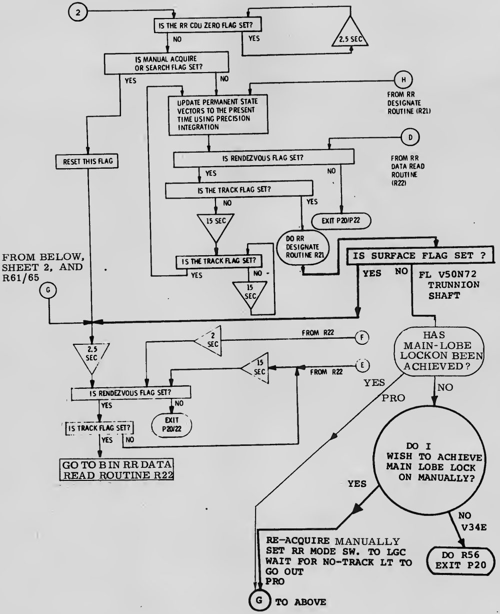


Figure 4.3.1-2. Rendezvous Navigation Program (P20) (Sheet 3 of 3)

TABLE 4. 3. 1-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH RENDEZVOUS NAVIGATION (SHEET 1 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
FL V37	R00	Request astronaut to select another program	- - -	R1 xxxxx R2 xxxxx R3 xxxxx
V05 N09E	Astronaut (R02)	Verify PROG alarm	00210 = IMU not operating in R1,R2, or R3	R1 xxxxx R2 xxxxx R3 xxxxx
V05 N09E	Astronaut (R02)	Verify PROG alarm	00220 = IMU not aligned in R1, R2, or R3	R1 xxxxx R2 xxxxx R3 xxxxx
FL V04 N12	R04	Display option code for assumed radar	R1 = option code for assumed radar R2 = LGC option code 00001 = RR 00002 = LR	R1 00004 R2 oooox R3 Blank
V22 E	Astronaut (R04)	Load desired radar code in R2	- - -	- - -
FL V50 N25	R04 and P20	Request astronaut to select RR auto mode	- - -	R1 00201 R2 Blank R3 Blank
FL V16 N72	R04	Display RR CDU angles	R1 = Trunnion angle, 360 minus RR CDU value R2 = RR shaft angle	R1 xxx.xx deg R2 xxx.xx deg
FL V50 N72	P20	Display RR CDU angles	R1 = Trunnion angle, 360 minus RR CDU value R2 = RR shaft angle	R1 xxx.xx deg R2 xxx.xx deg
FL V16 N78	R04	Display RR range, range rate, and TFI	Range Range Rate TFI = time from t_{IG} in min and sec to nearest sec. Max reading is 59B59. (-before, after t_{IG}, B = Blank).	R1 xxx.xx n. mi. R2 xxxxx. fps R3 xxBxx sec

TABLE 4.3.1-I
REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH RENDEZVOUS NAVIGATION (SHEET 2 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
FL V05 N09	R21	PROG alarm	00503 = R21 unable to acquire CSM (displayed in R1, R2, or R3 depending on presence or absence of other alarm codes)	R1 xxxxx R2 xxxxx R3 xxxxx
FL V50 N25	R23	Request astronaut to perform manual acquisition of CSM		R1 00205 R2 Blank R3 Blank
FL V05 N09	R22	PROG alarm	00525 = Delta theta greater than 3 deg (displayed in R1, R2, or R3 depending on presence or absence of other alarm codes)	R1 xxxxx R2 xxxxx R3 xxxxx
FL V06 N05	R22	Priority display delta theta		R1 xxx. xx deg R2 Blank R3 Blank
FL V06 N49	R22	Priority display excessive update parameters NOTE: Displays automatically. If astronaut calls up this display himself, he can get a display of his parameters if he does it right after a mark. In this case, it would not be a display of "excessive" updates.	R1 = Delta r; magnitude of difference between position state vector before and after incorporation of mark data R2 = Delta v; magnitude of difference between velocity state vector before and after incorporation of mark data NOTE: Both parameters not necessarily excessive Source code; Error source code causing this display where R3 = oooox x = 1 RR range x = 2 RR range rate x = 3 RR shaft angle x = 4 RR trunnion angle	R1 xxxx. x n. mi. R2 xxxx. x ft/sec R3 xxxxx

TABLE 4.3.1-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH RENDEZVOUS NAVIGATION (SHEET 3 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
FL V06 N49 (Cont.)			Source code indicates which measurement parameter (range, range rate, shaft angle, trunnion angle) is responsible for excessive update.	
FL V06 N99	V67E	Display RMS position, velocity, and angle bias errors of W-matrix	R1 = RMS position error R2 = RMS velocity error R3 = RMS bias error	R1 xxxxx. ft R2 xxxx.x fps R3 xxxxx. m rad
FL V05 N09	R23	To indicate if CSM presently outside allowable limits of present RR antenna mode	Alarm code 00501	R1 xxxxx R2 xxxxx R3 xxxxx
FL V16 N80	R24	Priority display of RR search parameters; indicates LGC-controlled search pattern in process*	R1 initially = 00000. If search is successful (RR data good discrete received) R1 = 11111. R2 initially = 00000. When RR designation begins, R2 = Omega (angle between RR LOS and LM+Z-axis)	R1 xxxxx. R2 xxx.xx deg R3 Blank
V05 N09E	Astronaut (R25)	Verify PROG alarm	00515 identifies RR CDU failure	R1 xxxxx R2 xxxxx R3 xxxxx

* Priority display is an internally-generated display that will override any other internally-generated display.

TABLE 4. 3. 1- I
REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH RENDEZVOUS NAVIGATION (SHEET 4 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
V06 N18	R60	Priority display final FDAI ball angles*	R1 = Roll angle R2 = Pitch angle R3 = Yaw angle	R1 xxx. xx deg R2 xxx. xx deg R3 xxx. xx deg
FL V50 N18	R60	Priority astronaut request to perform auto maneuver and display final FDAI ball angles*	Final FDAI ball angles, R1 = Roll; R2 = Pitch; R3 = Yaw; NOTE: If final FDAI ball angles computed result in ± 90 deg, yaw, transformation from IMU to FDAI in roll and pitch indeterminate; R1 and R2 will be set to 0. If yaw angles near ± 90 deg, values of R1 and R2 may not be reliable	R1 xxx. xx deg R2 xxx. xx deg R3 xxx. xx deg
V16 N56	V85E	To display RR antenna azimuth and elevation	R1 = RR LOS azimuth R2 = RR LOS elevation	R1 xxx.xx deg R2 xxx.xx deg R3 Blank

* If R60 called by R61 or R65

TABLE 4.3.1-II

EXTENDED VERBS USED WITH RENDEZVOUS NAVIGATION (P20)

VERB	Identification	Purpose and Remarks
40 N72 ENTR	RR CDU Zero	Used to zero the RR CDUs. Selected by DSKY entry at any time.
44 ENTR	Terminate RR Continuous Designate	Used to terminate continuous designate option of 41 N72. Selected by DSKY entry.
60 ENTR	Command LR to Position 2	Permits astronaut to drive the antenna to Position 2.
61 ENTR	Display DAP attitude error	Displays on the FDAI Error Needles the difference between the current CDU angles and the DAP commanded angles.
62 ENTR	Display total attitude error	Displays the total attitude error which is the desired CDU angles minus the present CDU angles.
63 ENTR	Call RR/LR Self-Test Routine, R04	Displays RR/LR information during self-test.
67 ENTR	W-Matrix RMS error display	Provides a means of displaying W-matrix RMS position, velocity, and bias errors which can be overwritten if reinitialization is desired. Reinitialization zeros off-diagonal (correlation) terms. Terminate via V34E.
80 ENTR	Enable LM state vector update	Causes the rendezvous data processing results to update the LM state vector.
81 ENTR	Enable CSM state vector update	Causes the rendezvous data processing results to update the CSM state vector.
85 ENTR	Display RR LOS azimuth and elevation	Provides for the display of the RR antenna azimuth and elevation.
93 ENTR	Enable W-matrix initialization	Permits the crew to reinitialize W-matrix. This is accomplished by resetting the RENDWFLG. This flag reset indicates a W-matrix is invalid and is reinitialized.
95 ENTR	No update of either state vector	Prevents state vector updating (LM or CSM).

unless he wishes to manually acquire the CSM as discussed in paragraph 4.3.1.1. If P20 is selected before the powered descent in the lunar mission, P20 must be entered and operated in the no-update mode; i.e., VERB 95 ENTR must be keyed in prior to selecting P20.

P20 has three alternative modes for controlling the rendezvous radar during target acquisition: the RR LGC Mode (R21), the RR Manual Mode (R23), and the RR Search Mode (R24). The LGC Mode or the Manual Mode can be selected by the astronaut at the beginning of P20; but the Search Mode can only be selected after the LGC Mode has failed to acquire the CSM.

The following flags are used during the operation of P20:

SURFACE flag — set denotes the LM is on the lunar surface (P22 only).
UPDATE flag — set denotes updating by marks allowed.
TRACK flag — set permits vehicle attitude to be controlled to align LM Z-axis to CSM LOS during navigation (P20) and targeting (P30s).
RENDEZVOUS flag — set denotes P20 or P22 is being used. Reset when P20/P22 is terminated.
SEARCH flag — set denotes RR Search Mode is being used.
MANUAL ACQUIRE flag — set denotes manual acquisition of CSM has been achieved.
R04 flag — set denotes alarm code 00521 is being suppressed.
NO RR MONITOR flag — set denotes the disabling of the angle monitor function of R25; occurs during RR Manual Mode.
LOSCM flag — set denotes LOS is being computed.
DESIGNATE flag — set denotes RR Designate is requested or is in progress.
CONTINUOUS DESIGNATE flag — set denotes continuous designate; LGC commands RR regardless of lock-on.
NO UPDATE flag — set denotes stopping the update of the state vector with RR data. This is done by the astronaut whenever desired.
REPOSITION flag — set denotes RR is being repositioned to the reference direction for present RR antenna mode.

The UPDATE flag controls state vector updating by P20. The flag is reset by VERB 37 and set by P20, P30, P32–35, P72–75; then it is reset during computations of the targeting programs, the P30s and P70s, so that P20 does not update the state vector during targeting program computations. It still reads the radar, however, and controls LM attitude.

The TRACK flag allows P20 (and P30s) to control vehicle attitude via R1 or R65, aligning the Z-axis to CSM LOS; it is reset by VERB 37 and set by the P20s, P30s, and P70s to assure tracking during navigation and targeting. The TRACK flag is reset during the P40s, since they control LM attitude during a burn. When the TRACK flag is reset, P20 does nothing but wait for it to be set.

Upon the crew's selection of P20 (VERB 37 ENTR 20 ENTR), the program checks the SURFACE flag to ensure it is not set, i.e., the LM is not on the lunar surface. The state-vector-update option is automatically set to the LM. This setting may be changed at any time later by one of the following entries:

a. VERB 80 ENTR to update the LM state vector.
b. VERB 81 ENTR to update the CSM state vector
c. VERB 95 ENTR to indicate no state-vector update.

The program then performs the IMU Status Check Routine (R02) and illuminates the PROG alarm light if the IMU is off or the IMU orientation is unknown. Should the PROG light be illuminated, the crew must key in VERB 05 NOUN 09 ENTR to see the appropriate alarm code displayed. (Alarm code 00210 is displayed if the IMU is not on; alarm code 00220 is displayed if the IMU orientation is unknown.) A flashing VERB 37 indicates that, as a result of the alarm, the program has entered the Final Automatic Request Terminate Routine (R00).

P20 then sets the UPDATE, TRACK, and RENDEZVOUS flags; resets the SEARCH, MANUAL ACQUIRE, and R04 flags; resets the NO RR MONITOR, LOSCM, DESIGNATE, and CONTINUOUS DESIGNATE flags; and disables the RR error counters.

The range between the LM and the CSM is then determined by taking the vector difference between the LM and CSM position vectors, which are extrapolated to the present time using conic equations. If the range is greater than 400 n. mi., program alarm 00526 is issued since the RR is unable to provide correct range information to the LGC. In this case, the astronaut would terminate P20 via the Terminate Tracking Routine (R56), keying in VERB 34 ENTR or VERB 56 ENTR, as discussed in paragraph 4.3.1.4.9, and recall P20 when the range is less than 400 n. mi., or wait until the range is less than 400 n. mi. and then recycle via VERB 32 ENTR.

After verifying that the range is less than 400 n. mi. (i.e., alarm code 00526 does not occur), P20 calls the Preferred Tracking Attitude Routine (R61) to align the LM +Z-axis along the LOS to the CSM. This ensures that the RR antenna will be designated in the correct antenna angular coverage region for operation. (Refer to Figure 4.3.1-3.) This attitude permits the LM optical beacon (centered with respect to the LM +Z-axis with a beamwidth of approximately 60 deg) to be visible from the CSM for optical tracking.

The LM +Z-axis is directed along the LOS to the CSM by the Fine Preferred Tracking Attitude Routine (R65), which is called two times, to perform seven computations, during each nominal 64-sec RR data cycle.

RR data are not used to update the navigation equations if the RR is more than 30 deg from the LM +Z-axis, ensuring that the LM optical beacon will be received by the CSM, and that a reliable estimate of the RR angle biases will be made when processing the data.

The LGC then checks to ensure that the RR Auto Mode discrete is being received from the RR. This discrete signifies that the RR is on and has been placed under LGC control by the astronaut's setting the mode control switch of the RR in the LGC position. Reception of this discrete at this time indicates that the astronaut wants to use the RR LGC Mode of target acquisition.

If the RR Auto Mode discrete is not present, and P20 is the only program running, a request is made to the astronaut via flashing VERB 50 NOUN 25 to select the RR Manual Mode by keying in ENTR (as described in paragraph 4.3.1.3.1), or to reselect the RR LGC Mode by placing the RR mode control switch in the LGC position and keying in PRO. If P20 is not the only program running, program alarm 00514 (indicating that the RR has been switched out of the Auto Mode) will be issued to avoid a conflict in the DSKY displays between P20 and other programs. Should this alarm occur, the astronaut can either terminate P20 via R56 (keying in VERB 34 ENTR or VERB 56 ENTR), or reselect the RR Auto Mode by again placing the RR mode control switch in the LGC position and keying in PRO.

If the LGC determines that the RR LGC Mode was selected (i.e., RR Auto Mode discrete is being received), the program next checks to ensure that the RR CDUs are not being zeroed. They are zeroed initially by the RR Monitor Routine (R25) when the RR Auto Mode discrete is first received from the RR, and are not zeroed again by R25 unless the status of the RR Auto Mode discrete changes. A check is then made to determine if either the MANUAL ACQUIRE or SEARCH flag is set, signifying that the RR Manual Mode or the RR Search Mode is being used. Since the present mode is assumed to be the RR LGC Mode, these flags should not be set.

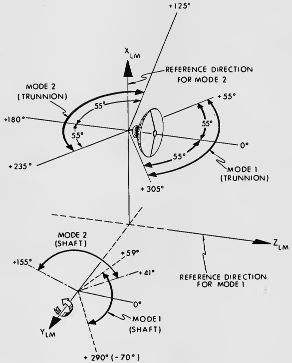


Figure 4.3.1-3. RR Antenna Shaft and Trunnion LOS Tracking Regions

Just before entering the RR Designate Routine (R21), the program makes a precision update of the CSM and LM permanent state vectors, and checks the RENDEZVOUS and TRACK flags. P20 then calls the RR Designate Routine (R21). The RR Track Enable discrete is automatically removed from the RR to ensure RR response to R21 commands. R21 initially points the RR antenna along the reference direction of Mode 1. (See Figure 4.3.1-3.) If R21 fails to acquire the CSM, the RR Search Mode is initiated, as described in paragraph 4.3.1.3.2. The LOS range vector ($\underline{r}_{LOS}$) and the velocity ($\underline{v}_{LC}$) of the CSM with respect to the LM are computed using the CSM and LM position and velocity vectors ($\underline{r}_C$, $\underline{v}_C$, $\underline{r}_L$, $\underline{v}_L$). After the computation of $\underline{r}_{LOS}$ and $\underline{v}_{LC}$, a check is made to determine if the LOS is within the angular tracking limits of either RR antenna mode, as shown in Figure 4.3.1-3. (Note that the limits shown in the figure are not the antenna gimbal mechanical limits, but the LOS limits within which the RR should track satisfactorily.) If the LOS is within the angular tracking limits of one of the RR antenna modes, R21 will ensure that the RR antenna is in that mode before designating the RR antenna along the LOS.

R21 designates the RR toward the CSM by issuing rate commands to the RR antenna gyros approximately every 0.5 sec. An approximate update for the LOS motion is made to $\underline{r}_{LOS}$ about every 0.5 sec until the counter N in R21 is decremented from 3 to 0. When N equals 0, the routine computes new values of $\underline{r}_{LOS}$ and $\underline{v}_{LOS}$, sets N equal to 3, and begins another designate command cycle until RR lock occurs or until 60 commands have been issued.

During R21, a check is made to see if the RR is within 0.5 deg of the present LOS range vector $\underline{r}_{LOS}$. If so, the RR track enable discrete is issued to the RR enabling the angle-tracking servos to track the target if its range-rate tracking network has already acquired the target. Issuance of this discrete also initiates the RR range tracker search if the velocity tracker has already acquired the CSM.

Approximately every 0.5 sec, R21 also checks to determine if the RR data good discrete is present. This discrete is sent to the LGC by the RR when lock-on is achieved in range and range rate, and the RR track enable discrete has been received from the LGC. If the RR data good discrete has not been received after issuing rate commands to the RR gyros 60 times (K = 0), the RR track enable discrete is removed and program alarm 00503 is issued, indicating a radar antenna designate fail. The astronaut then either repeats the designate process, or goes to the RR Search Mode by keying in PRO (VERB 33 ENTR) to begin the RR Automatic Search Routine (R24).

If the RR data good discrete is received during the designate process, R21 is terminated, and the shaft and trunnion angles indicating the direction of the RR antenna are displayed to the astronaut via VERB 50 NOUN 72 so he can confirm lock-on by the main radiation lobe before entering the RR Data Read Routine (R22). This confirmation is made either through the Crew Optical Alignment Sight (COAS), or the RR signal-strength meter. If the astronaut exercises manual control of the RR to ensure it is tracking on the main lobe, he does not key in PRO until after he has placed the RR mode control switch in the LGC position, and the RADAR panel NO TRACK light is extinguished. After confirmation of main lobe lock-on, the RENDEZVOUS and TRACK flags are checked to ensure that they are set before entering R22. R22 cycles through R65, the Fine Preferred Tracking Attitude Routine (Figure 4.3.1-16), before branching off for the first RR data sample.

The RR Data Read Routine (R22) obtains an RR mark—complete set of four data components (range, range rate, shaft angle, and trunnion angle)—from the RR at approximately one-minute intervals throughout the rendezvous phase, except during powered maneuvers. In addition to these data, the time of the measurement and the three IMU gimbal angles are also recorded. During R22, R65 is repeatedly called to obtain continuous or fine LM +Z-axis tracking of the CSM. The interval between successive state vector update marks (that is, the interval required to obtain each four-component mark) is about 64 sec.

After each set of RR data is read, but before it is incorporated, the calculated LOS for the time of the reading is compared with that indicated by the RR CDUs. If the difference is more than 3 deg, the probability of sidelobe acquisition is large and PROG alarm code 00525 is issued. The astronaut will PRO to obtain a flashing VERB 06 NOUN 05, which displays $\Delta\theta$, the size of the angle between the computed and actual RR LOS, for sidelobe verification. If the size of the displayed $\Delta\theta$ indicates RR sidelobe lock, the astronaut should recycle to the RR Designate Routine (R21) by keying in VERB 32 ENTR. Otherwise he can request the LGC to incorporate the data by keying in PRO.

Prior to incorporation, a check is made on the magnitudes of the changes in position and velocity (Δr, Δv) that each of the four components of each mark (R, $\dot{R}$, β, and θ) cause in the state vector. If the $\Delta\underline{r}$ or $\Delta\underline{v}$ that results exceeds certain predetermined values, the magnitudes of the corrections will be displayed via VERB 06 NOUN 49. In addition, a source code will be displayed indicating which component of the mark (range = 1, range rate = 2, shaft angle = 3, trunnion angle = 4) caused the update that exceeded the $\delta \underline{r}$, $\delta \underline{v}$ threshold; this can be useful in indicating the type of corrective action required.* The result of processing RR measurement data is an updated vehicle relative state and an 8-dimensional estimate of the position, velocity, and RR angle bias errors. The improved estimate of the updated vehicle's relative state vector is used to compute rendezvous targeting parameters in other programs.

The W-matrix is automatically initialized from pad-loaded values when P20 is called for the first time. W-matrix gain diminishes as marks are taken and correlations within the matrix acquire errors with continued extrapolation. The W-matrix is, therefore, normally reinitialized at CDH to stored RSS position, velocity, and angle bias values. Because reinitializing to diagonal values destroys the cross-correlation terms in the corners of the matrix, two ways of reinitializing are used.

The astronaut can reinitialize before taking CDH marks, by keying in VERB 67 ENTR, and writing over the values displayed by VERB 06 NOUN 99. In this case the correlation terms are destroyed and several marks will be required to reestablish them.

If, before reinitialization, the astronaut wishes to change the values used to initialize the W-matrix, he can change the values by octal load, keying in VERB 21 ENTR, and using reinitialization values prescribed in the crew charts or in the flight plan.

Alternatively, the astronaut can set up the reinitialization beforehand.

He can then permit three or four marks to be incorporated before keying VERB 93 ENTR, which will reinitialize the W-matrix to the prestored values when the next mark arrives. The VERB 67 approach is time consuming and difficult to perform between marks. Also it affects the W-matrix directly. The VERB 21, VERB 93 techniques allow the astronaut to load new values when it is convenient, far in advance of when he wants to reinitialize. The values put into the registers with VERB 21 do not affect the present W-matrix being used, nor does rediagonalization occur until a mark is processed following the reinitialization request via VERB 93 ENTR.

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*Refer to Users' Guide Section 4.2.1.5 on CSM P20 for N49 mark incorporation and procedures for H1 Rendezvous Guidance and Navigation.

4.3.1.3 Alternate Procedures

4.3.1.3.1 RR Manual Mode.—If P20 is the only program running, and the LGC indicates the auto mode discrete is not present (flashing VERB 50 NOUN 25, with checklist code 00201 in R1), the Manual Mode of target acquisition (R23) will be initiated if the astronaut keys ENTR in response to the display. This routine can only be performed, however, if P20 is the only program running (i.e., P20 is shown on the DSKY panel). Absence of this discrete at the beginning of P20 is ensured by not placing the RR mode control switch in the LGC position, as discussed in paragraph 4.3.1.1.

When the astronaut keys in ENTR to the flashing VERB 50 NOUN 25 display in P20, R23 is entered and the NO ANGLE MONITOR flag is set, the minimum deadband of the RCS DAP is selected, and the RR track enable discrete is issued to the RR. Issuing this discrete at this time ensures that no loss of RR angle tracking occurs when the mode control switch of the RR is placed in the LGC position after acquisition.

R23 next flashes VERB 50 NOUN 25 with code 00205 displayed in R1, requesting the astronaut to change the RR control switch to the SLEW position and perform manual acquisition of the CSM. If manual acquisition is achieved, the astronaut places the RR mode control switch in the LGC position, waits until the radar panel NO TRACK light is extinguished, and keys in PRO. When the RR mode control switch is placed in the LGC position, RR range tracking is interrupted and a new range search is initiated. When the RR acquires the target in both range and range rate, the NO TRACK light is extinguished, thus ensuring RR-tracking-network lock-on before entering R22.

After PRO is keyed in response to flashing VERB 50 NOUN 25, the LGC determines if the RR is within the limits of the present coverage mode. If it is not, program alarm 00501 is issued, and the astronaut either terminates the routine by keying in VERB 56 ENTR or VERB 34 ENTR (R56), or repeats the acquisition process via R61 by keying in recycle (VERB 32 ENTR). The astronaut uses R61 to realign the LM +Z-axis with the target LOS whenever he elects to repeat the manual acquisition process.

Once the acquired RR is returned to LGC control and the RR is within the present antenna mode limits, the astronaut-specified deadband is restored, and the NO ANGLE MONITOR flag is reset in R23. R23 then exits to P20 which sets the MANUAL ACQUIRE flag and calls R22.

4.3.1.3.2 RR Search Mode.—If R21 fails to acquire the CSM (alarm code 00503), the RR Search Mode can be selected by the astronaut by keying in PRO. R24 designates the RR antenna in a hexagonal search pattern about the estimated LOS, as illustrated in Figure 4.3.1-4. This search pattern requires approximately 42 sec to complete.

The LGC sets the SEARCH flag, and the RR track enable discrete is issued to the RR. This discrete is reissued at each corner of the search pattern in case it has been removed by some source, such as R25 (the RR Monitor Routine). Approximately every 6 sec, the position and velocity vectors of the CSM and LM are used to compute the desired RR pointing direction ($\underline{u}_D$), which is along $\underline{u}_{LOS}$ for the first 6 sec and steps counterclockwise to the six corners of the search pattern at 6-sec intervals. A check is made on $\underline{u}_D$ with respect to the angular coverage modes of the RR antenna. If $\underline{u}_D$ is not within the limits of either mode, the PROG alarm light is turned on, alarm code 00527 is stored, and the search pattern is stopped.

If the astronaut wishes to continue the search, he must reestablish the preferred tracking attitude via the Preferred Tracking Attitude Routine (R61). When $\underline{u}_D$ is within the limits and the correct antenna mode has been established, R24 designates the RR by issuing rate commands to the RR gyros about every 0.5 sec, with approximate corrections each time for lag error and target motion.

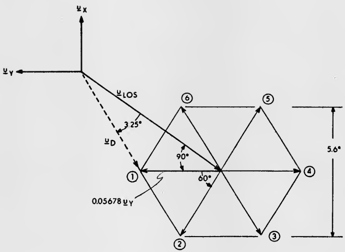
A periodic check is made to see if the RR data good discrete is being received from the RR, signifying the RR has acquired the target in range and range rate. This information is displayed via flashing VERB 16 NOUN 80. If the discrete is present, R1 is changed from 00000 to 11111, and the search is stopped.

The astronaut then checks to see if acquisition was obtained with the main radiation lobe of the RR. By manually altering the RR antenna position and observing the RR SIGNAL STRENGTH meter, he should be able to distinguish the main lobe from any sidelobes.

Having achieved and verified main lobe lock-on, the astronaut places the RR mode control switch in the LGC position, waits until the NO TRACK light is extinguished, and keys PRO in response to the flashing VERB 16 NOUN 80.

4.3.1.4 Associated Routines

The routines discussed below are those associated with P20 during the nominal and alternate procedures discussed above. The routines are presented here in numerical order, rather than in the order they occur in P20.



Note: This is the search pattern as viewed from the CSM.

Figure 4. 3. 1-4. RR Search Pattern

4.3.1.4.1 IMU Status Check Routine (R02).—This routine is called by programs requiring an aligned IMU. (Refer to Figure 4.3.1-5.) R02 checks the IMU operate bit and the IMU orientation (REFSMMAT) flag. If the ISS is not on, program alarm 00210 will be stored and the PROG lamp will light. If the IMU orientation is not known by the LGC, program alarm 00220 will be stored and the PROG lamp will light. By keying VERB 05 NOUN 09 into the DSKY the astronaut can have the stored alarm codes displayed to him for verification of the associated condition.

4.3.1.4.2 RR/LR Self-Test Routine (R04).—This routine provides DSKY displays and LGC downlink information to support the self-tests of the rendezvous radar and the landing radar. (Refer to Figure 4.3.1-6.) It is selected manually by DSKY entry of VERB 63 ENTR in conjunction with manual selection of the appropriate radar self-test at the LM console. (The radar test switch-position settings are RNDZ, OFF, and LDG.) R04 may be selected only when no other program or routine is using the RR. The OPR ERR light will be illuminated if the RR is in use.

The RR heaters must be in the operating position at least one hour before the selection of R04. Whenever a range or range-rate measurement is obtained from the RR, the RR data good discrete is also checked. If it is missing, the tracker fail alarm is issued. Self-testing is terminated by keying in VERB 34 ENTR.

4.3.1.4.3 LR/RR Read Routine (R20).—This routine reads the LR/RR parameter requested by the calling routine and performs various checks to ensure the system is operating correctly. (Refer to Figure 4.3.1-7.) Program alarms are issued (by illumination of the PROG lamp) as follows if errors occur in the RR readings:

a. Alarm code 00520 means no radar sampling has been requested from the radar at this time.
b. Alarm code 00521 means the program is not able to obtain a "good" radar sample (no data good discrete present).
c. TRACKER fail light comes on if the program is unable to obtain "good" RR samples on each required pass (i.e., either the data good discrete is not present, or the RR CDU has failed).

4.3.1.4.4 RR Designate Routine (R21).—This routine is automatically called by P20. The routine points the RR at the CSM until automatic acquisition of the CSM is accomplished or until alarm code 00503 is stored, the PROG light is lit, and VERB 05 NOUN 09 flashes requesting response. (Refer to Figure 4.3.1-8.) The RR servos are commanded by the LGC, after the LGC issues the track enable discrete,

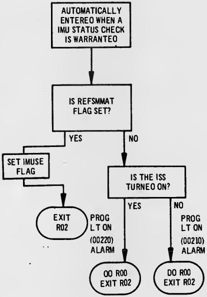


Figure 4.3.1-5. IMU Status Check Routine (R02)

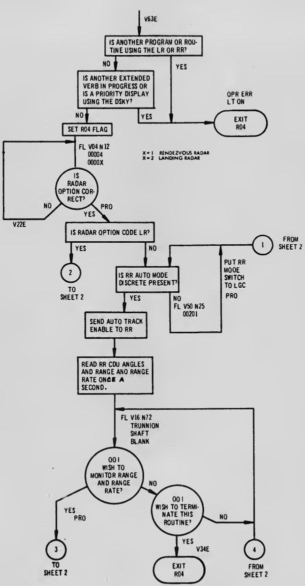


Figure 4.3.1-6. RR/LR Self Test Routine (R04) (Sheet 1 of 2)

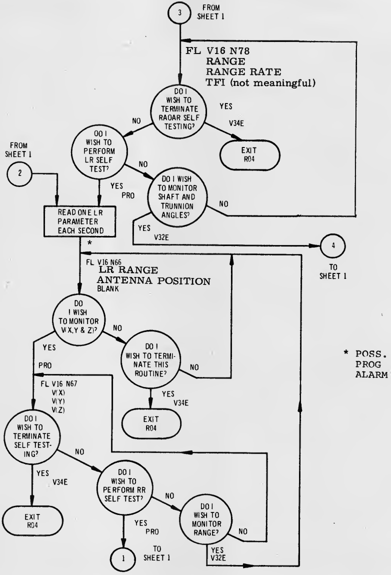


Figure 4.3.1-6. RR/LR Self Test Routine (R04) (Sheet 2 of 2)

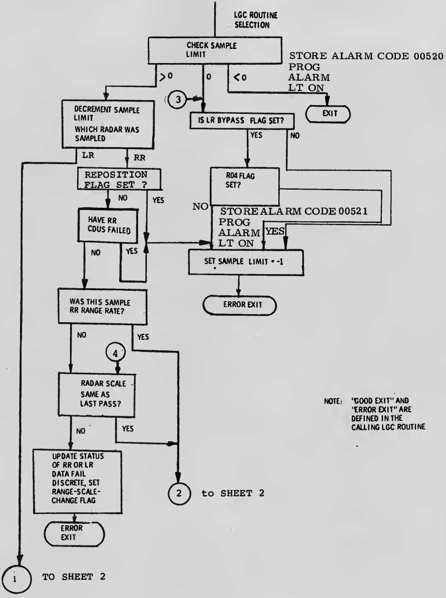


Figure 4.3.1-7. LR/RR Read Routine (R20) (Sheet 1 of 2)

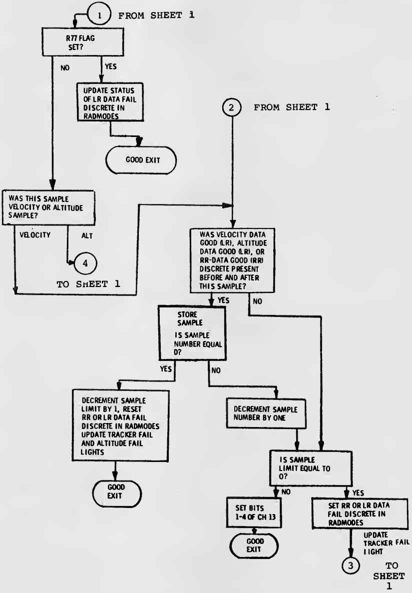


Figure 4.3.1-7. LR/RR Read Routine (R20) (Sheet 2 of 2)

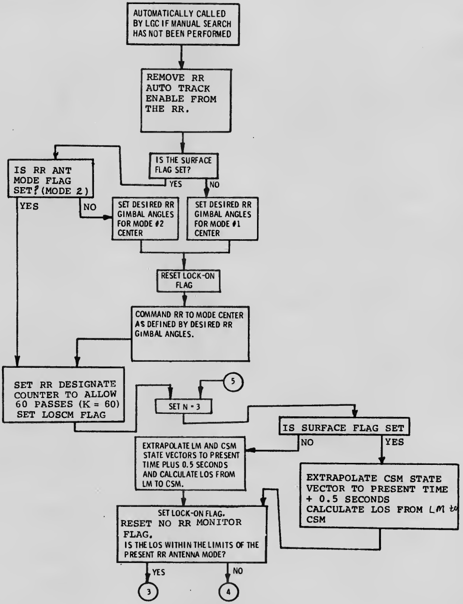


Figure 4.3.1-8. RR Designate Routine (R21) (Sheet 1 of 3)

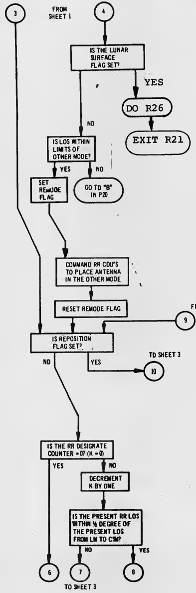


Figure 4.3.1-8. RR Designate Routine (R21) (Sheet 2 of 3)

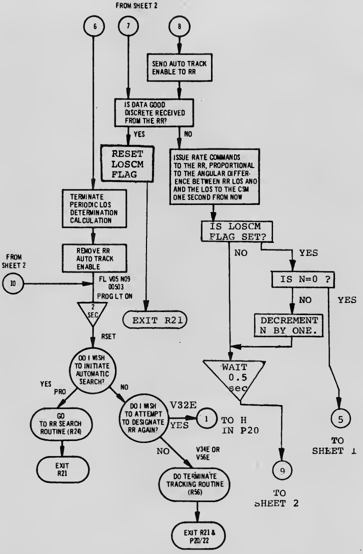


Figure 4.3.1-8. RR Designate Routine (R21) (Sheet 3 of 3)

until range-rate lock-on is achieved by the RR or until alarm code 00503 indicates R21 is unable to acquire the CSM.

4.3.1.4.5 RR Data Read Routine (R22).—This routine is automatically called by P20. (Refer to Figure 4.3.1-9.) R22 processes the automatic RR data in order to obtain the range, range rate, shaft angle, and trunnion angle between the LM and the CSM. These data are used to update the LM or the CSM state vector. R22 calls for R65 to maintain the LM +Z-axis aligned along the LOS from the LM to the CSM within the deadband of the DAP while P20 is in progress. Alarm code 00525 will occur (via flashing VERB 05 NOUN 09) if the delta theta (the difference between the RR indicated LOS and the state vector-indicated LOS) is greater than 3 deg. Due to the length of time involved in various computations of this routine, a call is made to R65 to ensure preferred tracking attitude is maintained.

4.3.1.4.6 RR Manual Acquisition Routine (R23).—This routine is used to acquire the CSM by manual operation of the rendezvous-radar antenna while the LM is in flight. (Refer to Figure 4.3.1-10.) The routine is automatically called by P20 in response to an astronaut request for a manual acquisition. R23 can be selected only when P20 is not running in conjunction with another program. Alarm code 00501 (flashing VERB 05 NOUN 09) indicates that the LOS to the CSM is outside the allowable limits of the present RR antenna mode.

4.3.1.4.7 RR Search Routine (R24).—This routine generates a search pattern to acquire the CSM when the RR has failed to acquire the CSM in the automatic mode. (Refer to Figure 4.3.1-11.) R24 allows the astronaut to confirm that reacquisition has not been by sidelobe. The routine is automatically called by R21 in response to an astronaut request for a search acquisition. If the desired RR LOS is not within the limits of either RR mode, a 00527 alarm is stored and the PROG lamp lit to indicate that a vehicle maneuver is required.

4.3.1.4.8 RR Monitor Routine (R25).—This routine is automatically called every 0.48 sec by an automatic program interrupt whenever the LGC is on. It monitors the RR status with respect to mode changes, RR CDU failure, and RR gimbal positions. (Refer to Figure 4.3.1-12.) If the RR gimbal angles exceed predefined limits (see Figure 4.3.1-3), R25 commands the RR gimbals to one of two reference positions (dependent upon RR antenna mode). If the RR auto mode discrete changes status, R25 sets various flags ensuring proper initiation or termination of various radar control functions within the LGC. When the RR is first put in the auto mode, R25 zeros the RR CDUs, determines the present RR antenna mode, and updates the TRACKER fail light. When the RR auto mode discrete is removed by the RR, R25

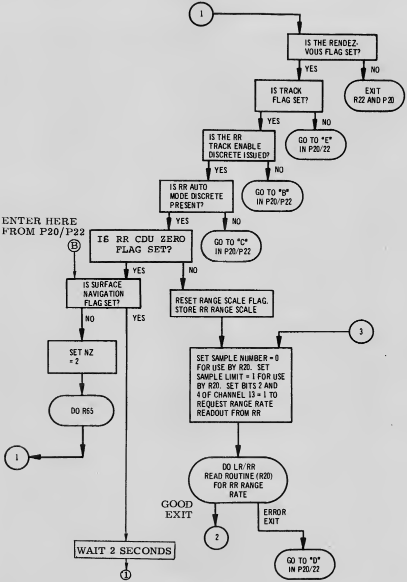


Figure 4.3.1-9. RR Data Read Routine (R22) (Sheet 1 of 4)

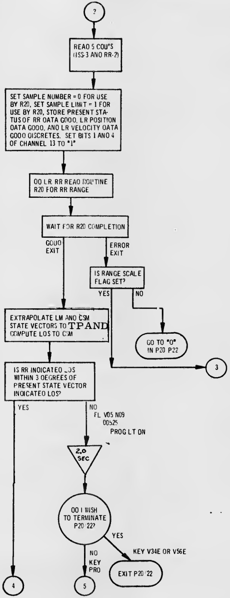


Figure 4.3.1-9. RR Data Read Routine (R22) (Sheet 2 of 4)

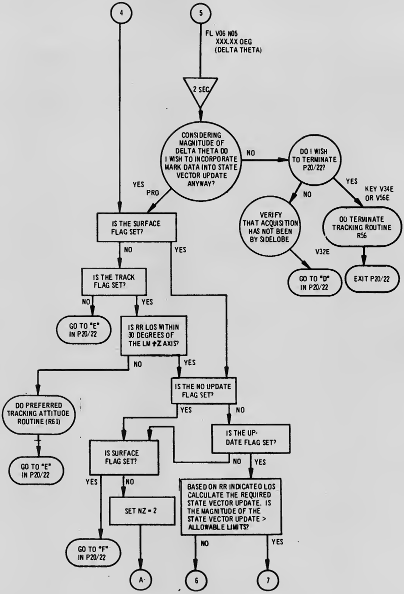


Figure 4.3.1-9. RR Data Read Routine (R22) (Sheet 3 of 4)

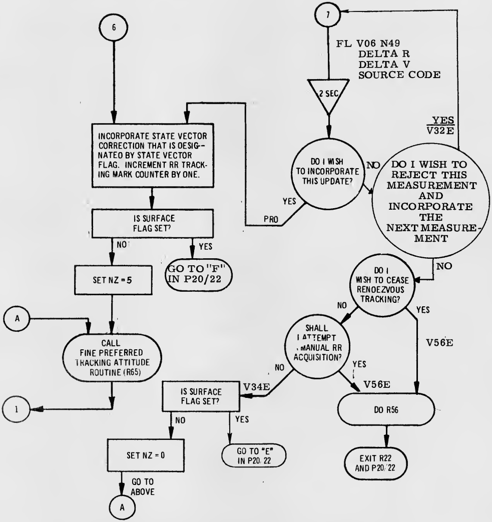
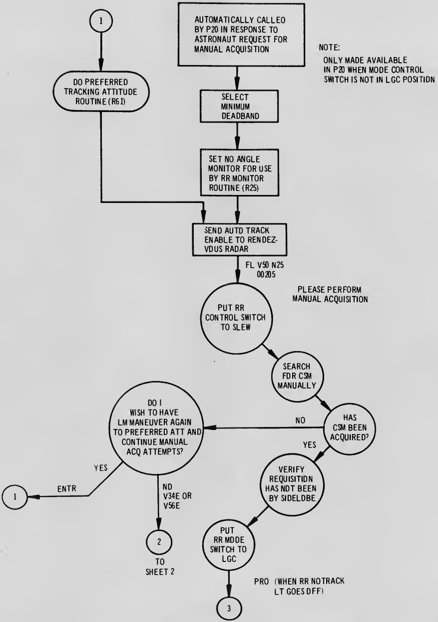


Figure 4.3.1-9. RR Data Read Routine (R22) (Sheet 4 of 4)



NOTE:
ONLY MADE AVAILABLE IN P20 WHEN MODE CONTROL SWITCH IS NOT IN LGC POSITION

Figure 4.3.1-10. RR Manual Acquisition Routine (R23) (Sheet 1 of 2)

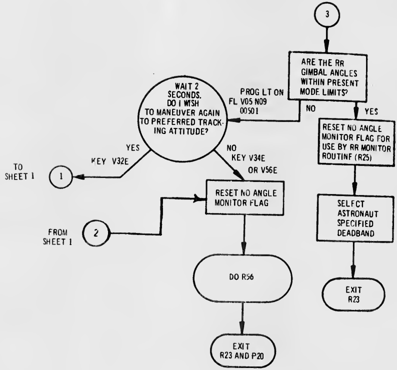


Figure 4.3.1-10. RR Manual Acquisition Routine (R23) (Sheet 2 of 2)

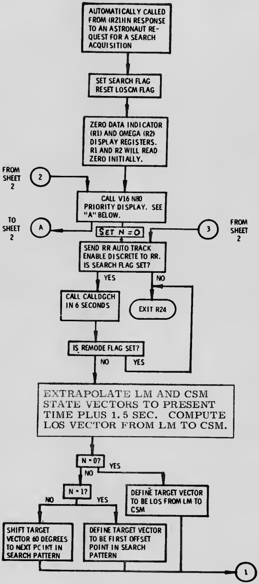


Figure 4.3.1-11. RR Search Mode (R24) (Sheet 1 of 2)

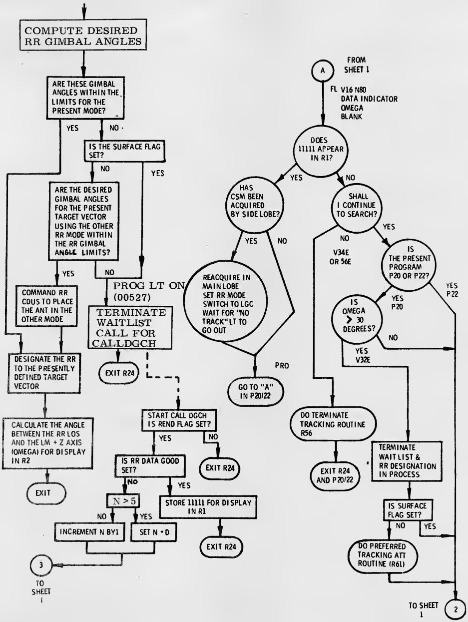


Figure 4.3.1-11. RR Search Mode (R24) (Sheet 2 of 2)

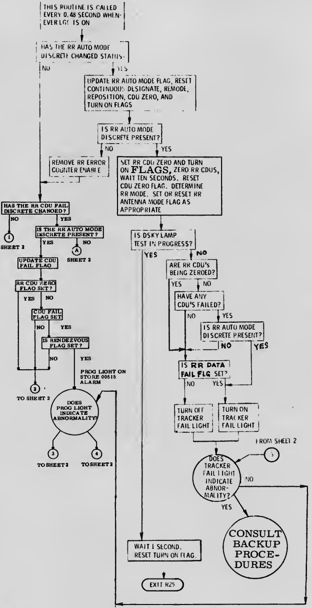


Figure 4.3.1-12. Monitor Routine (R25) (Sheet 1 of 2)

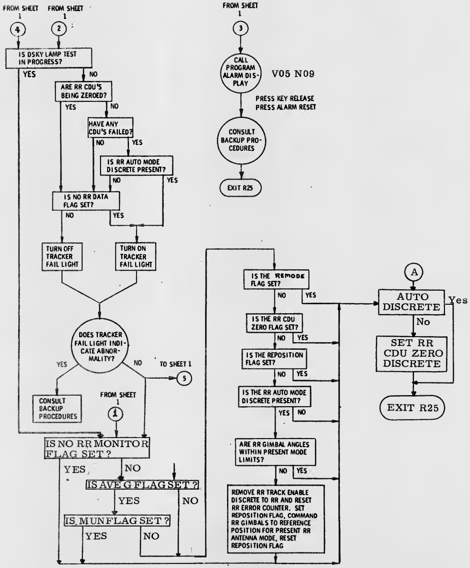


Figure 4.3.1-12. Monitor Routine (R25) (Sheet 2 of 2)

removes the RR Error Counter Enable from the RR CDUs in order to ensure no commands are being sent to the RR gyros. Alarm code 00515 indicates the RR CDU fail discrete is present. If the RR auto mode discrete is not present, the RR CDU zero discrete is set to inhibit RR CDU counter increments.

4.3.1.4.9 Terminate Tracking Routine (R56).—This routine is selected by keying in VERB 56 ENTR or VERB 34 ENTR in response to any flashing display in P20 (except VERB 06 NOUN 49). The routine terminates P20 if P20 is running in conjunction with another program. Otherwise, R56 selects R00 to exit P20. (Refer to Figure 4.3.1-13.)

4.3.1.4.10 Attitude Maneuver Routine (R60).—This routine maneuvers the LM to an attitude specified by the program in process. (See Figure 4.3.1-14.) This maneuver can be performed either automatically by the PGNCS or manually, with an optional final automatic PGNCS-controlled trim maneuver, and is monitored on the FDAI. R60 can be called by R61 or R65.

4.3.1.4.11 Preferred Tracking Attitude Routine (R61).—This routine is automatically called by P20, R23, and R24. R61 performs a single automatic trim maneuver to the preferred tracking attitude if the required maneuver is less than 15 deg; if the maneuver is not less, R61 notifies the crew that an attitude maneuver via R60 is required. (Refer to Figure 4.3.1-15.) By computing and commanding the preferred tracking attitude of the LM (when the LM +Z-axis is aligned along the LOS to the CSM, and the roll attitude about the LM +Z-axis is unconstrained), R61 allows RR tracking of the CSM and CSM tracking of the LM beacon.

4.3.1.4.12 Fine Preferred Tracking Attitude (R65).—This routine is automatically called by R22. (See Figure 4.3.1-16.) R65 performs the same functions as R61, except that R65 will perform a series of automatic trim maneuvers rather than a single trim maneuver.

4.3.1.5 Program Alarms

Eleven program alarm possibilities are associated with P20. Table 4.3.1-III lists the alarm codes, the causes, and the corrective action required, if any, for the following alarms:

00210 — IMU not operating
00220 — IMU not aligned or IMU orientation unknown
00501 — RR antenna out of present mode limits

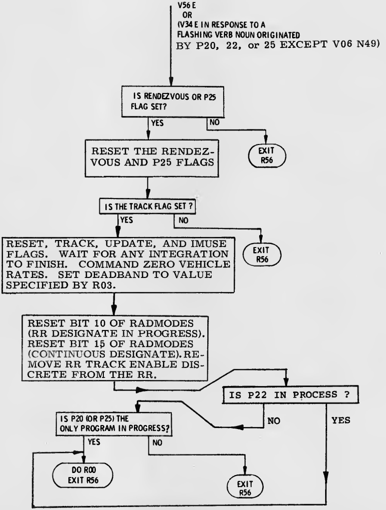


Figure 4.3.1-13. Terminate Tracking Routine (R56)

]

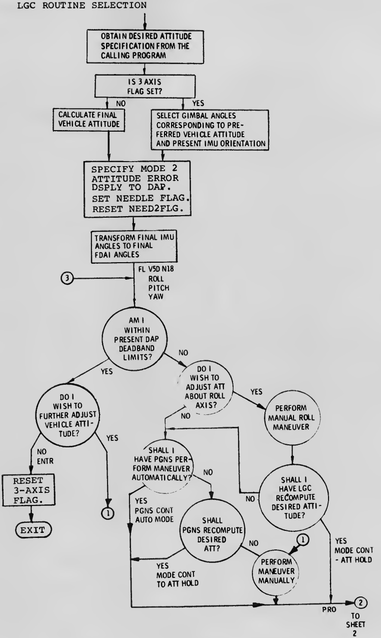


Figure 4.3.1-14. Attitude Maneuver Routine (R60) (Sheet 1 of 2)

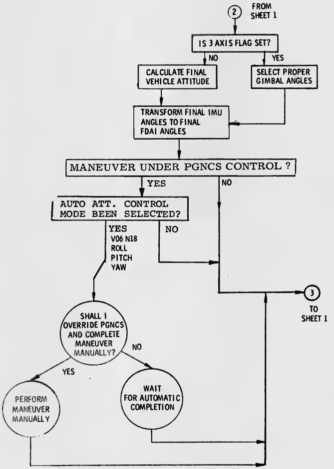


Figure 4.3.1-14. Attitude Maneuver Routine (R60) (Sheet 2 of 2)

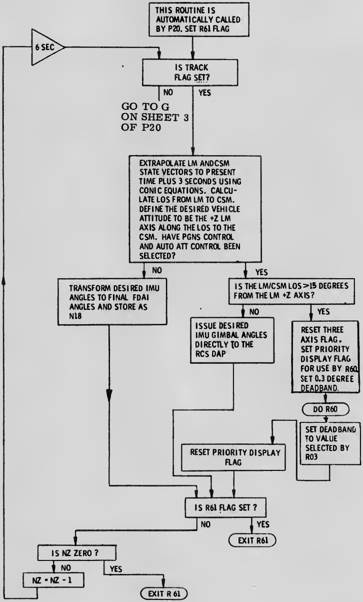


Figure 4.3.1-15. Preferred Tracking Attitude Routine (R61)

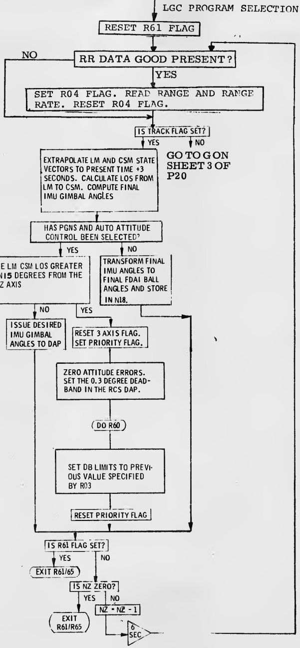


Figure 4.3.1-16. Fine Preferred Tracking Attitude Routine (R65)

TABLE 4. 3. 1- III

RENDEZVOUS NAVIGATION PROGRAM ALARMS (P20)

Alarm Code	Cause	Corrective Action
00210	ISS not on	Key V05 N09 to identify abnormality. In response to FL V37, turn on ISS and perform P51.
00220	IMU orientation unknown	Key V05 N09 to identify abnormality. In response to FL V37, enter P51.
00501	RR antenna angles are outside angle limits for valid angle measurements	R61 by keying in V32E, unless astronaut keys V56E to exit R23.
00503	R21 unable to acquire CSM	Initiate R24 (key PRO). RR antenna is thus designated in search pattern about the estimated LOS until able to acquire CSM.
00514	RR has been improperly switched out of LGC Mode when it should be supplying automatic measurements for P20	Either terminate P20 or reselect RR Auto Mode.
00515	RR CDU fail discrete present	Zero CDUs by RR mode switch or key in V40 N72. Wait at least 10 sec before clearing alarm. If alarm persists, trouble is serious.
00520	RR interrupt occurred when no request for radar data was made.	Reset alarm.
00521	Not able to obtain good radar sample as could not read radar. Occurs during R20. (No RR data good discrete present.)	Reset alarm. NOTE: P20 will try to do R21 if this occurs.
00525	Delta theta greater than 3 deg.	Key PRO for $\Delta\theta$ display in V06 N05. Accept the correction (PRO), or recycle (V32E) and take a new mark.
00526	Range between LM and CSM greater than 400 n. mi.	Wait until range is less than 400 n. mi. and V32E, or terminate P20.
00527	Desired RR LOS not within limits of either RR Mode	Vehicle maneuver required via R61.

00503 — Radar Antenna Designate fail
00514 — RR goes out of Auto Mode while in use
00515 — RR CDU fail discrete present
00520 — RADARUPT not expected at this time
00521 — Could not read radar
00525 — Delta theta greater than 3 deg
00526 — Estimated range greater than 400 n. mi.
00527 — LOS not within limits of either RR mode

The first two alarms can occur during R02, the IMU Status Check Routine. If the PROG alarm lamp illuminates, the astronaut keys in VERB 05 NOUN 09 ENTR to identify which alarm has been issued. Alarm code 00210 indicates the ISS is not on; alarm code 00220 indicates that the IMU orientation is unknown and must be aligned.

Alarm code 00501 can occur during the operation of R23. This alarm indicates that the RR antenna angles are outside the angle limits for valid angle measurements. The astronaut keys in VERB 32 ENTR to initiate R61, unless he wants to exit the routine via the Terminate Tracking Routine (R56).

Alarm code 00503 will occur if R21 is unable to acquire the CSM. The code will be displayed in one of the three registers, depending upon which other alarms are present at the time. If this alarm occurs, the astronaut should initiate R24 by keying PRO, which causes the RR antenna to be designated in a search pattern about the estimated LOS until it is able to acquire the CSM. Alternatively, a VERB 32 ENTR response will re-initiate R21.

Alarm code 00514 can occur if the RR has been switched out of the LGC Mode when P20 is operating with another program, e.g., P34. The astronaut can either terminate P20 via R56, or reselect the RR Auto Mode by again placing the RR mode control switch in the LGC position and keying PRO.

During the performance of R25, if the RR CDU fail discrete is present, alarm code 00515 will be issued. The astronaut should zero the CDUs by first exiting P20 via VERB 56 ENTR and then keying in VERB 40 NOUN 72. He should then wait at least 10 sec for completion of CDU zeroing before clearing the alarm. If the alarm persists, use of the RR is lost to the LGC and abort or backup procedures must be considered.

Alarm code 00520 indicates a radar interrupt occurred when no request for radar data was made. The astronaut should ignore alarm code 00520 unless it persists, indicating an LGC hardware problem.

Alarm code 00521 indicates the absence of the RR data good discrete, which means that the RR data cannot be read. The LGC will not use the RR data when the data good discrete is absent.

If delta theta ($\Delta\theta$ is the difference between the RR indicated LOS and the state vector indicated LOS) is greater than 3 deg during the Data Read Routine (R22), alarm code 00525 will be issued. Keying in PRO causes $\Delta\theta$ to be displayed via VERB 06 NOUN 05. The astronaut can either accept the correction by keying in PRO, or he can recycle and take a new mark.

At the beginning of P20, when the range between the LM and the CSM is computed, alarm code 00526 will be issued if the range is greater than 400 n. mi. The astronaut can either wait until the range is less than 400 n. mi. and proceed with P20 via recycle (VERB 32 ENTR), or he can exit P20 at this time via R56.

During the operation of R24, alarm code 00527 may occur, indicating that the desired RR LOS is not within the limits of either RR mode and, therefore, that a vehicle maneuver is required. The astronaut should then initiate R61 by keying in VERB 32 ENTR.

4.3.1.6 Restrictions and Limitations

The primary concern in the Rendezvous Navigation Program (P20) is the estimated relative position and velocity of one orbiting vehicle with respect to another. P20 does not attempt to solve for the inertial state vector of either vehicle. To compensate for measuring uncertainties that exist in solving for this estimated relative state vector, the following is used: a statistical weighting matrix (W-matrix) and an a-priori sensor variance (for determining how much emphasis is to be given to the measured data in updating the state vector and how much is to be given to the current estimate). Refer to subsection 4. 1, "Introduction to Coasting Flight Navigation," and to paragraph 4. 2. 1. 5, "Tracking and W-matrix Reinitialization Schedules."

4.3.1.7 Program Coordination and Procedures

The vehicle position and velocity information obtained with P20 provides the basis for the four rendezvous targeting programs, P32, P33, P34 and P35, which compute, in turn, the Δvs required for the CSI, CDH, TPI, and TPM maneuvers. Once P20 is initiated at the beginning of rendezvous, and radar lock is obtained, RR marks are processed at one-minute intervals between, and if necessary during, the targeting computations. P20 runs in the background simultaneously with the targeting routines. Radar track is broken each time a maneuver to a burn attitude is necessary and updating is inhibited while the actual targeting computations are performed. However, flashing VERB 16 NOUN 45 displays are provided at key points in each targeting program to display the number of RR marks taken at that point. If the number of marks taken is insufficient for proper targeting, the astronaut need only pause at the flashing 1645 display and P20 will resume updating at the one-mark-per-minute rate. When the requisite number of updates has occurred, the targeting computation can be resumed.

4.3.1.8 Restarts

P20 is restart-protected. Should a hardware restart occur, no crew action is required. The astronaut will note, however, that if a restart occurs after lock-on is achieved and tracking is taking place, P20 will automatically re-acquire the CSM and continue tracking. Thus, he would see the VERB 50 NOUN 72 display again.

BLANK

4.3.2 P21, Ground-track Determination —LGC

LM P21 is essentially the same as CSM P21, which is used prior to selecting lunar landmarks during orbital navigation (P22). During the nominal lunar landing and ascent, the LM position and altitude are known sufficiently not to require use of P21. Consequently, P21 LM would be used only in the unlikely case of an abort due to communications loss.

The program can be used in both earth and lunar orbit to determine the latitude, longitude, and altitude of either the LM or CSM at a time, GET, specified by the astronaut. Using the coordinate information thus obtained, landmarks suitable for marktaking in P22 orbital navigation can be chosen from maps of the lunar or terrestrial surface.

In earth or lunar orbit, P21 can be used to integrate either vehicle's state vector to a desired future time (as it is used with ground track determination); then, when the precision integration computation is finished, VERB 06 NOUN 91 can be keyed in to obtain a display of altitude, velocity, and flight-path angle of the vehicle trajectory extrapolated to the specified time.

4.3.2.1 Ground Track Determination Procedures

Table 4.3.2-I lists the displays that occur in P21. Figure 4.3.2-1 is the program flowchart.

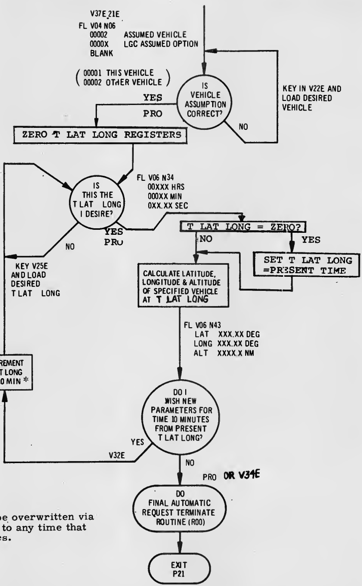
When the astronaut enters P21 via VERB 37, the program displays a 00001 code in R2, indicating the coordinates desired are for this vehicle. If so, the astronaut confirms by keying PRO. If not, the astronaut keys in VERB 22 ENTR, loads 00002 in R2, indicating the other vehicle, and then keys PRO. A flashing VERB 06 NOUN 34 display then appears with R1, R2 and R3 equal to zero. If the astronaut wants the latitude, longitude and altitude for the present time, he can key PRO. If he wants the information for another T-LAT LONG, he can key in VERB 25 ENTR, load the desired GET in R1, R2 and R3, and then key PRO. (Refer to Table 4.3.2-I.)

The LGC extrapolates the desired vehicle state vector to T-LAT LONG using precision integration, computes the corresponding altitude, and displays the result in the flashing VERB 06 NOUN 43 display. A PRO response to the LAT LONG ALT display terminates P21; a VERB 32 ENTR (recycle) response causes the program to increment the previous GET by 10 minutes and return to the flashing VERB 06 NOUN 34 to display it. A PRO will then recompute the vehicle coordinates for the

TABLE 4.3.2-I

P21-GROUND TRACK DETERMINATION PROCEDURES

DSKY	Register	Comments
V37 E21 E	DSKY P21	Only requirement for P21 is an up-to-date state vector. ISS not required.
FL V04 N06	R1 00002 R2 00001 R3 Blank	Vehicle code in R1 00002 for LM R2 00001 indicates this vehicle. May be changed to R2 00002 to indicate other vehicle. PRO if correct; V22E will permit R2 to be changed. Do not key V82E during this display.
FL V06 N34	R1 ooxxx. hr R2 oooxx. min R3 oxx.xx sec	Request load GET for lat-long desired in hours, minutes and seconds to nearest 0.01 sec. For present time set R1, R2, and R3 to all zeros. PRO to compute LAT-LONG for specified GET; key V25E to change time.
FL V06 N43	R1 xxx.xx deg R2 xxx.xx deg R3 xxxx.x n.mi.	Program displays vehicle latitude and longitude in degrees to nearest 0.01 deg in R1 and R2 (+ is North and + East, respectively) for specified GET. R3 contains altitude in nautical miles to nearest 0.1 n.mi. measured from launch pad radius (earth) or latest landing site radius (moon). V32E increments T LAT-LONG GET initially specified by 10 minutes, recycles to V06 N34 display. T LAT-LONG may then be overwritten via V25E to any desired time.
FL V37		PRO terminates P21.
V06 N91	R1 xxxxB n.mi. R2 xxxxx. fps R3 xxx.xx deg	Altitude to nearest 10 n.mi. Inertial velocity to nearest 1 fps. Flight path angle to nearest 0.01 degree. This display may be obtained in P21 any time after integration is complete.



*May be overwritten via V25E to any time that applies.

Figure 4. 3. 2-1. Ground-track Determination Program (P21)

new, 10-minute later T-LAT LONG. Successive VERB 32 ENTRs produce a series of LAT LONG ALT values for successive 10-minute intervals, one for each VERB 32 ENTR recycle keyed in.

4.3.2.2 Orbital Parameters

The astronaut can key in the VERB 06 NOUN 91 orbital parameters display during P21 after the precision integration extrapolation is complete (when the LGC CMPTR ACTY light goes out) and obtain vehicle altitude h, velocity v, and flight path angle for the time specified in NOUN 34. This display can be used after DOI, before CSI, and during abort trajectories to monitor orbital parameters. Alternatively, the VERB 82 orbital parameters display (see paragraph 4.2.4) can be called after the latitude-longitude-altitude display; i.e., after state-vector integration is complete. VERB 82 displays apogee and perigee height and time of free fall; this trajectory information supplements NOUN 91.

4.3.2.3 Alarms

The only alarm in P21 is the 20430 acceleration-overflow-in-integration alarm, which occurs when a register summing acceleration overflows during orbital integration. The 20430 alarm is always triggered well below the lunar surface. Consequently, although a 20430 alarm invariably signals an impact trajectory, the converse is not true; i.e., the absence of a 20430 alarm does not guarantee a trajectory to be safe.

4.3.2.4 Restrictions and Limitations

The only use presently envisioned for P21 LM is during off-nominal aborts. For reasons stated above, the 20430 alarm should never be depended upon as a GO/NO-GO test for impact trajectory. The orbital parameters (VERB 82), rendezvous parameters (VERB 83) and the VERB 06 NOUN 91 displays must be used instead. (Refer to Table 4.3.2-I.)

4.3.2.5 Restarts

P21 is not restart-protected. Should a restart occur, the crew would have to re-initiate the program.

4.3.3 P22, Lunar-surface Navigation-LGC

The Lunar Surface Navigation Program is used to perform the following:

a. To control the rendezvous radar (RR) to acquire and track the CSM while the LM is on the lunar surface

b. To update the CSM state vector on the basis of R and $\dot{R}$ tracking data from the RR

c. To track the CSM without updating its onboard state vector while the resulting RR data is downlinked for use in ground computation of the CSM state vector.

Currently authorized use of P22 includes LGC control of the RR to acquire, track and obtain R and $\dot{R}$ data in the no-update mode. That is, data are not processed onboard and incorporated to update the CSM state (b above), but are downlinked (a and c). In case of communication failure, a plane-change option in P22 can be used to compensate the onboard CSM state for precession of the CSM orbit, but no updates will be made.

Figure 4.3.3-1 shows the significant events in a typical Lunar Surface Navigation timeline plotted on a diagram of LM-CSM geometry during a 60-n. mi. orbital overpass. Times are measured from the instant the CSM comes within 400 n. mi. of the landing site. (Range is computed by the program using the onboard estimate of the CSM state vector. Ranges and times are, therefore, nominal, i. e., uncertain by 2 to 3 n. mi. and 2 to 3 seconds.)

Table 4.3.3-I gives the time, information displayed, R, $\dot{R}$, θ (elevation angle), and $\dot{\theta}$ for the key events in the P22 sequence.

P22 operation occurs in three consecutive phases: the pre-designate, designate and measurement phases. During the pre-designate phase, the program computes an RR acquisition angle and drives the RR antenna to it to await the CSM. At the predicted CSM arrival time, the LGC designates the RR, causing it to track the CSM estimated position, while the RR acquires (i.e., achieves auto-track of the radio frequency return from the CSM transponder). This effectively fulfills purpose a, above.

The designate phase ends and the measurement phase begins when the RR achieves lock and issues the data-good discrete. (Acquisition may occur as quickly as 5 sec but must occur within 42 sec, or a designate fail alarm is returned.) After RR

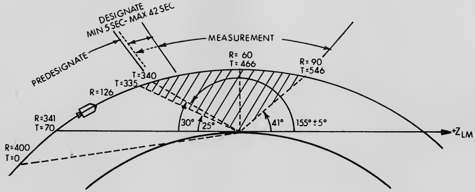


Figure 4. 3. 3-1. Typical Lunar-surface Navigation Geometry, Event Times and Ranges

TABLE 4. 3. 3-I

LUNAR-SURFACE NAVIGATION EVENT TIMES, DISPLAYS AND PARAMETERS

T (sec)	Event	Display	R (n. mi.)	$\dot{R}$ (fps)	θ	$\dot{\theta}$
					(deg)	(deg/ sec)
20	CSM R > 400 n.mi.	V16 N54 if in P22	>400			
0	CSM at 400 n. mi., enter P22	(V83 optional)	400			
15	R21 designates RR to center Mode 2	V16 N56, X-pointers				
70	CSM on horizon		341	-5021	0	0.05
110	R26 designates RR to Mode 2 limit	V16 N56, X-pointers				
335	CSM enters Mode 2 limit	X-pointers, V16 N56	126	-4551	25	0.21
340	RR acquires CSM	No track light				
466	CSM overhead	V85, V16 N56	60	0	90	0.84
546	CSM out of limits	NO TRACK light, X-pointers	90	+3867	41	0.38

lock, the program processes radar R and $\dot{R}$ data onboard (b) or downlinks it (c) for ground computation, until the farther limit of the marktaking window is reached.

RR Angle Display Coordinates

The shaded area in Figure 4.3.3-1 corresponds to the RR Mode 2 shaft limits shown in Figure 4.3.3-2 and in Figure 4.3.3-3. RR antenna direction is often specified by the LOS elevation angle above the horizontal (θ, in Table 4.3.3-I) but RR shaft and trunnion angles are displayed according to two different conventions.

The CSM approaches from the $-Z_{LM}$ direction and Figure 4.3.3-1 shows RR LOS angles measured from the $+Z_{LM}$-axis as displayed in VERB 16 NOUN 56 obtained via VERB 85. The RR Mode 2 LOS limits using VERB 85 range between +155 deg at the Mode 2 acquisition limit (25 deg elevation) and 41 deg at the far bound of Mode 2. Figure 4.3.3-3 shows the corresponding RR shaft angles as displayed in VERB 16 NOUN 72. The RR reference position is boresighted down the $+Z_{LM}$ axis, so the RR trunnion must turn 180 deg and then the shaft must rotate -25 deg to attain the +25 deg LOS elevation angle at the acquisition mode limit. The shaft angles are displayed positive in VERB 16 NOUN 72 and, therefore, range from 330 deg, ±5 deg at acquisition, to +220 deg at the far mode limit. The Mode 2 center is 180 deg trunnion, and 270 deg shaft in VERB 16 NOUN 72; 0 deg trunnion and 90 deg shaft in VERB 85. (Refer to Figure 4.3.3-3.)

4.3.3.1 Geometry and Timing

Table 4.3.3-I gives the times, measured in seconds from 400 n. mi., for the significant events in P22 when the LM is on the lunar surface and the CSM is orbiting at 60 n. mi.

Significant events in the acquisition sequence noted in Table 4.3.3-I are as follows:

a. The point, approximately 7-3/4 minutes (466 sec) before the zenith, where the CSM comes within the 400-n. mi. maximum range of the LM RR (T = 0 when R = 400 n. mi.). Initiation of pre-designate when the CSM is farther than 400 n. mi. causes an alarm.

b. The point, 70 seconds later, where the CSM crosses the landing site local horizontal (simultaneously with the spacecraft +Z-axis if the spacecraft is level, otherwise modified by the angle the spacecraft Z-axis is inclined to the landing site horizontal).

c. The time when the RR is designated just inside the Mode 2 limit.

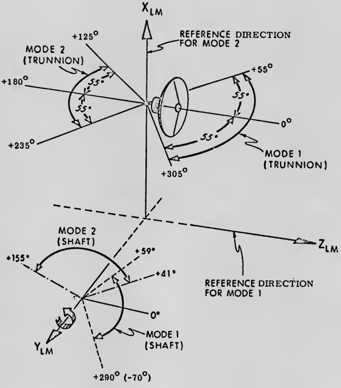
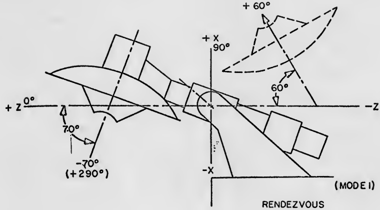
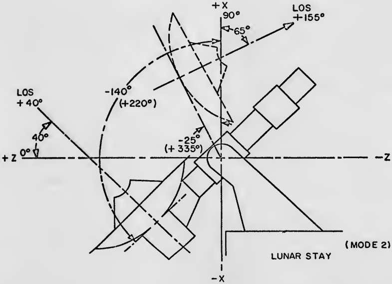


Figure 4. 3. 3-2. RR Antenna Shaft and Trunnion LOS Tracking Regions



(MODE I)

RENDEZVOUS



(MODE 2)

LUNAR STAY

Figure 4. 3. 3-3. RR Antenna Modes of Operation

d. The shaft angle at which the CSM enters the RR Mode 2 coverage, nominally 155 deg and 335 sec after T = 0, also varies by the angle between the spacecraft Z-axis and the local horizontal. A 5-deg tilt of the spacecraft Z-axis toward the CSM will cause acquisition to occur 23 n. mi. farther and 28 seconds earlier than nominal, so that minor variations in spacecraft attitude may have significant effects on the timing of acquisition and marktaking windows. Procedures for designating the RR, and monitoring the track acquisition and lock-up phases are discussed below.

The designate phase lasts 42 seconds, during which the LGC points the RR at the moving CSM while the radar attempts to automatically track and lock on the return from the CSM transponder. The CSM enters the RR Mode 2 antenna limit 131 seconds before the zenith and exits 80 seconds after, requiring a total of 211 seconds to traverse the entire Mode 2 marktaking window. Ten to fifteen seconds are required for the RR to obtain lock, and up to ten seconds to provide a margin at the acquisition window. Thirteen seconds are required to process each set of mark data in the onboard update case.

In the no-update case, R and $\dot{R}$ marks are obtained from the RR approximately every 3-1/2 seconds. Forty to 60 marks are, therefore, obtained and processed per pass—using downlink and ground processing—compared to the 10 to 15 that would be processed onboard if onboard updates were used.

4.3.3.2 Mission Situation and Operational Context

In the no-update case, P22 is used once on the first CSM orbital overpass after LM touchdown and again one or more orbits before launch to ensure that the launch site lies in the CSM orbital plane. The CSM Orbital Plane Change Routine in P22, at the astronaut's option, will compute the amount of the plane change required to rotate the estimated CSM orbital plane so that it contains the landing site. The plane change option is prescribed in case of communication loss to compensate for precession. The plane change computation requires that the astronaut input the launch time, which establishes the CSM position vector at launch; the CSM position vector is then rotated 90 deg retrograde to fix the point at which the plane change is performed. (See Figure 4.3.3-4.)

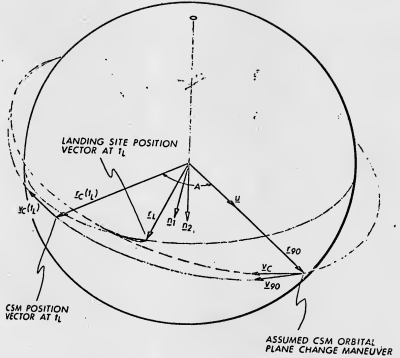


Figure 4.3.3-4. RR Lunar-surface Navigation CSM Orbital Plane Change Estimation

4.3.3.3 Nominal Operating Sequence

4.3.3.3.1 Acquisition.—After the result of the plane change (if any) is incorporated into the CSM state, the program checks the IMU status and conditions a number of flags required subsequently by various subroutines.* It then computes the LOS from the LM to the CSM to determine if its range is less than 400 n. mi. If not, the program issues a VERB 16 NOUN 54, with the onboard estimates of R and $\dot{R}$ displayed in R1 and R2 which are updated every 6 seconds until the range is less than 400 n.mi.

The program next checks to ensure that the RR auto mode discrete is present (i.e., that the RR mode switch is in the LGC position). If it is not, the program requests, via a VERB 50 NOUN 25 display on the DSKY, that the astronaut switch the radar to LGC. The RR Monitor Routine, R25, is called every 0.48 second, when the LGC is on, by the T4RUPT utility program to monitor the RR auto mode discrete, the RR CDU fail discrete, and the angular excursion of the RR antenna relative to the mode limits. R25 conditions various flags to ensure proper RR functioning when the RR auto mode discrete is first received as a result of placing the RR mode switch in the LGC position. The routine alters the status of these flags appropriately if the switch position is changed. If there is a CDU failure while the RR auto mode discrete is present, R25 turns on the PROG alarm light and the TRACKER fail light (on the DSKY) and stores the CDU fail alarm code (00515).

With the RR in the LGC mode and the RR auto mode discrete present, the program next checks the TRACK and RENDEZVOUS flags and performs a precision update of the LM and CSM permanent state vectors immediately before entering the RR Designate Routine, R21. (The time required to cycle through the Kepler subroutine, which is used repeatedly during the designation process, is a function of state vector age.) R21 computes the LOS from the LM to the CSM (LOS_{LC}) and determines if the LOS_{LC} is within the Mode 2 limit. If the LOS_{LC} is outside Mode 2, RR designation and acquisition obviously cannot take place, and program control is transferred to R26, the Pre-Designate Routine. R26 is designed to extrapolate the estimated CSM orbital path until it intercepts the antenna mode limit, thereby determining the vector to which the RR should be designated to achieve earliest possible acquisition. R26 extrapolates the LM onboard estimate of the CSM state vector in 10-second increments from the time R26 is entered (effectively the time when the astronaut keyed his response to the preceding plane-change display). A capability for sixty 10-second increments is provided in R26, and the last 10-second increment will, on the average, fall 5 seconds inside the Mode limit (hence the 150 deg ±5 deg angle for the start of

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* Refer to flowcharts, Figures 4.3.3-6 through 4.3.3-12.

designate). Having computed the earliest feasible LOS_{LC} for radar acquisition, R26 designates the RR CDUs continuously to that (static) acquisition angle until present time equals the predicted T_{LOS}. When $T = T_{LOS}$, R26 returns control to R21, which initiates the actual designation process (LGC-controlled RR tracking of the CSM) during which the RR should acquire, i.e., track and lock-on, the RF return from the CSM transponder.

R21 issues rate commands to the RR proportional to the difference between the current RR LOS and the RR LOS computed for one second ahead. When the RR LOS comes within 1/2 deg of the computed LOS_{LC}, the LGC issues the auto track enable discrete to the RR. R21 continues to designate rate commands to the RR until the data·good discrete is received from the RR or until 60 commands have been issued—which requires a maximum of 42 seconds.

The astronaut should have the RR shaft and trunnion angles displayed to him via VERB 85 (VERB 16 NOUN 72), and the shaft and trunnion rates displayed to him by the X-pointer on the RR panel. By monitoring the RR shaft angle in the VERB 16 NOUN 56 display of VERB 85 he can determine when the RR has been driven to the (static) pre-designate angle (150 deg ±5 deg) by R26, and by observing the trunnion rate transient at T_{LOS}, he will obtain an indication of when R21 begins RR designate.

4.3.3.3.2 Rendezvous Radar.—In the nominal case, the SIGNAL STRENGTH meter on the RR panel indicates the presence of an RF return and the NO TRACK light (on the RADAR panel) should go out within 5 to 10 seconds, indicating the presence of the data good discrete.

The data good discrete is issued by the RR when its range rate ($\dot{R}$) loop achieves lock, whereupon its angle track loop is closed simultaneously. If the RR fails to obtain $\dot{R}$ lock (data good present) within 45 seconds, a 00503 alarm signifying that RR is unable to acquire is issued. The astronaut can respond by either re-establishing the designate process or initiating RR search. The RR beamwidth (Figure 4.3.3-5) is sufficiently wide (3.3 deg) relative to target position uncertainty, that acquisition should consistently occur early in the designation phase; if it has not occurred after 45 seconds, a gross error in the LGC CSM state probably exists. This indicates that further designation is useless and the search option response is appropriate.

4.3.3.3.3 Data Read Options: Downlink or Onboard Update.—Upon receipt of the data good discrete, R22, the Data Read Routine, is called; this routine, in turn, calls R20. R20 begins to sample the R and $\dot{R}$ data supplied by the RR and processed by R22. If the data good discrete is lost, the NO TRACK light (on the RADAR panel)

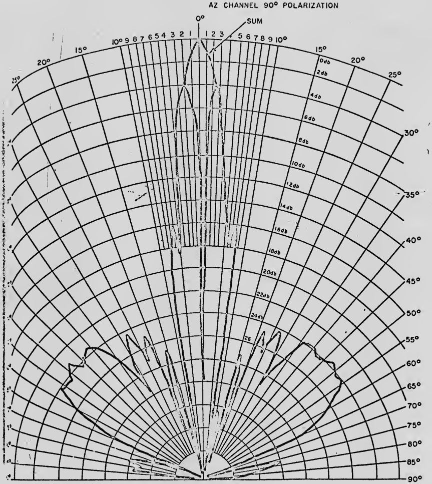


Figure 4. 3. 3-5. RR Lobe Pattern; Azimuth Channel AA-20

will go out, and, if the data sample is incomplete, the PROG light will light and a 00521 alarm (good radar sample not obtained) will result.

In the no update mode [when VERB 95 ENTR (see Table 4.3.3-IV) has been used to set the NO UPDATE flag)] a complete set of RR data, consisting of R, $\dot{R}$, and RR CDU angles, is read approximately every 3.5 seconds. The downlink list cycles every 2 seconds so that 30 or more RR measurements can be incorporated into ground computations on each CSM orbit.

After each RR mark, a 3-deg check is performed in R22; this check determines whether the RR LOS is within 3 deg of the CSM LOS computed from the state vector. A 00525 alarm is displayed if the angular difference is more than 3 deg. The alarm permits the astronaut to verify and correct an RR sidelobe lock condition during rendezvous. However, when navigation marks are being taken, with P22, on the lunar surface, no time is available to correct sidelobe lock and the astronaut should key PRO in response to the 00525 alarm and to the VERB 06 NOUN 05 $\Delta\theta$ display, in both the update and no-update modes. A 2-second priority hold is necessary before the first PRO response to the 00525 alarm. (Details of the appropriate procedure to follow are discussed in 4.3.3.5, below.)

In the nominal onboard update case, the program performs a threshold test on the R and $\dot{R}$ component of each RR mark before incorporating the result. If the magnitude of the update is excessive, it is displayed via VERB 06 NOUN 49 to the astronaut for an accept/reject decision. If the magnitude of the update is within limits, it is incorporated automatically. At present, a zero W-matrix is used to ensure no-update operation.

4.3.3.4 Program Operational Details

4.3.3.4.1 P22 Procedures.—Figure 4.3.3-6 is a flowchart showing the sequence of program and DSKY activity in P22. Table 4.3.3-II sums the DSKY displays. In the majority of cases in the initial VERB 04 NOUN 06 display, 00001 is usually loaded in R2. In the no-update use of P22, a good CSM state vector will be uplinked from the ground shortly before liftoff, which will incorporate the result of any plane change. Should a communication loss occur, relatively little time would elapse (2 orbits maximum) before launch. For the essentially equatorial CSM orbits used through APOLLO 14, the change in the plane of the CSM orbit is negligible. For later missions with significant orbital declination, the plane of the CSM orbit will precess and the plane-change option is authorized to compensate.

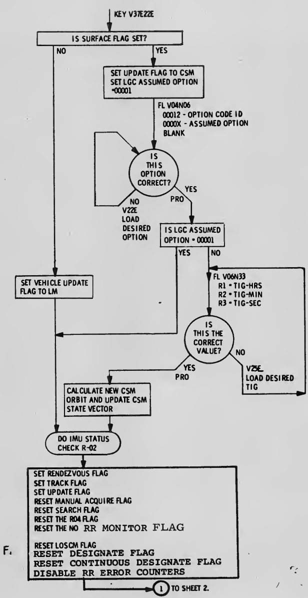


Figure 4.3.3-6. Lunar-surface Navigation Program (P22) (Sheet 1 of 3)

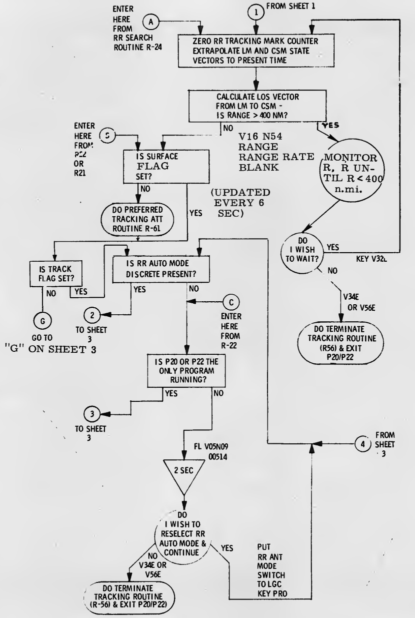


Figure 4.3.3-6. Lunar-surface Navigation Program (P22) (Sheet 2 of 3)

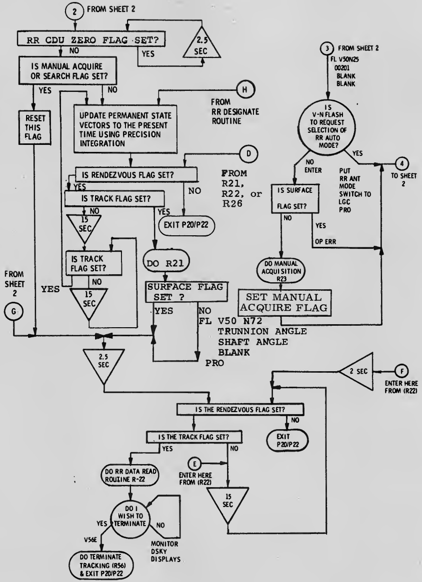


Figure 4. 3. 3-6. Lunar-surface Navigation Program (P22) (Sheet 3 of 3)

TABLE 4. 3. 3-II
REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LUNAR-SURFACE NAVIGATION (SHEET 1 OF 2)

DSKY	By	Purpose	Registers	Remarks
Key V37 E 22E	P22	Enter P22		
FL V04 N06	P22	CSM plane change	R1 00012 R2 oooox	R2=00001 CSM will not change plane. R2=00002 CSM will change plane. PRO if correct, V22E to reload R2.
FL V06 N33	P22	t_{IG} launch GET	R1 xxxxx hrs R2 xxxxx min R3 xxx. xx sec	PRO if correct, V25E to reload t_{IG}
PROG alarm light V05 N09	R02	IMU status unsatisfactory	R1 xxxxx R2 xxxxx R3 xxxxx	Rx = 00210 means IMU not on; Rx = 00220 means IMU not aligned. May appear in either R1, R2 or R3
PROG alarm light Key FLV05 N09	P22	CSM range greater than 400 n. mi.	R1 xxxxx R2 xxxxx R3 xxxxx	Alarm code 00526 may appear in R1, R2, or R3 depending on presence of other alarms; wait and key in V32E to recycle; V34E or V56E to terminate.
FL V50 N25	P22	RR Antenna mode switch not in LGC position	R1 00201 R2 Blank R3 Blank	RR Auto Mode discrete absent. Do not key in ENTR; put RR Antenna Mode switch in LGC position and key PRO.
PROG alarm FL V05 N09	R26	10 minute pre-designate mode entry search limit exceeded.	R1 xxxxx R2 xxxxx R3 xxxxx	Alarm code 00530; ordinarily will not occur since R>400 n. mi. test in P22 (no 00526 alarm) ensures less than 8 minutes of pre-designate time
PROG alarm light FL V05 N09	R21	00503 alarm = RR designate fail	R1 xxxxx R2 xxxxx R3 xxxxx	Alarm code 00503 may appear in R1, R2, or R3 depending on other alarms present. V32E will reinitiate RR Designate (R21). PRO will start R24 the RR Search routine. V34E and V56E will terminate.
PROG alarm light Key V05 N09	R20	00520 alarm = radar sample, request error or no R04; 00521 alarm = good radar sample not obtained	R1 xxxxx R2 xxxxx R3 xxxxx	Alarms not displayed until astronaut keys V05 N09 to verify PROG. NO TRACK light will accompany 00521 alarm. These alarms are likely to occur in combination with others.

TABLE 4. 3. 3-II

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LUNAR SURFACE NAVIGATION (SHEET 2 OF 2)

DSKY	By	Purpose	Registers	Remarks
PROG alarm FL V05 N09	R22	00525 alarm = delta theta (the difference between the RR LOS and the LOS computed from the CSM state vector) is greater than 3°.	R1 xxxxx R2 xxxxx R3 xxxxx	Indicates possible sidelobe lock, keying PRO will display delta theta magnitude; V34E or V56E will terminate P22
FL V06 N05	R22	Size of delta theta will indicate which side lobe ($\eta[3^{\circ}]$ first side lobe, etc.)	R1 xxx. xx R2 Blank R3 Blank	PRO response will incorporate data despite sidelobe lock V34E and V56E will terminate. V32E will reject mark and take another.
FL V06 N49	R22	ΔR to nearest 0. 1 n.mi. $\Delta \underline{v}$ to nearest 0. 1 fps. Source code 1 = range 2 = range rate	R1 xxxx. x R2 xxxx. x R3 oooox	Marks are incorporated by Keying PRO. Keying V32E will process next measurement. V34E will reject current mark and take another.
FL V16 N80	R24	Permits RR search to be monitored in progress	R1 xxxxx R2 xxx. xx R3 Blank	R1: 00000=RR Data Good discrete absent, 11111=RR Data Good discrete present. R2: Omega=Angle between CSM LOS and LM+Z-axis to nearest . 01°. Recycle (V32E) will reinitiate search; V34E or V56E will terminate P22; PRO will go to R20 then R22.
PROG alarm Key V05 N09 to verify	R24	Desired target LOS not within RR Mode 2 limits.	R1 xxxxx R2 xxxxx R3 xxxxx	00527 alarm = search pattern outside RR mode limits; may appear in any register with other alarms. V34E or V56E to terminate P22.
PROG alarm Key V05 N09; possible NO TRACK light.	R25	CDU fail	R1 xxxxx R2 xxxxx R3 xxxxx	00515 alarm = CDU failure NO TRACK light indicates data good lost. KEY REL and RSET to reset alarm.

If a plane change is specified in the flight plan, the corresponding launch time is input by the astronaut and the resulting orbital change is incorporated into the CSM state by the program. The program next performs the IMU Status Check, R02, which can return two alarms (IMU not on, IMU not aligned), both extremely unlikely. After R02, P22 initializes the necessary flags, briefly described in Table 4.3.3-III. The program sets the UPDATE, TRACK, and RENDEZVOUS flags and resets the SEARCH, MANUAL ACQUIRE, R04, NO RR MONITOR, LOSCM, DESIGNATE and CONTINUOUS DESIGNATE flags. The explanations given in Table 4.3.3-III are largely sufficient. Tracking and marktaking are allowed. The RR is to be operated in the Auto, not in the Manual mode. The 00521 alarm signifying failure to read RR data—which is inhibited while R04 tests the radar—is allowed. R25 (RR Monitor) is enabled and the LOS to the CSM computation disabled. RR designate (which points the RR) is inhibited along with continuous designate (which designates the RR but inhibits RR lock).

The program then zeros the RR tracking mark counter and disables the RR error counter. Next the LM and CSM state vectors are extrapolated to the present time for the 400-n. mi. check. If the flashing VERB 05 NOUN 09 display and 00526 PROG alarm occur, signifying the CSM is beyond RR range, the astronaut waits and then keys in VERB 32 ENTR. P22 next checks to see if the RR antenna mode switch is in the LGC position, returning a flashing VERB 50 NOUN 25 and 00201 Checklist code if it is not. Repositioning the antenna mode switch to LGC and keying PRO will ensure the presence of the auto mode discrete.

After ensuring that the CDUs are not being zeroed, and that the MANUAL and SEARCH flags are not set, P22 updates the LM and CSM state vectors to the present time, using precision integration, before entering R21, the Designate Routine.

4.3.3.4.2 RR Designate Routine (R21) and Pre-Designate Routine (R26).—R21 (Figure 4.3.3-7) first removes the RR auto track enable discrete, until designation is accomplished. Next, the routine selects CDU gimbal angles corresponding to the center of the Mode 2 antenna coverage and commands them to the RR, which drives the antenna to the center of Mode 2. R21 then sets the RR designate counter, which allows 60 designate passes (45 seconds) for the RR to obtain lock. The routine then sets the LOSCM flag for use in the designation process. The counter N, set to 3 in R21, causes the LOS from the LM to the CSM (LOS_{LC}) to be computed every fourth designate pass. The LOS_{LC} is computed 0.5 sec in the future and compared with the Mode 2 limits. Since the program is normally entered 5 minutes before CPA—well before the CSM reaches the RR mode limit—R21 exits at this point to R26, the Pre-Designate Routine, which computes the RR LOS vector at which the CSM will enter the Mode 2 limit.

TABLE 4. 3. 3- III

FLAGS USED IN P22

Flag Name	Set	Reset
UPDATE	SV updating by RR marks allowed	SV updating by RR marks not allowed
TRACK	Tracking allowed	Tracking not allowed
RENDEZVOUS	P20 or P22 running	P20 or P22 not running
SEARCH	RR in auto search	RR not in auto search
MANUAL ACQUIRE	RR manual acquire	RR auto acquire
R04	Alarm 00521 inhibited	Alarm 00521 allowed
NO RR MONITOR	Bypass RR monitor	Perform RR monitor
LOSCM	LOS being computed	LOS not being computed
DESIGNATE	RR designate requested	RR designate not requested or in progress
CONTINUOUS DESIGNATE	LGC commands RR without lock-on	LGC checks for lock-on
LOCK-ON	RR lock-on desired	RR lock-on not desired
RANGE SCALE	Scale change during LR/RR	No scale change during LR/RR

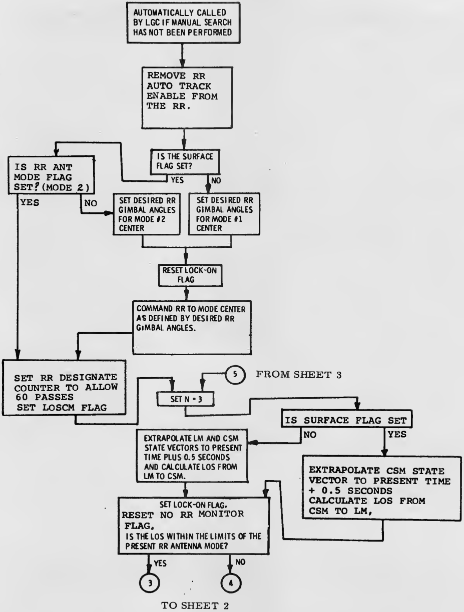


Figure 4.3.3-7. RR Designate Routine (R21)(Sheet 1 of 3)

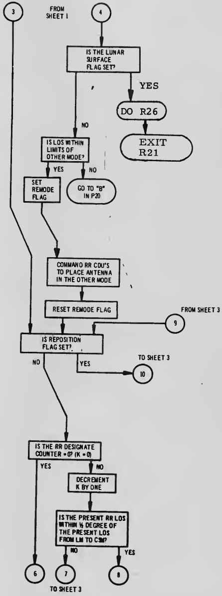


Figure 4.3.3-7. RR Designate Routine (R21)(Sheet 2 of 3)

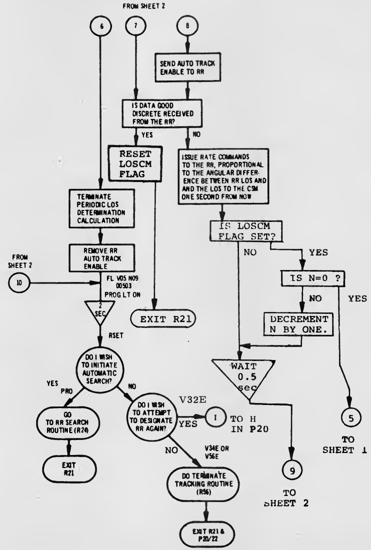


Figure 4.3.3-7. RR Designate Routine (R21)(Sheet 3 of 3)

R26 (Figure 4.3.3-8) computes the optimum orientation for acquisition within Mode 2 and continuously designates the RR to that orientation until the predicted entry time arrives, when it returns control to R21 for the actual designation. R21 then issues rate commands (Figure 4.3.3-7, Sheet 3) proportional to the difference between the present RR LOS and the computed LOS for one second in the future. The LGC continues to designate rate commands until the RR LOS comes within 0.5 deg, at which time the track enable discrete is issued to the RR by the LGC. When the RR achieves radar lock-on, it returns the data good discrete to the LGC. If the RR fails to acquire within 45 seconds (60 passes) the designation process stops and a flashing VERB 05 NOUN 09 PROG alarm light is issued, signifying that the RR is unable to acquire (alarm code 00503). The astronaut normally keys PRO in response, and R24, the RR Search Routine, begins.

When the RR acquires, it issues the data good discrete, which causes control to be returned to P22 from R21, and the Data Read Routine R22, to be entered.

4.3.3.4.3 Data Read Routine (R22) and LR/RR Read Routine (R20).—The Data Read Routine first checks several flags, returning to points earlier in the program if any are not properly set or reset. R22 sets a sample number, a sample limit and appropriate channel bits which cause R20 to sample first range-rate then range from the RR. Refer to Figures 4.3.3-9 and -10.

Several types of exit are possible from R20. Normally, R22 calls R20 once to obtain RR $\dot{R}$, then reads the 3 ISS CDU angles, the present time, and the 2 RR CDU angles and calls R20 again to obtain RR range. If the data good discrete is present during R20 data read, R22 will proceed to perform a 3-deg check before incorporating the measurement data. If the data good discrete is lost, R20 will cause the TRACKER light and the PROG alarm lights to illuminate and a 00521 alarm to be stored. When this happens, the program re-enters the Designate Routine automatically and attempts to re-acquire. In the case of CDU failure, R25 lights the TRACKER and PROG lights and stores a 00515 alarm.

When the RR reaches the far mode limit of the marktaking window, the antenna is commanded to the mode reference position and the RR track enable discrete removed by R25, the RR Monitor Routine (Figure 4.3.3-11). The RR will immediately lose lock and remove the data good discrete, lighting the NO TRACK light on the RADAR panel. On the next pass, R22 will find track enable missing and return to R21 and from there to R26 where, after approximately one minute to perform sixty 10-sec CSM increments, a 00526 alarm should occur.

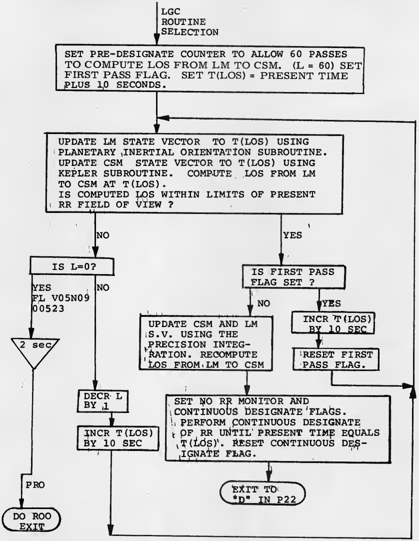


Figure 4. 3. 3-8. Lunar Surface RR Predesignate Routine (R26)

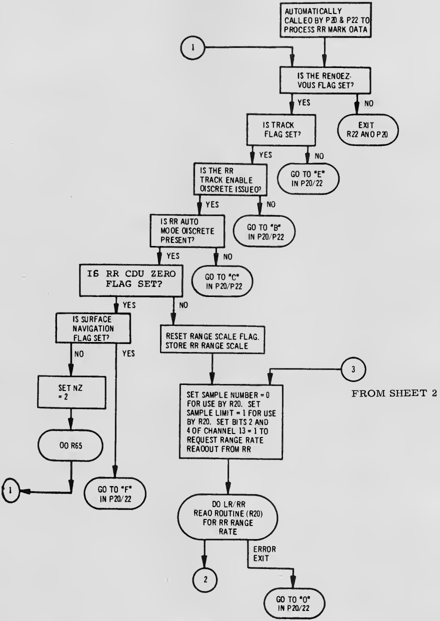


Figure 4.3.3-9. RR Data Read Routine (R22)(Sheet 1 of 4)

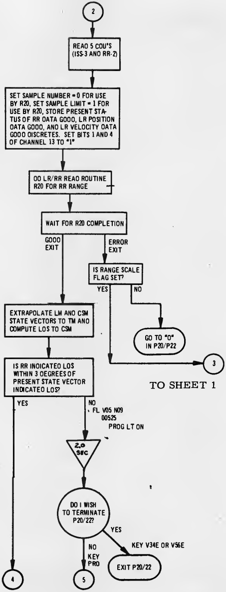


Figure 4.3.3-9. RR Data Read Routine (R22)(Sheet 2 of 4)

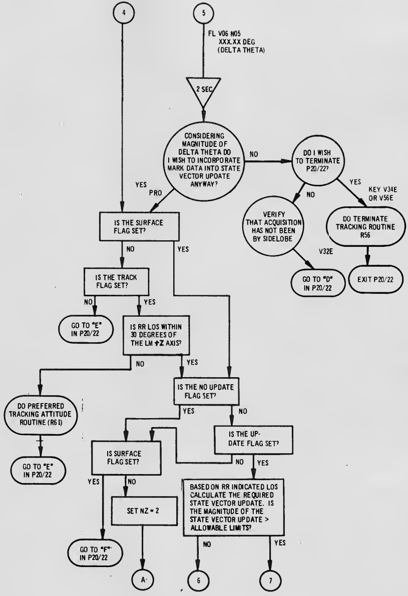


Figure 4.3.3-9. RR Data Read Routine (R22)(Sheet 3 of 4)

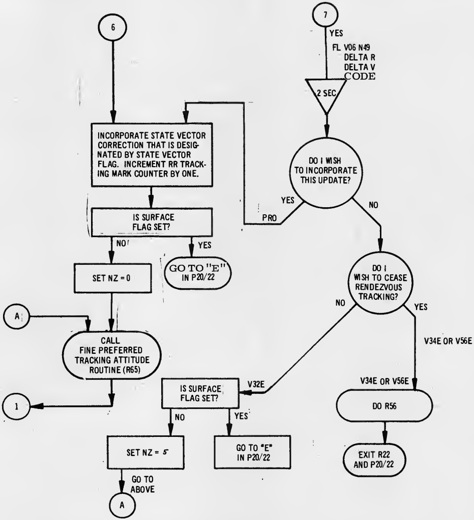
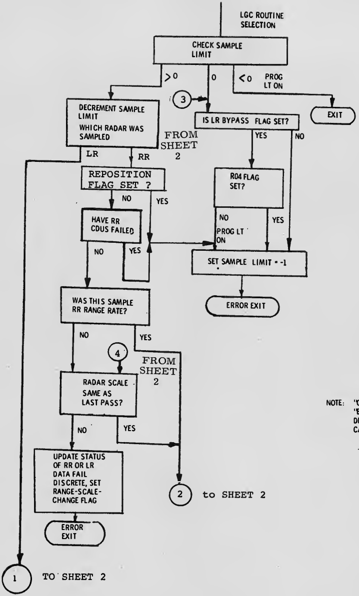


Figure 4.3.3-9. RR Data Read Routine (R22)(Sheet 4 of 4)



NOTE: "GOOD EXIT" AND "ERROR EXIT" ARE DEFINED IN THE CALLING LGC ROUTINE

Figure 4.3.3-10. LR/RR Read Routine (R20) (Sheet 1 of 2)

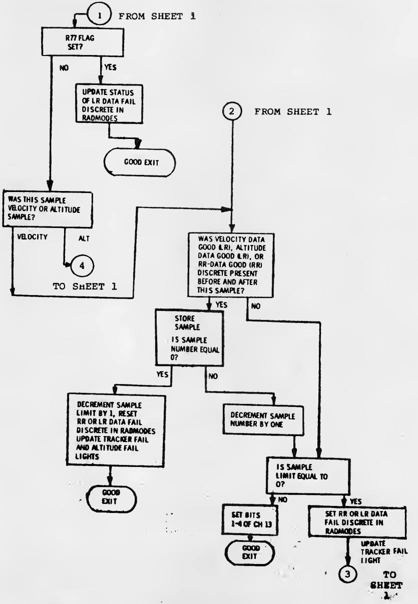


Figure 4.3.3-10. LR/RR Read Routine (R20)(Sheet 2 of 2)

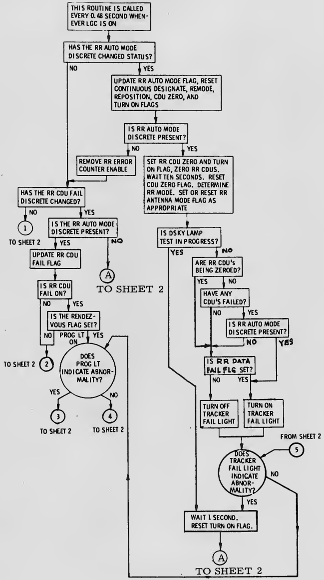


Figure 4.3.3-11. Monitor Routine (R25) (Sheet 1 of 2)

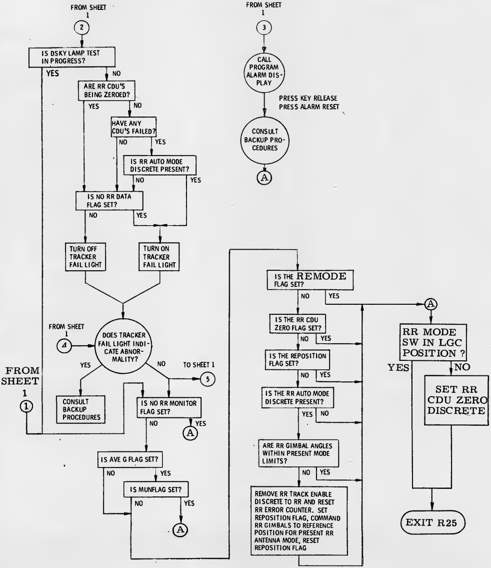


Figure 4.3.3-11. Monitor Routine (R25) (Sheet 2 of 2)

In the nominal onboard update case, the CSM state computed onboard will be within 3 deg (approximately 3 n. mi.) of the actual RR-CSM track—unless the radar has achieved lockup on a sidelobe, which is what the 3-deg check is for. In the no update case, the indicated RR CSM LOS may be more than 3 deg from the LGC-computed LOS. The procedure in both cases is to key two PRO responses in succession, each after a 2-sec priority delay. In the nominal case, there is insufficient time to correct a sidelobe lock condition and the R and $\dot{R}$ data are equally valid—whether acquired via the mainlobe or a sidelobe. In the no update case, the 3-deg check is irrelevant and the astronaut's only concern is to resume taking RR marks as quickly as possible after the 3-deg check. In the no update case, R22 checks the NO UPDATE and UPDATE flags and returns immediately for the next mark.

In the nominal onboard update case, the program calls INCORP1 to compute the ΔR and Δv resulting from the measurements just read and checks them against a threshold value. If they are below the threshold, they are automatically incorporated and the program returns for the next mark. If ΔR or Δv exceed the threshold, then they are displayed via a flashing VERB 06 NOUN 49 display, along with a source code (R3 = 1 or 2 for R, $\dot{R}$, respectively), for the astronaut's accept or reject decision. Following a PRO response, which causes the mark to be accepted, the program returns for the next RR mark. A VERB 32 ENTR response to the NOUN 49 display will cause the last measurement component to be rejected and the next measurement component to be processed after a 15-sec delay. Keying in VERB 34 ENTR will reject all measurement components and exit P22 after a 15-sec delay. Keying in VERB 56 ENTR will terminate P22.

4.3.3.4.4 RR Search Routine.—If the RR fails to acquire after 45 seconds, the astronaut can initiate the RR Search Routine (Figure 4.3.3-12) by keying a PRO response to the flashing VERB 05 NOUN 09, 00503 PROG alarm. R24 causes the RR to search a 6-sided pattern (Figure 4.3.3-13), which subtends 3.25 deg on each side. Six seconds are spent at the LOS initially designated and six are required to search each side for a total of 42 seconds for the entire search pattern.

4.3.3.5 Summary of Alarms and Displays

The following are the alarms associated with P22.

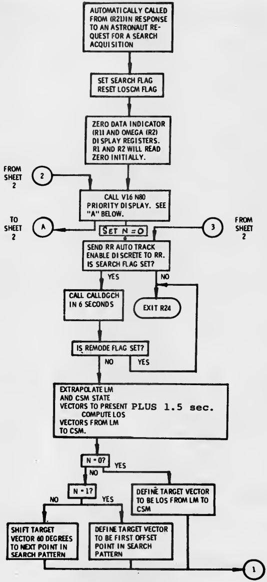


Figure 4.3.3-12. RR Search Mode (R24) (Sheet 1 of 2)

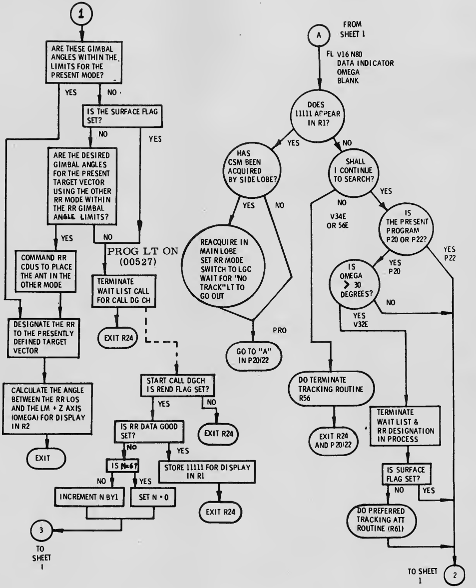
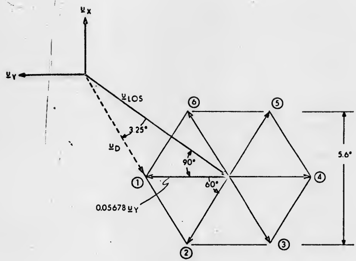


Figure 4.3.3-12. RR Search Mode (R24)(Sheet 2 of 2)



Note: This is the search pattern as viewed from the CSM.

Figure 4. 3. 3-13. RR Search Pattern

ALARMS

Alarm	Definition	Action
00210	IMU not operating	Computer exits P22
00220	REFSMMAT flag not set	Computer exits P22
00515	RR CDU fail	Zero CDUs, Exit P22 if alarm persists
00503	Designate fail	PRO to R24
00525	$\Delta\theta > 3$ deg	PRO, PRO
00527	Mode limit exceeded by RR	Exit P22, reselect
00530	CSM not in Mode 2 limit within 10 minutes	Exit P22

Table 4.3.3-II lists the regular verbs and displays in the order they occur in P22. Familiarity with the details of the individual routines, the acquisition sequence and the data incorporation process is assumed from the foregoing discussion. In the discussion that follows, emphasis is in proportion to operational significance. Several displays are straightforward enough and the response to them sufficiently predictable that they are virtually automatic (e.g., the flashing VERB 50 NOUN 25 with 00201 alarm that signifies that the RR auto mode discrete is absent). Several others, particularly some of the alarms caused by off-nominal conditions, are highly unlikely (e.g., the 00210 and 00220 unsatisfactory IMU status and 00515 CDU failure alarms). Ultimately, four key displays provide the basis for all the critical decisions the astronaut can make in P22. The astronaut's response to the first display in P22, the plane-change option, is predetermined by the flight plan and, therefore, requires a minimum of thought on his part and little discussion. He will PRO on the 00001 in R2 in most instances since the CSM orbit does not precess appreciably for near-equatorial orbits and, even if communications have failed, an MSFN-computed state vector will have been uplinked, on the previous orbit, that will include the necessary plane change.

The two IMU PROG alarms (00210 IMU not on; 00220 IMU not aligned) can occur only as the result of some gross failure. At 60 n. mi., the CSM comes within the RR 400-n. mi. range limit 466 seconds(~7 min, 45 sec) before CPA and 335 seconds (5 min, 35 sec) before the nominal Mode 2 limit (where nominal applies only when the LM is level). The astronaut can monitor range and range rate via the VERB 16 NOUN 54 display until R is less than 400 n.mi., or he can terminate via VERB 34 ENTR or VERB 56 ENTR rather than waiting if the time the CSM is predicted to come within range is excessive. By monitoring range in R2 and knowing that the Mode 2 limit will be entered at about 120 n.mi., he can anticipate the time at which designation will begin within a few seconds.

The R, $\dot{R}$ and θ display available via the VERB 83 ENTR extended verb (see Table 4.3.3-IV) provides another means of anticipating the 400-n. mi. limit and the onset of the designate phase.

The flashing VERB 50 NOUN 25 with 00201 code is simply a reminder to place the RR antenna mode switch in the LGC position, and has no special operational significance otherwise.

The RR CDU fail alarm is unlikely to occur; the procedure for verifying and correcting it is to zero the CDUs (via V40 N72 or with the RR mode switch), wait 10 seconds, then clear the alarm. If alarm persists, RR CDU has failed; exit program and consult contingency procedures. (Refer to Table 4. 3. 3-IV.) The 00526 alarm will occur when the CSM exits Mode 2.

The 00503 designate fail alarm is a crucial decision point during P22 acquisition. The astronaut will monitor the RR displays closely as the CSM enters the mode limit and will be able to tell from the SIGNAL STRENGTH meter if an RF return from the CSM transponder has been received, possibly one too weak or intermittent to permit lock. The Designate Routine will designate the radar for 42 seconds before returning the 00503 alarm, and, since acquisition would presumably have taken place if the computed CSM position were not in error, an immediate PRO response to initiate an RR search is indicated. The data good discrete will cause the TRACKER light to go out when RR data are received, if it had been previously lit.

NOTE: P22 does not update the TRACKER light before the data good discrete is received, so that its condition is not a reliable guide prior to RR lock-on. The NO TRACK light (on the RADAR panel) is wired directly to the RR tracking loop and is the best lock indicator.

If the flashing VERB 05 NOUN 09 display and 00525 PROG alarm occur in P22 (indicating actual RR LOS greater than 3 deg from computed CSM LOS), the correct response is to PRO, wait 2 seconds to see if the flashing VERB 06 NOUN 05 Delta Theta display confirms sidelobe lock, and to quickly PRO again, incorporating the data regardless of sidelobe lock.

TABLE 4. 3. 3-IV
P22 EXTENDED VERBS

DSKY	Identification	Purpose	Remarks
V41 N72E	RR CDU	To drive RR shaft and trunnion to angles specified (via V21 N73) by astronaut, and either (via V04 N12) continuously designate along that vector or permit RR lock.	Cannot be used during P22. Can be used prior to entering P22 to pre-position RR antenna to shaft and trunnion angles of desired LOS. PROG alarm (code 00502) if desired LOS is outside mode limits; 00503 if Designate Fail (with 00515 if CDU Fail). Continuous Designate terminated only by V44E.
V06 N72 or V16 N72	Display RR shaft and trunnion angles.	To monitor current RR shaft and trunnion angles.	Can be used during P22 and with other extended verbs.
V44E	Terminate V41 N72	Terminates continuous designate option in V41 N72 (above)	
V56E	Calls R56	Terminates P22	Selects R00 (same as V34E) except V56 need not be selected at flashing displays
V67E	Displays W-matrix	Displays W-matrix RMS error; permits W reinitialization.	If new W values are loaded, W-matrix initialization occurs at next measurement.
V83E	Calls R31	Computes and displays rendezvous parameters R, $\dot{R}$, θ. θ is angle between LM Z-axis and horizontal.	R display useful to judge designate initiation. IMU must be on for correct θ values. θ used to alter Mode 2 acquisition limit if LM is not level.
V85E	Displays RR Az and El	Displays RR antenna azimuth and elevation in R1, R2.	Cannot be used with any other extended verb active.
V95E	Sets no update flag	Inhibits CSM state vector update	Used when data are downlinked for ground computation.
V06 N38E	Displays TET	Displays progress of state vector integration. Time (TET) to which state vector is presently integrated R1 hrs R2 min R3 sec	TET to nearest 0. 01 sec.

4.3.3.6 Restrictions and Limitations

The ISS must be on and the IMU on and aligned accurately to a known inertial attitude, via P57, for the LGC to compute RR pointing information necessary for automatic acquisition of the CSM.

The RR Self-Test Routine must have been performed prior to entering P22.

The RR can track only within the Mode 2 limits (Figures 4.3.3-2 and 4.3.3-3) in P22.

P22 is to be operated in the no-update mode only. A zero W-matrix is stored for use with P22 and initialization—which occurs on selection of P22 and may also be caused by keying VERB 95 ENTR or by a restart—therefore assures no-update performance (ΔR equals 0; Δv equals 0) and maximum throughput of mark data via downlink to the ground.

4.3.3.7 Restarts

Restarts cause the program to return to a previous display unless they occur after the Data Read Routine is processing a mark. In the update mode, if a restart occurs while a set of mark data is being processed for incorporation, the program returns and processes the next available set of mark data, and the original RR mark will be lost along with the processing time. If the restart occurs after the mark data have been processed into an update, but before they have been accepted and/or read into the state vector, the program returns for the previous mark data and only the initial read-in time is lost.

In the no-update mode, marks are taken approximately every 3.5 seconds and a restart may cause the loss of one mark.

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4.3.4 P25, Preferred Tracking Attitude—LGC

The Preferred Tracking Attitude Program, P25, is a backup program to the Rendezvous Navigation Program, P20. P25 is selected when Rendezvous Navigation fails to operate correctly. P20 failure can be recognized during the Rendezvous Radar Self-Test Routine (R04), or through the behavior of P20, itself. Recurring NOUN 49s with Δr or Δv of large magnitudes, or a diverging trend in the VERB 06 NOUN 05 Δθs would notify the crew of P20 malfunctions. Should the rendezvous radar malfunction and prevent the correct operation of P20, P25 would be selected by the crew to provide an LM-preferred tracking attitude enabling CSM tracking of the LM optical beacon. P25 computes the preferred tracking attitude and performs the maneuver of the LM to this attitude for rendezvous. The preferred tracking attitude specified by P25 is obtained when the LM +Z-axis is aligned along the LOS to the CSM, and the roll attitude (about the LM +Z-axis) is unconstrained and is defined as necessary to avoid gimbal lock. The LM tracking beacon field of view is a 30-deg half-angle cone with the cone axis parallel to the LM +Z-axis. P25 will continue to maintain the preferred tracking attitude until its termination via the Terminate Tracking Routine (R56).

4.3.4.1 Procedures

Figure 4.3.4-1 diagrams the functional flow of P25; Table 4.3.4-I is a summary of P25 displays.

P52 or P57 must be completed before the selection of P25. As mentioned above, P25 is selected when P20 fails to operate correctly. Entry is made by keying VERB 37 ENTR 25 ENTR into the DSKY, and observing P25 on the DSKY PROG lights. If the Attitude Control switch is not already in the LGC Auto Mode position, the astronaut puts it in this position. P25 then calls the IMU Status Check Routine (R02) to ensure that the IMU is aligned to an orientation known by the LGC. If the IMU is off, or its orientation is unknown, the PROG alarm light is illuminated. The astronaut then keys VERB 05 NOUN 09 to identify the abnormality. Alarm code 00210 is displayed if the IMU is not on; 00220 is displayed if the orientation is unknown. The astronaut keys KEY REL and RSET and resets the alarm. A flashing VERB 37 indicates the program has entered the Final Automatic Request Terminate Routine (R00). If the IMU is on and the orientation is known, the IMUSE flag is set indicating the IMU is in use, and R02 is terminated.

P25 then automatically sets the TRACK flag indicating that tracking is allowed. The LGC checks to ensure the Attitude Control Switch is in the Auto Mode position.

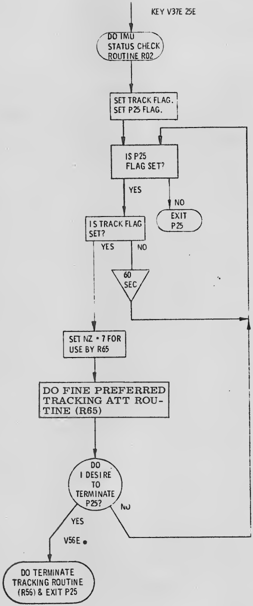

Figure 4.3.4-1 Preferred Tracking Attitude (P25)

TABLE 4.3.4-I
DISPLAYS ASSOCIATED WITH THE PREFERRED TRACKING ATTITUDE PROGRAM
(P25)

DSKY	Initiated By	Purpose	Register
FL V50 N18*	R60	R1 = roll R2 = pitch R3 = yaw Requests astronaut to perform automatic maneuver via R60 to attitude specified by P25. Displays final FDAI angles for the maneuver.	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
V06 N18*	R60	R1 = roll R2 = pitch R3 = yaw Displays final FDAI angles during execution of automatic maneuver.	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg

* Priority display if R60 is called by R65.

If it is not in this position, the program will recycle until it is. The crew has no indication of this recycling process. The P25 flag is automatically set indicating that P25 is running. These flags are then checked by the LGC to ensure they are set and have not been reset by some other LGC program.

N_Z, a counter index, is automatically set to 7 before calling the Fine Preferred Tracking Attitude Routine (R65), so that R65 will perform the Z-axis alignment eight times at 6-sec intervals. P25 then calls R65, which obtains continuous fine Z-axis tracking. R65 performs a series of automatic trim maneuvers to the preferred tracking attitude, unless a required maneuver exceeds 15 deg. If so, the crew is notified via a flashing VERB 50 NOUN 18 that a vehicle maneuver is required via R60.

When N_Z equals 0 in R65, the routine is exited, P25 then checks the TRACK flag. If the astronaut wants to recall R65 (the TRACK flag is not set), P25 will wait until the TRACK flag is restored. This can only be done by program control and is not a crew function.* When he no longer needs to maintain the preferred tracking attitude (i.e., when rendezvous is complete), the crew member can terminate P25 by keying in VERB 56 ENTR, initiating the Terminate Tracking Routine (R56).

4.3.4.2 Computational Sequence

Below is a discussion of the routines called by P25, in the order in which they are called, with a brief discussion of the function of the routine. Some of this material may overlap the discussion given above, but will provide an event-flow description that is logically consistent with Figure 4.3.4-1.

First, the IMU Status Check Routine, R02, (Figure 4.3.4-2) is called by P25 to ensure that the IMU is on and is aligned to an orientation known by the LGC. If it is not on, program alarm 00210 will occur. If the orientation is unknown by the LGC, program alarm 00220 will occur. The astronaut will key VERB 05 NOUN 09 to identify the abnormality.

Next, the Preferred Tracking Attitude Routine, R65, (Figure 4.3.4-3) is called by P25 to perform a series of trim maneuvers to the preferred tracking attitude, if each maneuver is less than 15 deg. If a required maneuver exceeds 15 deg, the crew is notified that an attitude maneuver is required via the Attitude Maneuver

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* The TRACK flag is reset by VERB 37 selection of any program, and is set by programs P30, P32, P33, P34, P35, P72, P73, P74, P75 and P76.

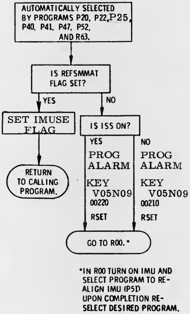

Figure 4.3.4-2 IMU Status Check Routine (R02)

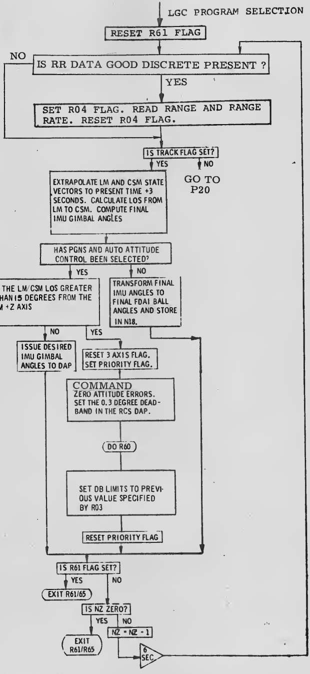

Figure 4.3.4-3 Fine Preferred Tracking Attitude Routine (R65)

Routine (R60). R65 computes the preferred tracking attitude of the LM, enabling CSM tracking of the LM beacon. P25 calls for this program to perform the fine Z-axis alignment eight times.

The Attitude Maneuver Routine, R60, (Figure 4.3.4-4) will be called automatically by R65 if the maneuver required to perform the preferred tracking attitude exceeds 15 deg. R60 maneuvers the LM to an attitude specified by P25. A priority display requiring a minimum of 2 sec wait before any keyboard activity acknowledgement (flashing VERB 50 NOUN 18) requests the astronaut to perform the maneuver automatically via R60. The registers Rl, R2, R3 display the FDAI angles (roll, pitch, and yaw, respectively).

When the LM has achieved the preferred tracking routine and rendezvous has been completed, the Terminate Tracking Routine, R56, (Figure 4.3.4-5) is called by the astronaut's keying in VERB 56 ENTR. R56 automatically terminates P25 if it is running in conjunction with another program; otherwise, R56 selects R00 to exit P25.

4.3.4.3 Program Alarms

Only two alarms are associated with P25. They are alarm codes 00210 and 00220, which can occur during the IMU Status Check Routine (R02). Code 00210 indicates the IMU is not on; code 00220 indicates the IMU is aligned to an orientation unknown by the LGC. If the PROG light is illuminated during the computational sequence of P25, the astronaut keys VERB 05 NOUN 09 to identify which of the two alarms has occurred. He then keys KEY REL and RSET on the DSKY to reset the alarms. A flashing VERB 37 indicates that, as a result of the alarm, P25 has entered the Final Automatic Request Terminate Routine (R00).

4.3.4.4 Restrictions and Limitations

P25 is called in the event of a rendezvous radar malfunction, so any degradation of the system would, of necessity, relate to that malfunction. Range and range-rate, angle error detection, shaft and trunnion angle error angle measurements would be impaired. P25 will, however, continue to maintain the preferred tracking attitude enabling CSM tracking of the LM optical beacon until it is terminated by the crew.

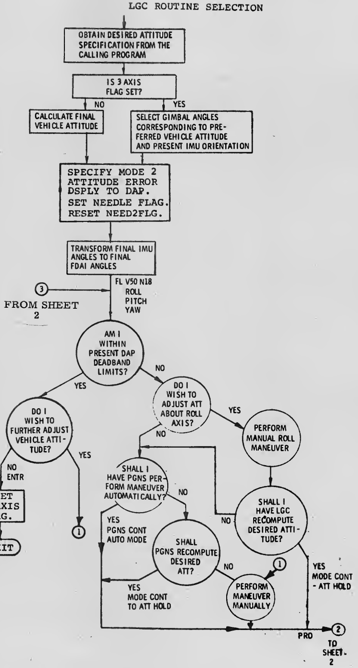

Figure 4.3.4-4 Attitude Maneuver Routine (R60) (Sheet 1 of 2)

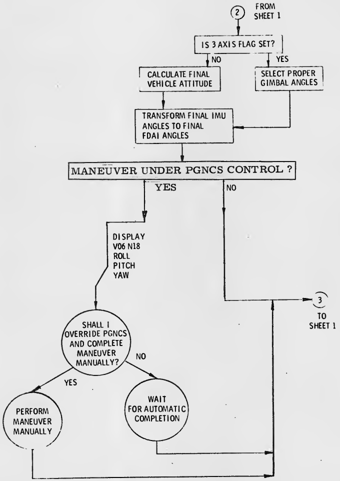

Figure 4.3.4-4 Attitude Maneuver Routine (R60) (Sheet 2 of 2)

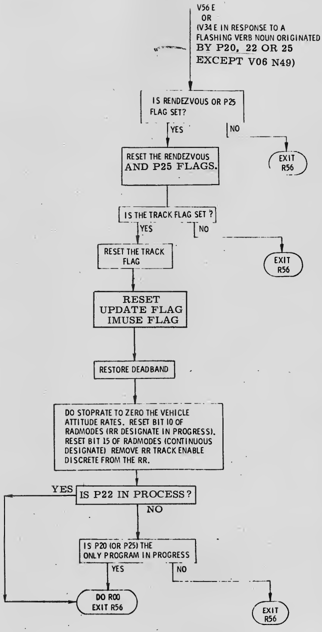

Figure 4.3.4-5 Terminate Tracking Routine (R56)

4.3.4.5 Restarts

P25 is restart protected against hardware and software restarts. Should a restart occur, the crew would notice nothing abnormal; and no crew action would be required.

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4.3.5 P27, LGC Update

The LGC Update Program is sufficiently like the CMC Update Program that a repetition of description and procedure would be superfluous. Refer to paragraph 4.2.5 for a complete description of CMC update. To adapt this to be applicable to the LM, the reader should note the following:

a. Change each reference to the CSM to LM, and each reference to the CMC to LGC.

b. Rather than the UP TLM switch, the LM has an UP DATA LINK switch which should be in DATA to accept uplinked data.

c. The LGC must be in P00 for P27 to be allowed to interrupt.

d. VERB 71 can be used for any update but is usually used to perform an LGC CSM/LM state vector update, an LGC desired REFSMMAT update, an LGC REFSMMAT update, or an LGC Lambert target update.

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SECTION 5.0

TARGETING

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5.1 INTRODUCTION TO AGC TARGETING

The onboard targeting routines are used before every mission maneuver requiring a P40, P41, or P42 thrusting program. The following is a partial list of maneuvers and their associated targeting programs:

Maneuvers Targeted by P30

Lunar-orbit Insertion (LOI_1) and Circularization (LOI_2)
Transearth Insertion (TEI)
Descent-orbit Initiation (DOI)
Translunar and Transearth Midcourse Corrections (MCC)
Translunar and Transearth Way-Station Return-to-Earth Aborts (RTE)
Phasing Maneuvers
  (rendezvous maneuvers that onboard
  rendezvous programs cannot target)
Some Rendezvous Out-of-plane Maneuvers

Maneuvers Targeted by P32–P35 (the Rendezvous Sequence)

P32	Coelliptic Sequence Initiation (CSI)
P33	Constant Delta Height (CDH)
P34	Transfer Phase Initiation (TPI)
P35	Transfer Phase Midcourse (TPM)

Maneuvers Targeted by P37

Return to Earth (RTE)

Although there is no computer requirement (i.e., there is no alarm indicating a bad state vector) for navigation during any part of the mission, the targeting programs are normally preceded by navigation or state-vector uplink to improve the onboard estimate of the current vehicle state vectors. The computer targeting will miss the desired objectives to the degree that position and velocity estimates in the APOLLO guidance computer (AGC) are inaccurate. Further, state vector estimates degrade with the passing of time; it follows that the closer good navigation or state vector uplink is performed to the selection of a targeting program, the better will be the targeting—hence, the better the maneuver.

Every CM P40 or P41 maneuver or LM P40, P41, or P42 maneuver must be preceded by one of the P3x targeting programs. The targeting programs calculate the burn parameters necessary for a thrusting maneuver.

There are, in fact, five classes of maneuvers, four of which involve targeting:

1. Pretargeted maneuvers comprise earth-orbit insertion, translunar insertion, lunar landing, aborts and lunar ascent, and reentry. (Strictly speaking, LM P70 and P71 aborts are not pretargeted, but the distinction between them and the other maneuvers mentioned in class 1 will not be evident to the crew.)
2. Ground-targeted maneuvers comprise LOI, TEI, DOI, various orbital changes around the moon, and translunar and transearth midcourse corrections, or return to earth aborts.
3. Rendezvous maneuvers comprise CSI, CDH, TPI, TPM, and out-of-plane maneuvers.
4. Return-to-earth maneuvers comprise cislunar aborts without communication.
5. Untargeted maneuvers comprise docking, passive thermal control, crew-originated attitude maneuvers (R62), etc.

Clearly, the AGC targeting programs involve only classes 2, 3, and 4. P30 relates to all class 2 maneuvers and some out-of-plane maneuvers. P32–P35 target most rendezvous (class 3) maneuvers. P37 targets all class 4 maneuvers. The remainder of this introduction examines considerations relative to classes 2–4 and, then, summarizes the methods of targeting computation and the coordinate system (local vertical) used in targeting.

5.1.1 Class 2 Maneuvers (P30)

All maneuvers in class 2, ground-targeted maneuvers, are uplinked to the AGC into P30 registers. For these maneuvers, P30 is not precisely a targeting program, but a program for checking data transmitted from the ground and the compatibility of onboard and ground state vectors. In addition to uplinked maneuvers, however, P30 can be used to target rendezvous out-of-plane maneuvers. Such maneuvers take advantage of P30's convenience as a method for targeting maneuvers conceived in local-vertical coordinates. (Local-vertical coordinates, which are relevant to all targeting programs, are discussed in paragraph 5. 1. 5.)

Primarily, then, P30 is a program for displaying various burn-related parameters for astronaut approval and for calculating the matrix that relates local-vertical coordinates to basic-reference coordinates used by the thrusting programs.

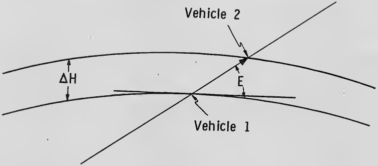
5.1.2 Class 3 Maneuvers (Rendezvous)

In contrast to P30, which is a general-purpose targeting program, each of the other targeting programs has a specific purpose. The rendezvous-targeting programs are P32–P35. The following is an overview of rendezvous considerations that should prove helpful when examining the individual programs. (Rendezvous navigation is discussed in paragraph 4.2.1.)

Basically, there are two methods for achieving rendezvous: (1) direct transfer to intercept; (2) rendezvous using intermediate parking orbits. The AGC has the means for targeting both types of rendezvous. Each method has advantages and disadvantages. The direct transfer is faster, but certain abort situations pose problems: (1) lighting conditions cannot be standardized, (2) there are often large maneuver magnitudes, (3) closing rates may be quite fast, and (4) the final approach cannot be standardized to simplify training and monitoring requirements. Parking-orbit rendezvous, on the other hand, allows the final phase to be standardized and permits smaller maneuver magnitudes, thereby minimizing the effects of a poor maneuver. The disadvantage of a parking-orbit rendezvous is that it tends to be long and drawn out.

GEMINI and early APOLLO rendezvous flight plans used the parking-orbit rendezvous for two reasons: (1) GEMINI spacecraft did not have a navigation filter, so the final phase was planned to allow easy crew monitoring. Early APOLLO rendezvous flight plans followed the GEMINI experience; (2) uncertainty about the reliability of the new APOLLO system favored the smaller maneuver magnitudes of parking-orbit rendezvous in order to minimize the effects of a single bad burn.

Any parking-orbit rendezvous must eventually target a direct transfer to intercept. The difference is that a parking-orbit rendezvous sets conditions for a standardized transfer. The onboard capability for parking orbit rendezvous, known as the coelliptic sequence of maneuvers (P32 and P33), usually involves two parking orbits. The two maneuvers are designed to result in an orbit that (1) is coelliptic—that is, has a constant altitude differential—and (2) has a particular phase-angle–altitude-differential relationship defined by a particular elevation angle (E):



The first maneuver in the coelliptic sequence is designed to obtain the proper phasing, i.e., the correct E after the subsequent coelliptic maneuver; the second maneuver produces the coelliptic orbits. Coelliptic orbits, together with the proper E, produce the following desirable conditions: (1) closing rates are slow; (2) astronaut takeover is very easy in the event of computer malfunction; (3) errors can be discovered quickly by monitoring the elevation-angle changes.

Transfer to intercept, whether or not it is done in the context of parking-orbit rendezvous, simply involves planning the time and place of intercept and aiming to hit the spot at the proper time. P34 targets such trajectories; P35 targets midcourse corrections to such trajectories.

Figures 5.1-1 and 5.1-2 illustrate typical rendezvous profiles from two points of view. Figure 5.1-1 is a moon-centered inertial plot, and Figure 5.1-2 is a relative plot in a curvilinear coordinate system.* The following typical phase angles are also included in Figure 5.1-1:

Insertion-CM, 16 deg ahead of LM
CSI-CM, 8.6 deg ahead of LM
CDH-CM, 4 deg ahead of LM
TPI-CM, 1.6 deg ahead of LM

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*Figure 5.1-2 was prepared by the Orbital Procedures Section for MSC Internal Note No. CF-R-69-26.

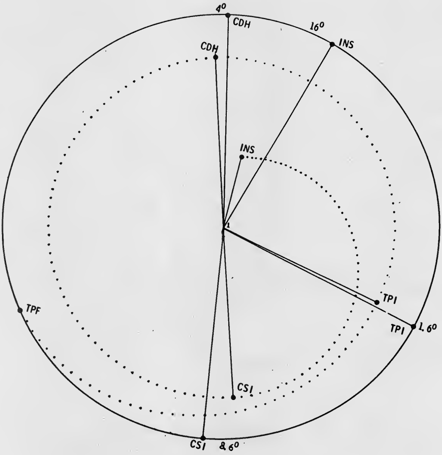
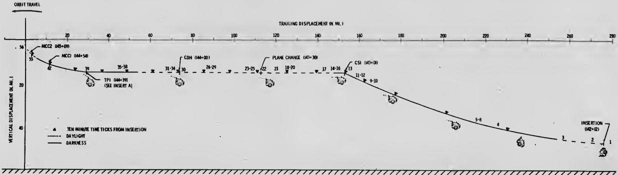


Figure 5.1-1. Moon-centered Inertial Plot Showing the Nominal G-Mission Rendezvous



LM MAJOR EVENTS

	GROUND ELAPSED TIME	EVENT
1.	142+12	INSERTION
2.	142+13	AGS TARGET CSI
3.	142+16	IMU REFSMMAT ALIGN (P52)
4.	142+25	INITIALIZE W-MATRIX (10000, 10, 15)
5.	142+26	INITIATE RR NAVIGATION (P20)
6.	142+26	PGNCS TARGET CSI (P32)
7.	142+27	AGS UPDATE AND ALIGN
8.	142+28	INITIATE AGS RADAR UPDATES
9.	142+49	TERMINATE RR NAVIGATION (23 MARKS)
10.	142+49	PGNCS FINAL CSI COMP
11.	142+52	TERMINATE AGS RADAR UPDATES (9 UPDATES)
12.	142+53	AGS FINAL CSI COMP
13.	143+01	CSI THRUSTING MANEUVER (P41)
14.	143+05	INITIALIZE W-MATRIX (2000, 2, 5)
15.	143+04	RESUME RR NAVIGATION
16.	143+04	TARGET CDH (PGNCS P33 AND AGS)
17.	143+07	RESUME AGS RADAR UPDATES
18.	143+21	TERMINATE RR NAVIGATION (17 MARKS)
19.	143+22	OBTAIN CSM RDOT FOR PLANE CHANGE
20.	143+22	EXTERNAL ΔV FOR PLANE CHANGE (P30)
21.	143+24	TERMINATE AGS RADAR UPDATES (7 UPDATES)
22.	143+30	RCS PLANE CHANGE MANEUVER (P41)
23.	143+31	REINITIALIZE W-MATRIX (V93)
24.	143+32	RESUME RR NAVIGATION
25	143+32	TARGET CDH (PGNCS P33 AND AGS)
26.	143+48	TERMINATE RR NAVIGATION (15 MARKS)
27.	143+48	PGNCS FINAL CDH COMP
28.	143+51	TERMINATE AGS RADAR UPDATES (7 UPDATES)
29.	143+52	AGS FINAL CDH COMP
30.	144+00	CDH THRUSTING MANEUVER (P41)
31.	144+02	REINITIALIZE W-MATRIX (V93)
32.	144+03	RESUME RR NAVIGATION
33.	144+05	TARGET TPI (PGNCS P34 AND AGS)
34.	144+05	RESUME AGS RADAR UPDATES
35.	144+27	TERMINATE RR NAVIGATION (24 MARKS)
36.	144+27	PGNCS FINAL TPI COMP
37.	144+30	TERMINATE AGS RADAR UPDATES (9 UPDATES)
38.	144+31	AGS FINAL TPI SEARCH COMP
39.	144+39	TPI THRUSTING MANEUVER (P41)
40.	144+41	REINITIALIZE W-MATRIX (V93)
41.	144+41	RESUME RR NAVIGATION
42.	144+41	TARGET MCC1 (PGNCS P35 AND AGS)
43.	144+41	RESUME AGS RADAR UPDATES
44.	144+51	TERMINATE RR NAVIGATION (9 MARKS)
45.	144+51	TERMINATE AGS RADAR UPDATES (6 UPDATES)
46.	144+51	PGNCS AND AGS FINAL MCC1 COMP
47.	144+54	MCC1 THRUSTING MANEUVER (P41)
48.	144+56	REINITIALIZE W-MATRIX (V93)
49.	144+56	RESUME RR NAVIGATION
50.	144+56	TARGET MCC2 (PGNCS P35 AND AGS)
51.	144+56	RESUME AGS RADAR UPDATES
52.	145+06	TERMINATE RR NAVIGATION (9 MARKS)
53.	145+06	TERMINATE AGS RADAR UPDATES (6 UPDATES)
54.	145+06	PGNCS AND AGS FINAL MCC2 COMP
55	145+09	MCC2 THRUSTING MANEUVER (P40)
54.	145+12	BRAKING (P47)

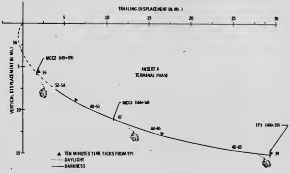


Figure 5.1-2. H1 Mission Rendezvous; CSM-centered Motion

In Figure 5.1-2, the vertical displacement is shown nearly constant from CSI to TPI. Thus, the orbits are nearly coelliptic before the CDH maneuver. In another flight plan, this need not be the case. In such an instance, the LM relative position plot would not be horizontal until after CDH.

During the transfer phase, the elevation angle for the LM (which can be drawn by connecting LM to CM, at the origin of the plot, and drawing a line through the LM position and parallel to the trailing displacement axis) can be seen to increase smoothly. This allows easy monitoring of rendezvous progress, as the elevation angle is quick to indicate targeting errors in the braking phase.

Accurate state vector estimates are most important during rendezvous. Because of this, all the rendezvous programs are designed to be used with Rendezvous Navigation (P20, paragraph 4.2.1). Marks can be incorporated during most displays, and each targeting program has a special recycle capability that allows a preliminary estimate of the maneuver before navigation is completed.

5.1.3 Class 4 Maneuvers (P37)

The CM computer (CMC) has a capability of targeting a return-to-earth maneuver without the use of ground communication. With the exception of a small zone of no solution (nearly impossible to get to with the current flight plan), P37 will target for a return to the entry corridor from any time of ignition placing the spacecraft outside the lunar sphere of influence. The program is discussed in detail in paragraph 5.2.6.

5.1.4 Targeting Computations

The targeting programs can be classified by the type of maneuver targeted (either External Δv or Lambert) or by the method of computation (iterative or noniterative). For large maneuvers, External Δv does not rotate the spacecraft to follow a continuously redefined required velocity. This allows easy out-the-window monitoring. Therefore, all ground-targeted maneuvers are targeted in the External-Δv mode by P30.

Lambert maneuvers have two advantages, however, over External Δv maneuvers. The primary advantage of Lambert maneuvers is that the guidance is a closed loop, rather than an open loop. Further, the computer can take into account variations in the effects of gravity during the maneuver and adjust the commanded thrust direction accordingly. These advantages allow onboard targeting of large maneuvers in the

AGC, which does not have the computer capacity or speed to precompute gravity variations, as required for large-maneuver External-Δv targeting. Accordingly, onboard-targeted return-to-earth maneuvers (P37) are in the Lambert mode. Rendezvous maneuvers (P32 through P35), however, are ordinarily of such small magnitude that the use of Lambert or External Δv was determined on the basis of ease of programing. (P32 and P33 are External Δv; P34 and P35 are Lambert.)

Whether an iterative or noniterative method of computation is used depends, generally, on the extent that perturbations affect the solution. Since no analytic expression completely describes the forces acting upon a vehicle traveling between the earth and the moon, targeting of such a trajectory involves first an analytic approximation, then orbital integration to determine the error, a second approximation to compensate for the error, and so on, bracketing the solution until either an imposed iteration limit is reached or the approximation converges on the desired solution. Noniterative targeting is used by P30, P33, and, in lunar orbit, P34 and P35;* iterative targeting is used by P32, P37, and, when not in lunar orbit, P34 and P35.

An example of iterative targeting is the Lambert offset technique used with P34 and P35. Given a transfer time and two points in inertial space, Lambert allows an appropriate conic trajectory to be constructed between the two points. In P34, the first point is the active-vehicle position at TPI, the second point is the passive-vehicle position at intercept, and the transfer time is the transfer time of the passive-vehicle trajectory between TPI and transfer-phase final (TPF). The AGC computes the second point and the transfer time based on a stored central angle of transfer (CENTANG) and on a stored ignition time (t_{IG}).

Since Lambert calculations ignore such perturbations as oblateness, however, it is recommended that P34 target as follows when the spacecraft are in earth orbit (i.e., R1 of NOUN 55 = 2) (refer to Figure 5.1-3):

1. Passive-vehicle position vector is precision extrapolated to intercept time.
2. A Lambert solution ($\Delta \underline{v}$ at t_{IG}) is calculated for a conic trajectory that will obtain intercept.
3. Based on the Lambert solution, the AGC extrapolates a precision trajectory, incorporating perturbations, through the specified transfer time.

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*P33 does iterate to find t_{IG}(TPI), but not to target for $\Delta \underline{v}$(CDH). See paragraph 5.2.3.

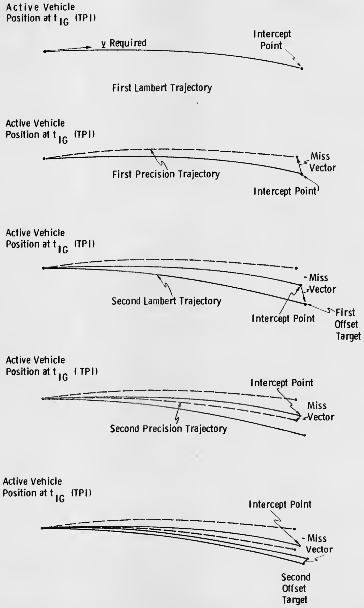


Figure 5.1-3. An Example of Lambert Offset Targeting

4. The resulting miss vector (the precision-extrapolated vector minus the Lambert target vector) is subtracted from the initial target vector in order to produce the <u>first</u> <u>offset</u> target.
5. A Lambert solution for the offset target is calculated, as in step 2.
6. Based on the new Lambert solution, a second precision trajectory is extrapolated.
7. The resulting miss vector is subtracted from the first offset target to produce a <u>second</u> offset target.
8. Steps 4 through 6 are repeated until a specified number of offsets have been targeted (usually two in earth orbit).

In lunar orbit, where the effect of perturbations is minimal, Lambert targeting is modified as follows. Instead of a precision extrapolation as in step 1, the passive-vehicle position vector is extrapolated to intercept time by the conic method. The Lambert solution (step 2) is then produced, and, since the effect of perturbations is small, the errors in the two conic trajectories tend to cancel. This eliminates the need for iterative offsets.

A similar offset procedure is used in P37. The Return to Earth Program must produce the correct flight-path-angle (FPA) at the correct altitude, rather than a particular position at a particular time (as in P34). The procedure for P37 is as follows:

1. P37 first calculates a conic solution ($\Delta \underline{v}$ at t_{IG}) that would, ignoring perturbations, obtain the entry FPA at the proper altitude (400,000 ft above the Fischer ellipsoid), or offset altitude on subsequent iterations.
2. Using the $\Delta \underline{v}$ from step 1, the AGC extrapolates a precision orbit to the desired FPA.
3. The altitude existing at that point is compared with the desired altitude (400,000 ft).
4. Based on the miss in altitude, an offset target altitude for a new conic solution is produced.
5. Steps 1 through 4 are repeated, each iteration refining the offset, either until the precision-altitude converges to 400,000 ft or until an iteration limit is reached.

5.1.5 <u>Local-vertical Coordinates</u>

All the targeting programs display their solution in local-vertical coordinates. Local-vertical (LV) coordinates have their origin in the spacecraft; they rotate as the spacecraft revolves around the central body. The +Z(LV) axis lies along the line-of-sight (LOS) from the spacecraft to the central body. Z(LV) defines the local horizontal plane: any line through the spacecraft and perpendicular to Z(LV) lies in the horizontal plane. The unitized projection of the vehicle velocity vector into the horizontal plane determines X(LV). Y(LV) completes a right-handed system: that is, it is to the right, as one faces forward along X(LV). In other words, the CM body axes coincide with LV axes when the vehicle is oriented heads up, wings level, facing forward, with the Z body axis parallel to the local vertical. In the LM (un-docked), the body axes are rotated 90 deg, such that, for a heads-up, facing-forward (out the window), wings-level, X-body-parallel-to-local-vertical orientation, the correlation is as follows:

X-body = -Z(LV)
Z-body = X(LV)
Y-body = Y(LV)

Vehicle velocity is divided between the X(LV) and Z(LV) directions. For elliptic orbits, the majority of the velocity lies in the X(LV) direction. At apsidal crossings (i.e., for apogee or perigee crossings), the Z(LV) component of velocity is zero. If the vehicle is less than 180 deg before apogee, the Z(LV) component of velocity is positive. In a circular orbit, Z(LV) is always zero. For hyperbolic orbits, the X(LV) component of velocity approaches zero as the vehicle gets farther from the central body, but the Z(LV) component is still zero at perigee.

Figure 5.1-4 is a diagram of an elliptic orbit that illustrates how LV coordinates rotate, and how the vehicle velocity vector takes on various amounts of a Z(LV) component, being zero at the apsides.

It can be seen that vehicle velocity, when expressed in LV coordinates, will always have a zero Y(LV) component, because Y(LV) is perpendicular to the orbital plane of transfer. After an out-of-plane maneuver, when the Y component of the change in velocity in LV coordinates [Δv(LV)] is nonzero, the LV coordinate system rotates such that the Y(LV) component of vehicle velocity is again zero. The following discussion illustrates the role of LV coordinates in achieving a coplanar rendezvous configuration.

Figure 5.1-5 shows two orbits that are out of plane with respect to each other. Nodes denote intersection of one orbit with the plane of the other (only incidentally

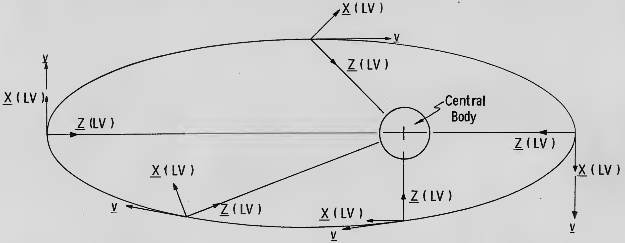


Figure 5.1-4. Rotation of Local Vertical Coordinates

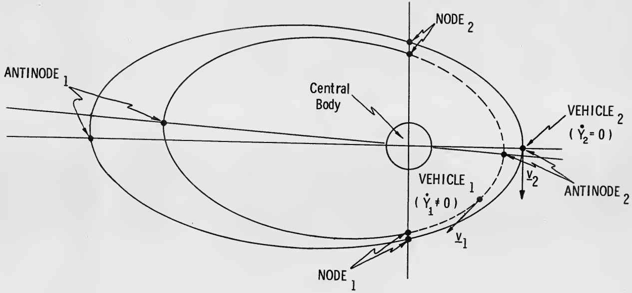


Figure 5.1-5. Non-Coplanar Orbits

do orbits themselves intersect) and occur twice a revolution, for two noncoplanar orbits about a single point. An out-of-plane maneuver with the proper change in velocity at a node will produce coplanar orbits. Antinodes are points where out-of-plane distance is at a maximum. Note that the antinodes are 90 deg from the nodes.

Vehicle 2 is at an antinode. Vehicle 2's velocity vector ($\underline{v}_2$) is parallel to the plane of transfer of vehicle 1. Vehicle 1 is approaching a node. Vehicle 1's velocity ($\underline{v}_1$) has a component ($\dot{Y}_1$) perpendicular to the plane of vehicle 2.

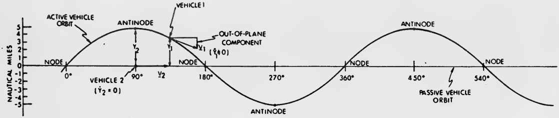
When vehicle 1 reaches the nodal point n_2, $\dot{Y}_1$ will be at a maximum. Suppose vehicle 1 does a maneuver at its current position that adds the following $\Delta\underline{v}$ (LV) to $\underline{v}_1$:

$$\Delta\underline{v} = -\dot{Y}_1 \, \underline{Y}_1 \text{ (LV)}$$

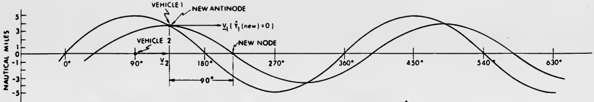
where $\underline{Y}_1$ (LV) = Unit Vector of Y(LV) axis of vehicle 1

Now $\dot{Y}_1 = 0$, since it was nulled out; hence, vehicle 1 is at an antinode. Since vehicle 1 has been made to be at an antinode, i.e., the point where the thrust occurs is the new antinode, a node can be expected 90 deg later. An examination of Figure 5.1-6 shows this to be the case. If $\dot{Y}_1$ is nulled at the new node, 90 deg later, then the vehicles will be coplanar.

There is a slight discrepancy in this logic: the $\Delta\underline{v}$ should be $\Delta\underline{v} = -\dot{Y}_1 \, \underline{Y}_2$ (LV). For the small Y values occurring during APOLLO rendezvous, this discrepancy is usually negligible. If $\dot{Y}$ is nulled during the CSI or CDH, the discrepancy does not exist. (See paragraph 5.2.3 or 5.2.2.)



In the above figure, the orbital plane of VEHICLE$_2$ is represented by the horizontal axis. The sine wave represents the displacement of the orbital plane of VEHICLE$_1$



The added sine wave shows the effect of a burn by VEHICLE$_1$ where ΔV_{LV} equals $-\dot{Y}_1 \cdot \underline{Y}_2$ (LV).
Note that the period remains the same but the magnitude is diminished

Figure 5.1-6. Example of the Effects of an Out-of-Plane Maneuver

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SUBSECTION 5.2

CMC TARGETING PROGRAMS

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5.2.1 P30, External Δv — CMC

The purpose of P30 is to enable an external $\Delta \underline{v}$ maneuver to be targeted in local vertical coordinates, to initialize certain registers for P40/P41, and to display parameters related to an external $\Delta \underline{v}$ maneuver. The program can be used either with an uplinked t_{IG} and velocity change vector, to accomplish a plane-change maneuver calculated in R36, or with input in local vertical coordinates from any other source. Figure 5.2.1-1 is a flowchart of P30.

5.2.1.1 P30 Assumptions

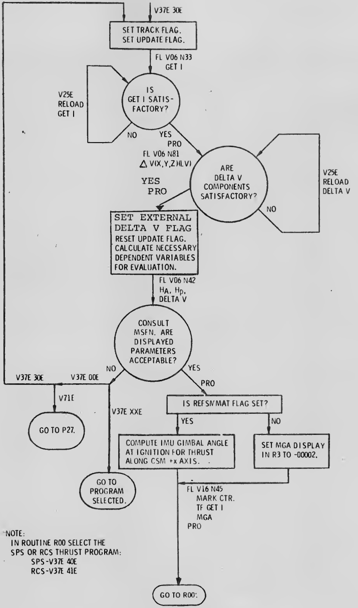
The assumptions under which P30 operates and a brief explanation of each follow:

1. The above-mentioned t_{IG} and velocity-change vector have been uplinked via P27, were computed in R36 and recorded by the astronaut as T(EVENT) and $(0, -\dot{Y}, 0)$ (assuming the CM was chosen as the vehicle) or a maneuver has been input from some other source.
2. If this is an uplinked burn, then concurrent with the operation of P27, a PAD has been voiced up from the ground.
3. The ISS need not be running or aligned for P30 to run to completion.
4. If P30 is run during rendezvous, Rendezvous Navigation (P20) can continue to run and marks can be incorporated during the first two flashing displays.
5. If the burn is ground-targeted, P30 is keyed in with sufficient time to allow for ground confirmation of displayed burn parameters.

5.2.1.2 Discussion of Inputs and Outputs

Tables 5.2.1-I and 5.2.1-II delineate P30 inputs and outputs, respectively. Noteworthy explanations of these inputs and outputs are given below.

If the maneuver is uplinked and any of the inputs or outputs are out of tolerance with the PAD voiced up from the ground, either the ground computer or the CMC has a bad state vector, or is malfunctioning. The burn should be postponed until new parameters can be uplinked, or the computer malfunction is diagnosed and corrected. If all outputs agree, within tolerances, with the PAD, or if the maneuver is on-board calculated to correct out-of-plane conditions, PRO should be used for inputs 1 and 2 and outputs 1, 2 and 3. Output 4, VHF and optics marks, is a part of NOUN 45, the exit display for all targeting programs, and is relevant only if P30 is used during the rendezvous sequence. Output 5, time from ignition, is self-explanatory.



NOTE:
IN ROUTINE R00 SELECT THE
SPS OR RCS THRUST PROGRAM:
SPS-V37E 40E
RCS-V37E 41E

Figure 5.2.1-1. External Δ v Program (P30)

TABLE 5.2.1-I

EXTERNAL Δv INPUTS (P30)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time of ignition	TIG	FL V06 N33	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec	If the burn is uplinked, these registers will display the uplinked t_{IG}. If an onboard-calculated out-of-plane maneuver is being targeted then T(EVENT) must be loaded.
2.	Impulsive velocity change vector	DELTA V(LV)	FL V06 N81	R1 xxxx. x X R2 xxxx. x Y R3 xxxx. x Z	If the burn is uplinked, these registers will display the uplinked $\Delta \underline{v}$ (LV). If an onboard-calculated out-of-plane maneuver is being targeted, then (0, $-\dot{Y}$ (CSM), 0) must be loaded.

TABLE 5. 2. 1-II

EXTERNAL Δv OUTPUTS (P30)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Apogee altitude above pad radius/latest landing site radius	APO ALT	FL V06 N42	R1 xxxx. x n. mi.	Maximum number (9999. 9), if scaling is exceeded.
2.	Perigee altitude above pad radius/latest landing site radius	PER ALT	FL V06 N42	R2 xxxx. x n. mi.	Maximum number (9999. 9), if scaling is exceeded.
3.	Magnitude of velocity change	DELTA V	FL V06 N42	R3 xxxx. x fps	
4.	Rendezvous marks taken	MARK-COUNT	FL V16 N45	R1 xxBxx VHF marks taken, optics marks taken	
5.	Time from ignition	TFI	FL V16 N45	R2 xxBxx min, sec	Maximum reading, 59 min, 59 sec; negative before t_{IG}, positive after t_{IG}.
6.	Middle gimbal angle	MGA	FL V16 N45	R3 xxx. xx + degrees if alignment of of IMU is known. -00002, otherwise.	

If R3 in NOUN 45 (output 6) indicates an excessive MGA (perhaps greater than 70 deg), the astronaut should consider realignment. If the ISS is not running, or if its alignment is unknown (in both instances, output 6 equals -00002), it must be powered up, and/or aligned before the burn. After the computer has received a PRO response to VERB 16 NOUN 45, P30 exits via R00 (flashing VERB 37).

Note that although P30 was once used for determining orbital parameters, especially for translunar and transearth coast, VERB 82 has now supplanted that function.

WARNING: The calculation of the apogee and perigee of the orbit resulting from the P30-targeted maneuver is based on an impulsive $\Delta \underline{v}$, and can be very wrong for maneuvers of long duration.

If either P40 or P41 is keyed in after a P30-targeted burn, and then P30 is again keyed in (for the same burn), input 2 [DELTA V(LV)] should be reloaded with the original value, since P40/P41 rotate this vector through a central angle and then store it back in the original location eliminating the unrotated vector.

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5.2.2 P32, Coelliptic Sequence Initiation (CSI)–CMC

P32 is part of the coelliptic sequence (P32 plus P33) of rendezvous targeting. The coelliptic sequence is designed to result in orbits in which the difference in altitude between the two orbits is nearly constant. Once coelliptic orbits have been achieved, the transfer phase (P34 plus P35) follows. This phase is designed to effect an intercept trajectory and a braking maneuver, allowing docking by the pilot of the active vehicle. Maneuvers to correct out-of-plane conditions can be made at any time in the rendezvous sequence. (See Figure 5.2.2-1.)

Two thrusting maneuvers make up the coelliptic sequence, the CSI (coelliptic sequence initiation) maneuver and the CDH (constant delta height or altitude) maneuver. P32 computes a horizontal maneuver for CSI parallel to the plane of the passive vehicle at the astronaut-specified t_{IG} (CSI).

The magnitude and direction of this maneuver depend on four factors:

a. The state vectors of the two vehicles at t_{IG} (CSI)
b. The astronaut-specified time for the transfer phase initiation (TPI)[*]
c. CDH apsidal crossing (or 180-degree option)
d. The line-of-sight elevation angle (E).[**]

5.2.2.1 CSI Maneuver

In the nominal case, rendezvous is initially started with a poor estimate of the LM state vector; Rendezvous Navigation is therefore needed to improve the estimate of that state vector. Once that is done, the CSI maneuver must be targeted via P32, and then accomplished via P40 or P41.

AVERAGEG, which updates the state vector during powered flight, tends to degrade the estimate of that vector so that Rendezvous Navigation is again needed to improve the state vector. During rendezvous, the cycle repeats: navigation, targeting,

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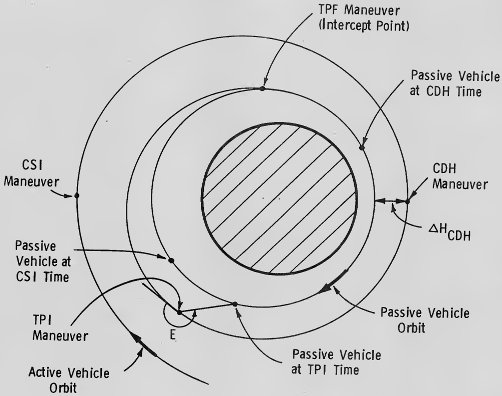
[*] t_{IG} (TPI) will usually occur at midpoint of darkness to allow good lighting conditions for final rendezvous.

[**] The line-of-sight elevation angle (E) allows the pilot of the active vehicle to boresight on the passive vehicle at t_{IG} (TPI). In this case, to boresight means that the thrust vector will be nearly coincident with the SXT LOS to the LM. As a backup to computer failure, the astronaut may thrust while holding the CM in the SXT LOS attitude.



NOTE: ΔH_{CDH} is not strictly LM altitude minus CSM altitude, but the altitude of the point on the LM or orbit directly below the CSM at CDH, minus the CSM altitude. This distinction becomes significant when the passive vehicle is in a highly elliptical orbit and the central angle between the two vehicles at the CDH time is large. (This diagram is not in scale.)

Figure 5.2.2-1. An Example of a CSM-active Rendezvous Configuration maneuver. Four targeting programs are used for coelliptic sequence rendezvous, and each must interface with P20 and P40 or P41.

P32 is designed to run while Rendezvous Navigation (P20) is operating. Preliminary estimates of the maneuver can be made before navigation is completed. P32 targets an external $\Delta \underline{v}$ maneuver for P40 or P41.

P32 contains an iteration loop, using the CSI $\Delta \underline{v}$ as the independent variable to obtain the specified TPI conditions. Under nominal flight configuration, the iteration scheme converges very quickly; the total final computation usually takes about 3 minutes.

As was mentioned above, rendezvous navigation can be carried on while P32 is running. Automatic VHF marks can accumulate throughout the program. Optics marks can be taken during any of the flashing displays of P32 (except alarms) until PRO is keyed in response to VERB 16 NOUN 45, by using R21 of R23. If marks are to be taken, the ISS must be operating and aligned. This is a requirement of P20.

P32 depends on a good knowledge of the state vectors of the two vehicles with respect to each other. Since P32 is performed after injection or abort, a situation that usually gives a poor initial estimate of the LM state vector, a certain minimum number of marks should be taken before final computation in P32. This number is mission-dependent, but usually fifteen optics and fifteen VHF marks will be sufficient.

5.2.2.2 Discussion of Inputs and Outputs

A user-oriented flowchart and two tables summarizing input and output of P32 follow. The information below is necessary to properly interpret the flowchart, Figure 5.2.2-2:

TRACK and UPDATE flags refer to P20. If TRACK flag is set, tracking is allowed; if it is reset, tracking is not allowed. If UPDATE flag is set, the state vector may be updated from marks; if reset, the state vector may not be updated from marks.

REFSMMAT FLAG SET means IMU alignment is known. If REFSMMAT flag is reset, IMU alignment is not known.

FINAL FLAG SET indicates the astronaut has keyed in PRO in response to VERB 16 NOUN 45. FINAL FLAG RESET indicates he has not.

Table 5.2.2-I lists the input displays of P32, which all come at the beginning of P32. Under nominal conditions, program inputs are as indicated on the voiced-up

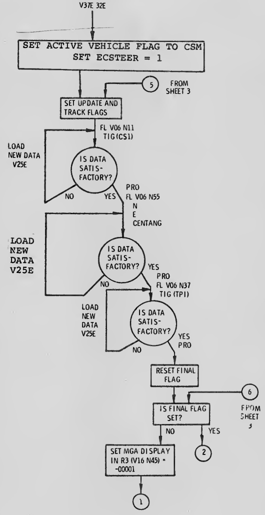


Figure 5.2.2-2. Coelliptic Sequence Initiation (CSI) (P32) (Sheet 1 of 3)

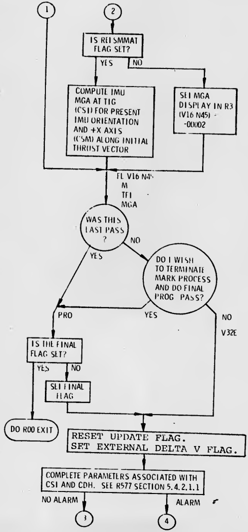
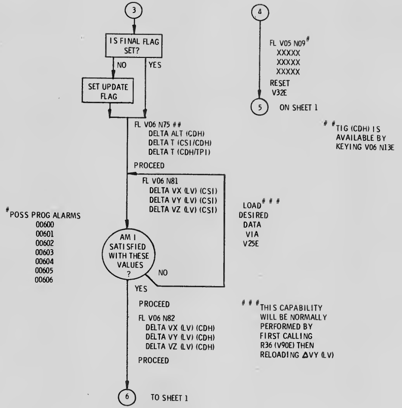


Figure 5.2.2-2. Coelliptic Sequence Initiation (CSI) (P32) (Sheet 2 of 3)



#POSS PROG ALARMS
00600
00601
00602
00603
00604
00605
00606

##TIG (CDH) IS AVAILABLE BY KEYING V06 N13E

###THIS CAPABILITY WILL BE NORMALLY PERFORMED BY FIRST CALLING R36 (V90E) THEN RELOADING ΔVY (LV)

Figure 5.2.2-2. Coelliptic Sequence Initiation (CSI) (P32) (Sheet 3 of 3)

TABLE 5.2.2-I
P32 PROGRAM INPUTS (SHEET 1 OF 2)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time of CSI ignition	TIG(CSI)	FL V06 N11	R1 ooxxx. hr R2 oooxx. min R3 oxx.xx sec	Astronaut must load TIG(CSI)
2.	The number of the post-CSI apsidal crossing of the active vehicle at which t_{IG} (CDH) should occur, or the integral multiple of 180^o transfer angle at which t_{IG}(CDH) will occur.	N	FL V06 N55	R1 xxxxx.	N is usually the first input to change when alarm conditions arise. (See section on alarms.)
3.	Elevation angle. The angle between the CSM/LM LOS and the CSM local horizontal, referenced to the direction of flight. (See R577, Section 5.4.2, Figure 4.2-2).	E	FL V06 N55	R2 xxx.xx deg	The passive vehicle can be boresighted at this angle for TPI burn. While changing E might eliminate some alarms, E should remain constant, as all chart solutions depend on a particular E-angle.
4.	180-degree option	CENTANG	FL V06 N55	R3 00000, unless changed by astronaut V23ENTR	Loading any non-zero value into R3 will produce a CDH burn at a transfer angle from CSI of N times 180 deg.

TABLE 5. 2. 2-I

P32 PROGRAM INPUTS (SHEET 2 OF 2)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
5.	Time of TPI ignition	TIG(TPI)	FL V06 N37	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec	Astronaut must load t_{IG} TPI. t_{IG} (TPI) minus t_{IG} (CSI) ought to be at least 70 minutes for lunar orbit, when the 180-degree option is used. An absolute minimum would be 25 minutes. If N is increased, t_{IG} (TPI) must be increased

<u>NOTE:</u> The astronaut should terminate all these input displays with a PRO keystroke. If at any time the astronaut wishes to change the displayed values, he may load new ones by first keying in the appropriate load verb.

PAD. If an alarm occurs, the program should be recycled to check input. If input was good, the procedures described in the section on alarms should be followed. If the solution appears bad although no alarms have occurred, the program must be reselected via VERB 37 ENTR 32 ENTR to check input.

Table 5.2.2-II lists P32 output. VERB 16 NOUN 45 is both the first and the last output display; its purpose is to show the status of rendezvous navigation in the CMC. R1 shows the number of marks incorporated since the latest significant event in P20.*

R1 can be used to indicate when the W-matrix should be reinitialized, and how many more marks should be taken with the current W-matrix, as specified by mission procedures.

R2 shows how much time is left before ignition to take marks and perform final P32 computation. R3 indicates whether the CMC will accept marks. If R3 equals -00001, then final computations have not been made by the CMC and marks will be incorporated if taken during any flashing display. If the astronaut wishes to terminate the marking process and use the current estimate of the state vector in the CMC, he should key PRO in response to a VERB 16 NOUN 45 display. After such a keystroke, no more marks will be incorporated by the CMC. The computer will calculate the burn parameters for a final time, display the various other outputs and then redisplay VERB 16 NOUN 45. At this time, the IMU status is indicated in R3. If alignment is unknown, R3 equals -00002. Otherwise, the MGA at t_{IG}(CSI) will be shown as a positive number. Having once keyed PRO as a response to VERB 16 NOUN 45, a second PRO response will terminate the program via Routine 00. [Recycling, using a VERB 32 ENTR response at this point is useless because no parameters will change (no marks can be accepted); the astronaut must wade through the other outputs before he can reach Routine 00.]

Output 4, ΔH_{CDH}, is critical to the operation of the pre-TPI routine called by P33 and P34. In particular, if the sign of ΔH_{CDH} is plus, indicating that the CM will be below the LM after CDH, then an E-angle of anything greater than 180 degrees will cause a 00611 alarm in P33 and P34. Such a situation is considered unlikely. Should it occur, sometime before final P33 computation the astronaut should key VERB 06 NOUN 55 ENTR and follow with the appropriate load verb to change E, in

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* Significant events are, Rendezvous Navigation first begun (i.e., P20 keyed-in for first time), W-matrix re-initialized, AVERAGEG, P37, or P76 terminated.

TABLE 5. 2. 2-II

P32 PROGRAM OUTPUTS (SHEET 1 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Accumulated Marks	Mark Counters	FL V16 N45	R1 xxBxx: VHF marks, Optics marks	VERB 32 ENTR starts computation process using latest update of state vector. PRO terminates mark process and starts final computation. See expanded commentary below.
2.	Time from ignition	TFI	FL V16 N45	R2 xxBxx: min, sec maximum: 59 min, 59 sec	Indicates time available for rendezvous navigation, execution time final P32 computation and burn preparation before t_{IG} (CSI).
3.	Middle gimbal angle (see comments at right)	MGA	FL V16 N45	R3 xxx.xx deg	-00001 indicates a PRO response to VERB 16 NOUN 45 has not been received. -00002 indicates a PRO response has been received, and the alignment of the ISS is unknown. +xxx.xx deg indicates a PRO response has been received and shows the (positive) MGA at TIG (CSI). A PRO response for a second time will allow the program to go to Routine 00.

TABLE 5.2.2-II
P32 PROGRAM OUTPUTS (SHEET 2 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
4.	Passive vehicle altitude minus active vehicle altitude at t_{IG} (CDH).	DELTA ALT (CDH)	FL V06 N75	R1 xxxx.x n. mi.	Normal response to VERB 06 NOUN 75 is PRO.
5.*	t_{IG} (CDH) minus t_{IG} (CSI)	DELTA T(CSI/CDH)	FL V06 N75	R2 xxBxx	Computed in hours, minutes, and seconds, of which only the minutes and seconds are displayed. See expanded notes below.
6.*	t_{IG} (TPI) minus t_{IG} (CDH)	DELTA T (CDH/TPI)	FL V06 N75	R3 xxBxx	Computed and displayed same as output 5.
7.	Impulsive Δv, in local vertical coordinates, for CSI	DELTA V (LV) (CSI)	FL V06 N81	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	Astronaut can change this vector by using VERB 25 ENTR. If unchanged, only R1 will be non-zero. A plane change can be exercised by keying R36, VERB 90 ENTR, and including the result in the Y component (R2) of the DELTA V(LV). See paragraph 9.2.4.
8.	Impulsive $\Delta \underline{v}$, in local vertical coordinates, for CDH	DELTA V(LV)	FL V06 N82	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	Calculation of DELTA V(LV) (CDH) assumes that the CSM was active at CSI.

*t_{IG} (CDH) is available by keying VERB 06 NOUN 13 ENTR

R2, to the value that the LM should use in a nominal TPI maneuver. (See paragraph 5.2.4.)

If output 4 is small (less than about 5 n. mi. magnitude), the astronaut should be prepared for a possible 00611 alarm in P33 due to excessive iterations. It is possible that varying t_{IG}(CDH) will avoid such problems; therefore, if he expects such a problem, the astronaut should select P33 for preliminary calculations very soon after CSI to allow time for searching for a solution. (See paragraph 5.2.3.)

The other outputs of P32 are self-explanatory. The following facts, however, should be emphasized. The minutes part of output 5 and 6, DELTA T (CSI/CDH) and DELTA T (CDH/TPI), are displayed modulo 60. That is, if the minutes of either output 5 or output 6 are greater than 60, they are divided by 60 and the remainder is displayed. Thus, it is possible to see values in outputs 5 or 6 that appear to be less than 10 minutes, even though no alarm has been called. Simply remember that output 5 plus output 6 must equal the time interval between t_{IG}(CSI) and t_{IG}(TPI). If the result appears to be an hour or two less, then the above process has occurred.

P32 calculates the CSI maneuver to be only along the X-axis of local vertical coordinates. If a plane change is desired at t_{IG}(CSI), the astronaut can call R36 (VERB 90 ENTR), and load the negative of the computed $\dot{Y}$ value for the CSM into the Y component (register 2) of the DELTA V(LV). (See paragraph 9.2.4 for an explanation of R36.)

Mission planning for the G flight specified that the CMC do P32 instead of P72 and simply change the sign of the burn and subtract a 1-fps bias for comparison with the LGC and chart solutions. It should be noted, however, that under such circumstances, there is no reason to expect output 8, DELTA V(LV) (CDH), to agree with the LGC output. Such agreement will only occur in P33, after CSI has occurred.

5.2.2.3 Program Coordination

Program coordination of P32 is not very complicated because P20 is usually the only program running along with it. This, again, is mission-dependent, but final computations in P32 should come 9 to 12 minutes prior to t_{IG}(CSI). A minimum of 3 minutes should be allowed for final P32 computation. Final computation time could increase, however, with a poor orbital configuration. A poor configuration would exist when the LM is in an off-nominal orbit (after an abort, for instance). In such a case, a preliminary computation should be made as soon as possible to see if more time should be allowed for final P32 computation.

5.2.2.4 Procedures for Correcting Alarm Conditions

When an alarm occurs and the astronaut wishes to change some input variable, he should key VERB 32 ENTR and use the appropriate load verb when the proper display comes up. In all cases, upon occurrence of an alarm display from P32, the first source of error to be considered should be bad input. The astronaut should recycle and check his input. Other possible sources of alarms are poor orbital configuration and bad estimates of state vectors in the CMC. If the estimates of state vectors contained in the CMC are believed to be bad, procedures should be followed to correct the situation. (See paragraph 4.2.1.) The following paragraphs assume good input conditions and good CMC state vector estimates.

All alarm codes are part of flashing display VERB 05 NOUN 09. A PRO response will do nothing; VERB 32 ENTR will recycle P32, allowing different inputs; VERB 34 ENTR will force the program to go to R00.

A list of alarm codes and procedures that may allow the program to run to completion follows:

a. Alarm code 00600 may occur if the E-angle line-of-sight from the active vehicle at TPI does not intersect the circle formed by the passive vehicle's radius at TPI.
b. Alarm code 00601 may occur if the post-CSI pericenter altitude is insufficient.
c. Alarm code 00602 may occur if the post-CDH pericenter altitude is insufficient.
d. Alarm code 00603 may occur if there is insufficient time between t_{IG} (CSI) and t_{IG} (CDH).
e. Alarm code 00604 may occur if there is insufficient time between t_{IG} (CDH) and t_{IG} (TPI).
f. Alarm code 00605 may occur if excessive iterations are occurring—without convergence.
g. Alarm code 00606 may occur if two successive iterations occur with a $\Delta \underline{v}$ greater than 1000 fps.

Alarm 00600 occurs if the active vehicle is so high relative to the passive vehicle at TPI, that it would be impossible to see the other vehicle with the given E-angle. This particular alarm will not occur in P72, using the same inputs, so one solution is to make the other vehicle do the CSI maneuver. (If that is done, however, it is conceivable that alarm 00601 or 00602 will occur, and a ground targeted maneuver will be required.) Increasing TPI time of ignition by one orbit, and increasing N by 1 or 2 may also help. One last possibility is to advance TPI time in 15-minute increments on successive cycles of P32. This violates the precondition that TPI be in the midpoint of darkness, but it may work.

Alarm codes 00601 and 00602 will generally occur when the active vehicle is forced to go into a lower orbit to catch up in phasing with the passive vehicle. The astronaut can try any of the following: increase TPI time, modify N, have the other vehicle perform the CSI maneuver, request a phasing maneuver of ground.

Alarm code 00603 can always be avoided by using the 180-degree option (input 4 nonzero).

Should alarm 00604 occur, recycle and use the 180-degree option. Should the alarm occur again, increase the TPI time by one orbital period, retaining the 180-degree option.

Alarm 00605 is unlikely to occur. Should it occur, however, either recycle with a different N, usually increasing N by 1, or move the whole sequence up by one orbital period.

Alarm code 00606 may occur if Δt (CSI/TPI) is too small for a given configuration. Increasing TPI time should lower the $\Delta \underline{v}$.

5.2.2.5 Restarts

P32 is restart protected

5.2.3 P33, Constant Delta Altitude Targeting (CDH) —CMC

The Constant Delta Altitude (CDH) maneuver results in an active vehicle orbit that remains at a nearly constant radial distance from the passive vehicle orbit. A CDH maneuver is usually targeted after a CSI maneuver in order to set up conditions for the transfer phase. (Refer to paragraphs 5.2.2 and 5.2.4 for an explanation of the CSI and TPI maneuvers, respectively.)

P33 targets for a CDH maneuver, using a t_{IG}(CDH) supplied by the astronaut at the beginning of P33 and a t_{IG}(TPI) and elevation angle (E) supplied by the astronaut at the beginning of P32.* In addition to targeting for CDH, P33 uses the pre-TPI routine to find the precise time when it will be possible to do a TPI maneuver, after CDH, using the desired E-angle. This allows the Command Module (CM) pilot to plan his post-CDH actions.

The targeting of the CDH maneuver within P33 is separate from the determination of the correct t_{IG}(TPI). Whereas a CDH maneuver is calculated simply by equalizing the velocities in the z-direction of the local vertical coordinate system, the pre-TPI routine takes the input t_{IG}(TPI) and uses it as an initial estimate in an iterative search for the precise time when the elevation angle coincides with the desired E-angle.

5.2.3.1 P33 Computational Sequence

After P33 is selected, it first enables tracking and mark incorporation by setting TRACK and UPDATE flags. Then the CM computer (CMC) flashes VERB 06 NOUN 13, which requests the astronaut to supply a t_{IG}(CDH) for the program. Under most circumstances (unless subsequently changed by the astronaut), the time displayed will be the t_{IG}(CDH) computed in P32. This value should only be used if the CM performed the CSI maneuver. If the LM performed the CSI maneuver, the LM t_{IG}(CDH) should be keyed in. Almost immediately after the proper value is keyed in, the CMC will flash VERB 16 NOUN 45, which requests the astronaut to determine whether the next computation cycle will be a preliminary or final computation. The appropriate responses to flashing VERB 16 NOUN 45 are VERB 32 ENTR and PRO for a preliminary and a final computation, respectively.

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* The CM pilot will probably use the t_{IG}(CDH) calculated by P32, if the CM performed the CSI maneuver. If the LM performed CSI, the CM pilot should use the t_{IG}(CDH) calculated by the LGC. Some alarm recovery procedures involve changing t_{IG}(CDH). (See paragraph 5.2.3.4.)

After a response to VERB 16 NOUN 45, the CMC prevents any mark incorporation for the duration of the succeeding calculations by resetting the UPDATE flag. These calculations can be divided into two parts. The first involves the calculation of a maneuver that will make the active vehicle orbit coelliptic with the passive vehicle orbit. The second takes the resultant orbit, and attempts to find the time when the desired E-angle exists.

The first calculation is purely analytical, and simply calculated the $\Delta \underline{v}$ necessary to make the active vehicle $\dot{H}$ [velocity along the local vertical at t_{IG}(CDH)] equal to the passive vehicle orbital $\dot{H}$; that is, the $\dot{H}$ on the passive vehicle orbit at the intersection of the passive vehicle orbit and the line formed by the projection of the active vehicle's position vector into the passive vehicle's plane.

The second calculation is the pre-TPI routine. It uses the t_{IG}(TPI) input into P32 as an initial estimate in an iteration scheme to find the exact time when the desired E-angle exists. If the pre-TPI routine cannot find the required time, a VERB 05 NOUN 09 alarm is flashed; the alarm code is 00611. If no alarm occurs, or if PRO is keyed in response to the flashing VERB 05 NOUN 09 display, P33 proceeds to the next display (VERB 06 NOUN 75). Before flashing this display, however, P33 determines whether the astronaut has keyed PRO in response to VERB 16 NOUN 45. If the FINAL flag is set, then he has keyed PRO; if reset, he has not, and P33 allows marks to be incorporated by setting the UPDATE flag. The VERB 06 NOUN 75 display [ΔH_{CDH}, Δt (CDH/TPI), Δt (TPI/TPI)], follows immediately, and is followed in turn by VERB 06 NOUN 81, $\Delta \underline{v}$(LV). If the astronaut wishes to produce a node, 90 deg after CDH, he may overwrite the contents of R2 of the NOUN 81 display with the value of $-\dot{Y}$(CSM) computed by R36, when T (EVENT) in NOUN 16 equals t_{IG}(CDH).*

The next display is VERB 16 NOUN 45. If the last computation completed was preliminary, the CM pilot will normally wait until a few more marks are incorporated before requesting a final computation. If the last computation completed was final, another PRO response to VERB 16 NOUN 45 allows the program to exit via R00.

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*R36 is initiated by keying in VERB 90 ENTR; $\dot{Y}$(CSM) is displayed in R2 of NOUN 90 in R36. Refer to paragraph 5.2.7.

5.2.3.2 Input and Outputs

A flowchart, Figure 5.2.3-1, and two tables, Table 5.2.3-I and Table 5.2.3-II, which summarize the operations of P33 follow. To understand the flowchart, the following definitions should be made:

a. TRACK and UPDATE flags refer to P20. If TRACK flag is set, tracking is allowed. If reset, it is not allowed. If UPDATE flag is set, the state vector may be updated from navigation marks. If it is reset, no updating from marks is possible.

b. REFSMMAT flag set indicates that the IMU alignment is known; reset, it is unknown.

c. FINAL flag set indicates the astronaut has keyed PRO in response to VERB 16 NOUN 45. Reset means he has not. (Refer to paragraph 5.2.3.1.)

Table 5.2.3-II lists P33 output. Outputs 1, 2, and 3 are a part of VERB 16 NOUN 45, which is both the first and last output display; its purpose is to show the status of Rendezvous Navigation (P20) in the CMC. R1 shows the number of marks incorporated since the latest significant event in P20.* R2 shows how much time is left before ignition to take marks and perform the final P33 computation. R3 indicates whether the CMC will accept marks or not. If R3 equals -00001, final computations have not been made by the CMC, and marks can be incorporated during any flashing display, except the alarm display. If the astronaut wishes to terminate the marking process and use the current estimate of the state vectors in the CMC, he should key PRO in response to a VERB 16 NOUN 45 display.

After PRO is keyed, no more marks will be incorporated into the state vector until reselection of a targeting program, and the CMC will calculate the maneuver parameters for a final time, display the other outputs, and redisplay VERB 16 NOUN 45. After a final computation, the IMU status is indicated in R3 of NOUN 45. If alignment is unknown, R3 equals -00002. Otherwise, the middle gimbal angle at t_{IG}(CDH) will be shown as a positive number. Once PRO has been keyed as a response to VERB 16 NOUN 45, keying a PRO again—as a second response—will terminate the program via Routine 00. [A VERB 32 ENTR response at this point is undesirable because no parameters will change (that is, no marks will be accepted or incorporated),

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*See paragraph 4.2.1 for the significance of the number of marks taken. Some examples of significant events in P20 are, Rendezvous Navigation first begun, W-matrix reinitialized, P76 terminated and AVERAGEG terminated.

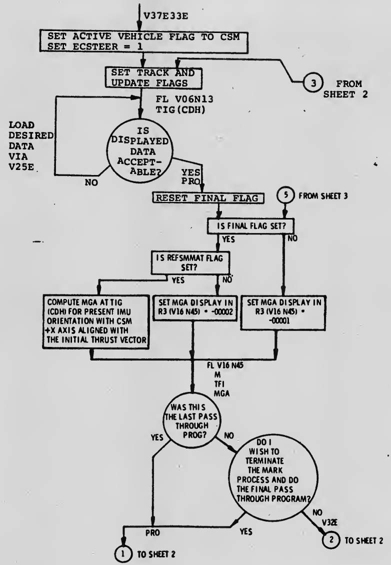


Figure 5.2.3-1. Constant Delta Altitude (CDH) Program (P33) (Sheet 1 of 3)

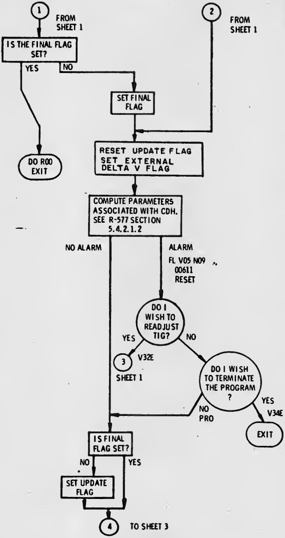
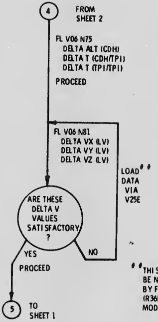


Figure 5.2.3-1. Constant Delta Altitude (CDH) Program (P33) (Sheet 2 of 3)



**THIS CAPABILITY WILL BE NORMALLY PERFORMED BY FIRST CALLING (R36) (V90E) THEN MODIFYING DELTA VY (LV)

NOTE: GETI (TPI) AVAILABLE VIA N37.

Figure 5.2.3-1. Constant Delta Altitude (CDH) Program (P33) (Sheet 3 of 3)

TABLE 5.2.3-I

P33 INPUT

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1*	Time of CDH ignition	t_{IG}(CDH)	FL V06 N13	R1 ooxxx. hr R2 oooxx. min R3 oxx.xx sec	This time is initially computed by P32. It should be changed if LM did CSI, to LGC-computed t_{IG} (CDH) or to recover from alarm conditions. (See paragraph 5.2.3.4.)
2*	Time of TPI ignition	t_{IG}(TPI)	None	None	This time is also an input to P32. It is used as an initial guess in the pre-TPI routine called by P33 to calculate the actual time when E (input 3) exists. Under certain conditions, it may be changed to help recover from alarm conditions. To call it up, in VERB 06 NOUN 37 ENTR. (See paragraph 5.2.3.4.)
3*	Elevation angle	E	None	None	This angle is also an input to P32. It will be displayed in R2 of NOUN 55 if it is called up by the astronaut. It can be changed to recover from alarm conditions. (See paragraph 5.2.3.4.)

* These inputs are already available in the CMC at the time P33 is keyed in.

TABLE 5.2.3-II

P33 OUTPUT (SHEET 1 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1	Accumulated marks	Mark counters	FL V16 N45	R1 xxBxx VHF marks, optics marks	VERB 32 ENTR starts computation process using latest update of state vector. PRO terminate mark process and completes final computation. See expanded commentary below.
2	Time from ignition	TFI	FL V16 N45	R2 xxBxx min, sec max. = 59 59	Indicates time available for rendezvous navigation before CDH burn.
3	Middle gimbal angle	MGA	FL V16 N45	R3 xxxxx	-00001 indicates a PRO response to VERB 16 NOUN 45 has not been received. -00002 indicates a PRO response has been received, and the alignment of the ISS is unknown. +xxx.xx indicates a PRO response has been received and shows the (positive) MGA at t_{IG}(CDH), in 0.01 degrees. A PRO response for a second time will allow the program to go to Routine 00 (terminate).
4	Passive vehicle orbit altitude minus active vehicle orbit altitude at t_{IG}(CDH)	DELTA ALT(CDH)	FL V06 N75	R1 xxxx.x n. mi.	Normal response to VERB 06 NOUN 75 is PRO.

TABLE 5.2.3-II
P33 OUTPUT (SHEET 2 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
5*	t_{IG}(TPI), as defined by P33, minus t_{IG} (CDH).	DELTA T(CDH/TPI)	FL V06 N75	R2 xxBxx	Computed in hours, minutes, and seconds, of which only the minutes and seconds are displayed. (See expanded notes, below.) It is conceivable that this value might be negative;i.e., t_{IG}(TPI), as defined by P33, is before t_{IG}(CDH).
6*	t_{IG}(TPI), as defined by P33, minus t_{IG} (TPI), as defined by P32, earlier.	DELTA T(TPI/TPI)	FL V06 N75	R3 xxBxx	Minutes displayed modulo 60. If a PRO response was received to alarm display VERB 05 NOUN 09, R3 will be zero, and R2 will be calculated using t_{IG}(TPI) as defined by P32.
7	Impulsive Δv, in local vertical coordinates, for CDH	DELTA V(LV)	FL V06 N81	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	A plane change can be made by keying in R36, VERB 90 ENTR, including the negative of the Y(CSM) result in the Y component of the DELTA V(LV). (See paragraph 9.2.4.)

*t_{IG}(TPI) computed by P33 can be displayed by keying in VERB 06 NOUN 37 ENTR.

and the astronaut will have to wade through the other outputs, uselessly, before he can reach Routine 00.]

Output 4, ΔH_{CDH}, is the radial distance at CDH between the active vehicle and the passive vehicle orbit just above or below it. Output 4 is critical to recovery from alarm conditions. (See paragraph 5.2.3.4.)

Output 5 is Δt(CDH/TPI). In trying to determine the correct t_{IG}(TPI), P33 first calculates the CDH maneuver parameters, and then extrapolates the post-CDH orbit. On the basis of that orbit, the pre-TPI routine searches for the correct t_{IG}(TPI). Using the computer mathematics, the post-CDH orbit can be extrapolated backwards in time, before CDH, as well as forward. It is conceivable that the proper E-angle might exist only before CDH, based on the post-CDH orbit. That is, if it were possible for the active vehicle to have been on the post-CDH orbit prior to CDH, then the proper E-angle would have existed at some time prior to CDH. Should this be the case, the computer will not be aware of the time difference, and will accept the indicated solution as a valid one. The astronaut can detect the occurrence of such a situation by observing output 5.

A negative output 5 indicates that P33 calculated TPI as coming before CDH. One of the conditions that P32 calculations must satisfy is that the time interval between CDH and TPI [Δt(CDH/TPI)] be greater than 10 minutes to allow time for rendezvous navigation after CDH. Output 5 of P33, however, can be negative, allowing no time for rendezvous navigation after CDH. Further, P33 accepts a negative solution as a valid solution. P33 also accepts an output 5 value of less than 10 minutes as a valid solution—a situation that would not provide sufficient navigation time. These situations might occur if CSI were poorly targeted, because of bad state vector estimates, or poorly executed. In any case, the CM pilot should carry out the CDH maneuver as targeted (assuming CSM-active) and select P34 with the time option (E equals 00000), with t_{IG}(TPI) set according to mission procedures.

The minutes part of outputs 5 and 6 [Δt(CDH/TPI) and Δt(TPI/TPI)] are displayed modulo 60. A large Δt(TPI/TPI); i.e., a large difference between the input t_{IG}(TPI) and the calculated t_{IG}(TPI), usually means that Rendezvous Navigation after CSI has considerably changed the CMC estimate of the vehicle states. This large difference is likely to occur if CSI were poorly targeted or poorly executed.

5.2.3.3 Program Coordination

Program coordination when using P33 is straightforward. A preliminary calculation is usually made fairly soon after CSI to get some idea of the maneuver characteristics;

a final computation ought to be made 9 to 12 minutes before t_{IG}(CDH), according to mission procedures. P33 can run by itself (in which case the ISS need not be operating) or it can run in conjunction with P20 (in which case marks can be incorporated during any flashing display—except an alarm display—until final computation is initiated by the astronaut by a PRO response to VERB 16 NOUN 45). The minimum time to allow for a final computation is 3 minutes.

Optimum targeting in P33 depends on relatively error-free estimates of the state vectors of the two vehicles with respect to each other. Ordinarily, there is ample time between CSI and CDH for P20 to reduce state vector errors. If SXT marks are taken in batches, as is recommended when both the SXT and the VHF are operating, P33 should be held at VERB 16 NOUN 45 until the end of a batch, and then a recycle or a final computation should be performed.

5.2.3.4 Alarms

Alarm code 00611 is the only alarm likely to occur during P33. Its occurrence indicates to the crew that the pre-TPI routine is unable to locate the time of existence of the proper E-angle. Figure 5.2.3-2 and Table 5.2.3-III summarize crew actions in response to a 00611 alarm.

In general, the recommended procedure in response to a 00611 alarm is for the CM pilot to attempt a correction of the alarm. The chart solutions, which depend on the correct E-angle at t_{IG}(TPI), will then be valid, and the rates and angles after TPI will be more familiar to the astronaut. If time does not permit an attempt at correction, rendezvous can be accomplished by keying PRO in response to the flashing VERB 05 NOUN 09 alarm display. This allows the program to terminate the current cycle without again searching for the proper t_{IG}(TPI). Another recycle or final computation will presumably cause another alarm, if no inputs are changed. The CM pilot should then perform the CDH maneuver as targeted (including any out-of-plane correction planned), and select P34, using the time option.

The following four circumstances could give rise to the 00611 alarm:

a. Excessive iterations because of small ΔH_{CDH}
b. Excessive iterations because the actual t_{IG}(TPI) is more than about 30 minutes from the input t_{IG}(TPI)
c. ΔH_{CDH} inconsistent with requested E
d. Active vehicle too high above the passive vehicle.

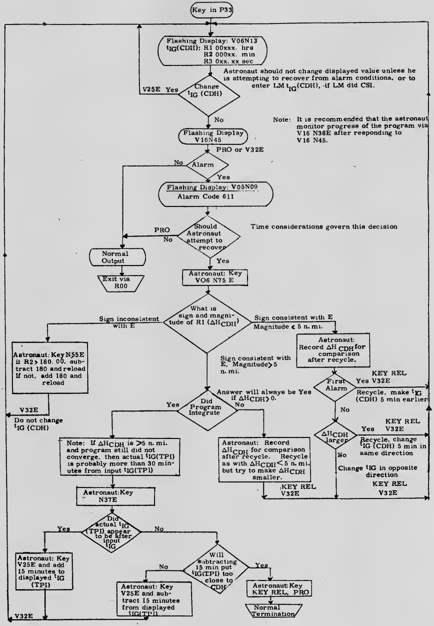


Figure 5. 2. 3-2. Alarm Code 00611 Conditions and Crew Actions

TABLE 5.2.3-III
ALARM RECOVERY SUMMARY

Circumstances giving rise to 00611 alarm	Diagnostic	Cause	Recovery
1. Excessive iterations	Monitor program via VERB 16 NOUN 38 ENTR. Oscillation occurs quickly. ΔH_{CDH}(R1 in NOUN 75) < 5n. mi.	Pre CSI configuration slightly off-nominal; Not serious.	Record ΔH_{CDH} for comparison if alarm recurs. Attempt to increase magnitude of ΔH_{CDH}. Recycle, changing t_{IG}(CDH) by 5 min. intervals, according to change in ΔH_{CDH}
2. Excessive iterations	Monitor program via VERB 16 NOUN 38 ENTR. Actual t_{IG} appears far from input t_{IG}(TPI). Oscillation does not occur quickly. ΔH_{CDH} not necessarily small.	Post-CSI rendezvous navigation has produced significant changes in state vector estimates.	If time permits, change t_{IG}(TPI) via VERB 06 NOUN 37 ENTR, followed by appropriate load verb.
3. SIGN of ΔH_{CDH} inconsistent with E.	R1 NOUN 75 has wrong sign. (If E > 180°, ΔH_{CDH} must be negative. If E < 180°, ΔH_{CDH} must be positive).	Pre-CSI configuration is off-nominal, or wrong E was loaded.	Key in VERB 06 NOUN 55 ENTR; if E in R2 is less than 180°, add 180° and reload. If R2 is greater than 180°, subtract 180° and reload.
4. Active vehicle too high relative to passive vehicle.	R1 in NOUN 75 is negative and quite large.	Post-CSI navigation produced significant changes in state vector estimates.	Recycle as in 1, but attempt to diminish magnitude of ΔH_{CDH}

The astronaut can often foresee circumstances 1 and 3 by checking the output of P32. If output 1, ΔH_{CDH}, is less than 5 n. mi., or is of the wrong sign, the CM pilot should select P33 soon after CSI to check for alarm conditions.*

Circumstances 2 and 4 could only arise (assuming CDH is used as a part of the coelliptic sequence) from a poorly targeted (due to bad onboard state vector estimates) or a poorly executed CSI maneuver. The astronaut might suspect poor targeting and poor execution if IMU alignment is known to have been poor before CSI; if insufficient marks were taken before CSI; or if CSI is known to have been poorly executed. In any case, the CMC will assume that CSI targeting and execution went well, and will not give an alarm until Rendezvous Navigation (P20) has had time to modify the relative vehicle state vectors, bringing them more in line with the true situation. That is, the CMC can only be made aware of the fact that CSI was poorly targeted or executed by a period of rendezvous navigation after CSI. Without such navigation, a 00611 alarm will not arise from circumstances 2 and 4, in spite of the fact that the real situation might warrant such an alarm. Therefore, if P20 marking indicates a large state vector error by producing excessive updates after CSI, the CM pilot should be prepared for the occurrence of a 00611 alarm in P33.

Recovery procedures are different for each circumstance causing a 00611 alarm. It is, therefore, necessary first to determine the nature of the cause. As was mentioned above, output 1 from P32 should warn the CM pilot that ΔH_{CDH} is either too small, or is inconsistent with E. But poor targeting or execution of CSI could also have produced this anomalous ΔH_{CDH}. Therefore, even if ΔH_{CDH} appeared good in P32, these circumstances should not be excluded. The first action in an attempt to recover from alarm conditions, therefore, is to examine ΔH_{CDH}, the contents of R1 of NOUN 75.

If ΔH_{CDH} is inconsistent with E, then 180 deg should be added to E (displayed as R2 in NOUN 55) if E is less than 180 deg; 180 deg should be subtracted from E if E is greater than 180 deg.

If ΔH_{CDH} is consistent with E, but is less then 5 n. mi., the astronaut should recycle (VERB 32 ENTR) and subtract 5 minutes from t_{IG}(CDH), because, under most circumstances, the pre-CDH orbits are converging. If the alarm occurs again,

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* If E is greater than 180 deg, ΔH_{CDH} should be negative; if E is less than 180 deg, ΔH_{CDH} should be positive.

ΔH_{CDH} should again be checked to see if it is now larger or smaller than before. If it is larger, recycle and subtract another 5 minutes. If it is smaller, then the orbits are diverging, and a later t_{IG}(CDH) should be tried.

If ΔH_{CDH} is positive, greater than 5 n. mi., and consistent with E, then the actual t_{IG}(TPI) lies more than about 30 minutes from the input t_{IG}(TPI) supplied from P32. If ΔH_{CDH} is negative, indicating active vehicle above passive vehicle, greater than 5 n. mi., and consistent with E, then either t_{IG}(TPI) lies more than about 30 minutes from the input t_{IG}(TPI), or the active vehicle is too high above the passive vehicle. By monitoring the progress of the program (via VERB 16 NOUN 38 ENTR), the astronaut can determine whether the active vehicle is too high above the passive vehicle (the program does not attempt to search for E under such conditions), or whether the actual t_{IG}(TPI) is too far before or after the input t_{IG}(TPI).

To describe how to monitor the program, it is first necessary to describe how the pre-TPI routine works. The pre-TPI routine accepts as input the active and passive vehicle state vectors, extrapolated to the input t_{IG}(TPI), the initial estimate used in the search for the actual t_{IG}(TPI). At this point, the alarm conditions of E, inconsistent with ΔH_{CDH} and active vehicle too high above the passive vehicle, are tested.

If these 2 tests are satisfied, the program first determines whether the correct E-angle exists before or after the given t_{IG}(TPI), and then proceeds to extrapolate the two vehicle state vectors, in steps limited to 250 sec, towards the time when the correct E-angle exists. This continues until the E-angle is reached.

When the CM pilot monitors P33, via VERB 16 NOUN 38, he will see the time associated with the vehicle state vectors. The displayed time, expressed in hours, minutes and seconds, will be augmented until the input TPI time is reached and the pre-TPI routine is entered. Then it will increase, if the actual t_{IG}(TPI) is after the input t_{IG}(TPI), or diminish if the opposite is true.

If the active vehicle is too high above the passive vehicle, or if E is inconsistent with ΔH_{CDH}, the program will not iterate after input t_{IG}(TPI) is reached. If ΔH_{CDH} is too small, the times will probably oscillate very soon after the input t_{IG}(TPI) is reached, and continue to oscillate for quite a while. If the actual TPI time is too far from the input TPI time, i.e., greater than approximately 30 minutes, then the displayed time will move quite far from the input t_{IG}(TPI) before oscillation begins.

If the active vehicle is too high relative to the passive vehicle, the CM pilot should recycle and augment t_{IG}(CDH), in an attempt to diminish ΔH_{CDH}. If an alarm occurs again, ΔH_{CDH} should be checked to see if it is smaller (in which case another recycle and a second augmentation of t_{IG} (CDH) is in order), or larger (in which case t_{IG} (CDH) should be diminished).

If actual t_{IG}(TPI) is far from input t_{IG}(TPI), the input t_{IG}(TPI), available in NOUN 37, should be moved in the direction of the actual t_{IG}(TPI).

5.2.3.5 Restarts

A restart that occurs during the operation of P33 will only cause a time loss (the maximum time loss is just less than the time required for final computation), not a loss of validity in the solution.

5.2.4 P34, Transfer -phase Initiation (TPI) —CMC

P34 targets for the Transfer Phase Initiation maneuver (TPI), a part of the rendezvous sequence. The TPI maneuver occurs after the coelliptic sequence maneuvers (CSI and CDH), which are designed to produce a configuration at TPI with two important characteristics: coelliptic orbits, and a particular elevation angle, E, between the active-to-passive LOS and the +x direction of the local vertical coordinate frame at t_{IG}(TPI). If the coelliptic sequence is successful in producing such a configuration, the second part of the rendezvous sequence, the transfer phase, has the following four desirable properties:

a. The closing rate is rather slow

b. The changes in the LOS elevation angle are predictable

c. The direction of the thrust vector for the TPI maneuver very nearly coincides with the LOS

d. The magnitude of the change in velocity, measured in feet per second, is very close to twice the difference in altitude between the orbits, measured in n. mi.

These properties allow for easy monitoring of the transfer phase, and easy astronaut takeover in the event of computer malfunction during and after the TPI maneuver.

P34 must interface with two other programs, P20, Rendezvous Navigation, and P40 or P41, the thrusting programs. P20 is needed after every maneuver in the rendezvous sequence to improve the estimate of the state vectors. The thrusting programs carry out the maneuver targeted by P34. A preliminary estimate of the maneuver can be computed before navigation is completed; marks can be incorporated during some flashing displays, until the final computation is initiated.

P34 is divided into two computation phases. The first sets up the input to the second. The first phase can be done one of two ways. It either accepts a desired E-angle and iterates to find the time when the angle exists, or it accepts a time and calculates the E-angle existing at that time.

The second phase takes the calculated (or requested) E-angle and calculated (or requested) time, and the requested CENTANG, and calculates a Lambert maneuver designed to effect intercept. The maneuver calculation can be done in one of two ways. The target vector is determined either conically, or with a specified number of precision offsets.

5.2.4.1 P34 Computational Sequence

When P34 is called, it first enables tracking and mark incorporation by setting TRACK and UPDATE flags. Then the CMC flashes VERB 06 NOUN 37, which requests the astronaut to supply a t_{IG}(TPI) for the program. Under most circumstances, the time displayed will be that computed by P33. If a 00611 alarm out of P33 was bypassed, then the time displayed will be that input by the astronaut to P32 (unless it was subsequently changed by the astronaut). VERB 06 NOUN 55 is then displayed. NOUN 55 allows the astronaut to exercise the two choices available in P34: the E-angle-time (in R2, E does not equal 0 or E equals 0) choice, and the conic-precision offset targeting (in R1, NN equals 0 or NN does not equal 0) choice. After VERB 06 NOUN 55, P34 flashes VERB 16 NOUN 45, which allows the astronaut to monitor the progress of Rendezvous Navigation by displaying the mark counters. VERB 16 NOUN 45 also requests the astronaut to determine whether the next cycle will be a preliminary or a final computation. The appropriate responses are, VERB 32 ENTR and PRO, respectively.

After a response to VERB 16 NOUN 45 is made, the CMC prohibits further mark incorporation for the duration of the succeeding calculations by resetting the UPDATE flag. These calculations can be divided into two parts. If the E-option is exercised, by loading + xxx.xx (where xxx.xx is nonzero) into R2, the first part of P34 is the pre-TPI routine, which determines exactly when the correct E-angle exists. If the proper time is found, then P34 flashes VERB 06 NOUN 37. If P34 cannot find the proper time, alarm 00611 occurs as a part of VERB 05 NOUN 09. If the time option is exercised, by loading +00000 in R2 of NOUN 55, the first part of P34 will take the input t_{IG}(TPI) and compute the E-angle existing at that time and flash the result as part of the VERB 06 NOUN 55 display.

After either E or the proper t_{IG}(TPI) is calculated and displayed, P34 targets an intercept course. If the current pass is the final computation, the impulsive $\Delta \underline{v}$ is displayed in local vertical coordinates, (VERB 06 NOUN 81) which allows the astronaut to overwrite R2 with $-\dot{Y}$(CSM), from R36, to produce a node 90-deg later. Should R2 be written over, P34 recomputes the target vector accordingly. The $\Delta \underline{v}$ is displayed in LOS coordinates (VERB 06 NOUN 59) for recycles and final computation.

VERB 16 NOUN 45 follows almost immediately. If the last computation was preliminary, the CM pilot will probably wait until a few more marks are incorporated before requesting a final computation. If the last computation was final, keying PRO allows P34 to exit via R00.

5.2.4.2 Inputs and Outputs

A flowchart, Figure 5.2.4-1, and two tables, Table 5.2.4-I and Table 5.2.4-II, describing P34 input and output follow. To understand the flowchart, the following facts must be known.

1. TRACK and UPDATE flags refer to Rendezvous Navigation. If the TRACK flag is set, tracking is allowed. If the TRACK flag is reset, tracking is not allowed. If the UPDATE flag is set, marks will be incorporated; if it is reset, marks can be taken, but will not be incorporated.
2. FINAL flag set means a PRO response to a flashing VERB 16 NOUN 45 display has been received; reset, a PRO response has not been received.

Input 1, t_{IG}(TPI), will ordinarily be retained as displayed. This value for t_{IG}(TPI) is usually the same as the one computed in P33. If everything has gone well, the input t_{IG}(TPI) should be quite close to the time when the actual elevation angle coincides with the desired E (input 3).

Input 2, NN, governs which method of calculation the program will use in the second computation phase. If NN equals 00000, the program will calculate a conic approximation of the correct TPI maneuver. In the lunar gravitational sphere, the accuracy of this method is equivalent to target offsetting. Its advantage over the other method, called when NN does not equal 00000, is its speed in obtaining an answer. For earth-orbital rendezvous, NN equals 00002 is recommended for a correct answer because of oblateness effects, in spite of the time consumed in using it. (Refer to Table 5.2.4-I.)

Input 3, E, governs which method of calculation the program will use in the first computation phase. If E equals 00000, the program will calculate a maneuver appropriate to the input t_{IG}(TPI). If E does not equal 00000, the program will accept the input number as an angle, to the nearest 0.01 degree, and use the input t_{IG}(TPI) (input 1) as an initial estimate for the pre-TPI routine.

Input 4, CENTANG, indicates the orbital central angle through which the passive vehicle must pass between t_{IG}(TPI) and intercept. Implicit in CENTANG is a target vector and a transfer time, which the Lambert targeting routine uses as input.

Table 5.2.4-II lists P34 output. Outputs 1-3 are contained in VERB 16 NOUN 45, which is both the first and the last output display. The purpose of VERB 16 NOUN 45 is to show the status of P20 in the CMC. R1 shows the number of marks incorporated

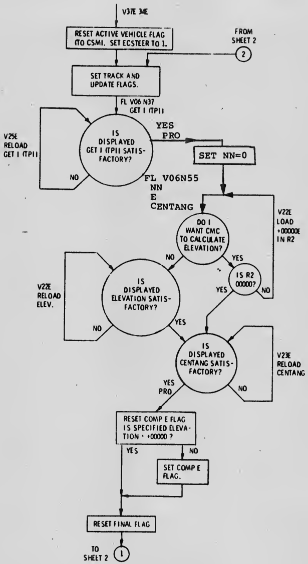

Figure 5.2.4-1. Transfer Phase Initiation Program (P34) (Sheet 1 of 3)

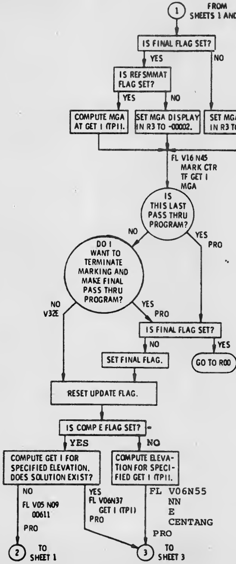

Figure 5.2.4-1. Transfer Phase Initiation Program (P34) (Sheet 2 of 3)

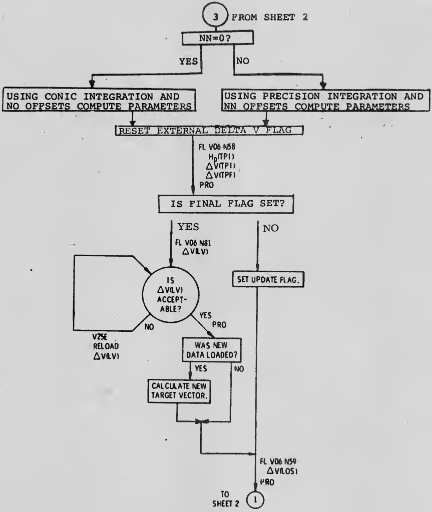

Figure 5.2.4-1. Transfer Phase Initiation Program (P34) (Sheet 3 of 3)

TABLE 5.2.4-I

P34 INPUT

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1	TPI time of ignition	TIG(TPI)	FL V06 N37	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec	This will initially flash the value computed by P33 (unless subsequently changed by the astronaut). If the E-option is used, input 1 will be used as an initial guess as the program tries to locate the time when the elevation angle coincides with the desired E (input 3). If the time-option is exercised, then input 1 will be the actual t_{IG} (TPI).
2	Conic-precision switch; if positive, number of offsets to be used in Lambert targeting.	NN	FL V06 N55	R1 xxxxx	If input 2 = 00000, the recommended value for lunar orbital activities, the very fast conic integration will be used to calculate the TPI maneuver. Input 2 = +00002 is recommended for earth orbit activities to account for oblateness effects. Any positive number will cause the program to use precision offsets.
3	E-option-time-option switch; if nonzero, desired E angle	E	FL V06 N55	R2 xxx. xx deg	If input 3 = 00000, program will accept input 1 as desired t_{IG}(TPI), and calculate a TPI maneuver for that time. If input 3 ≠ 00000, the program will use input 1 as an initial guess in an attempt to find the time when the elevation angle coincides with input 3.
4	Central angle through which the passive vehicle must pass from t_{IG}(TPI) to intercept.	CENTANG	FL V06 N55	R3 xxx. xx deg	This is set according to mission procedures.

TABLE 5.2.4-II

P34 OUTPUT (SHEET 1 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1	Accumulated Marks	Mark Counters	FL V16 N45	R1 xxBxx VHF marks, optics marks	VERB 32 ENTR starts computation process using latest update of state vectors. A PRO terminates mark incorporation and completes final computation.
2	Time from Ignition	TFI	FL V16 N45	R2 xxBxx min, sec maximum: 59 min, 59 sec	Indicates time available for rendezvous navigation before TPI burn.
3	Middle Gimbal Angle	MGA	FL V16 N45	R3 xxxxx	-00001 indicates a PRO response to VERB 16 NOUN 45 has not been received. -00002 indicates a PRO response has been received, and the alignment of the ISS is unknown. +xxxxx indicates a PRO response has been received and shows the (positive) MGA at t_{IG}(TPI), in 0.01 degrees. A PRO response for a second time will allow the program to go Routine 00.
	If the astronaut requested the time option by putting in +00000 for E (input 3), then outputs 4, 5 and 6 will follow outputs 1, 2 and 3, and then output 8 will follow. Otherwise 4, 5, and 6 will be skipped, and 7 will follow 1, 2, and 3.				
4	Number of target offsets	NN	FL V06 N55	R1 xxxxx	This register will display whatever was put in by the astronaut.
5	Elevation angle. (see input 3 for definition)	E	FL V06 N55	R2 xxx.xx deg	This register will now display the actual elevation angle for the given t_{IG}(TPI).

TABLE 5.2.4-II

P34 OUTPUT (SHEET 2 OF 3)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
6	Orbital central angle of the passive vehicle during transfer from t_{IG}(TPI) to intercept.	CENTANG	FL V06 N55	R3 xxx. xx deg	This register will display whatever was put in by the astronaut.
7	Calculated time ignition for TPI	TIG(TPI)	FL V06 N37	R1 ooxxx. hrs R2 oooxx. min R3 oxx. xx sec	When the astronaut wishes to do TPI with a certain E-angle, the program searches for a time when that E-angle exists. Output 7 is that time.
8	Perigee altitude	PER ALT	FL V06 N58	R1 xxxx. x n. mi.	This perigee altitude is altitude above pad radius, for the earth, or altitude above the latest landing site, for the moon.
9	Impulsive change in velocity for TPI	ΔV(TPI)	FL V06 N58	R2 xxxx. x fps	P34 and P35 burns are Lambert maneuvers.
10	Impulsive change in velocity for TPF	ΔV(TPF)	FL V06 N58	R3 xxxx. x fps	
11	Impulsive change in velocity vector in local vertical coordinates	ΔV (LV)	FL V06 N81	R1 xxxx. x fps X R2 xxxx. x fps Y R3 xxxx. x fps Z	Displayed only after final computation. Crew has the option at this time to redefine the $\Delta\underline{v}$(LV) components for the subsequent thrusting maneuver.

TABLE 5.2.4-II

P34 OUTPUT (SHEET 3 OF 3)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
					If the astronaut wishes to produce a node 90° after TPI, he should select the rendezvous out-of-plane display, Routine 36 (VERB 90 ENTR), and then overwrite R2 of Δv (LV), using the appropriate load verb, with - Y (CSM)
12	Impulsive change in velocity vector in LOS coordinates.	ΔV(LOS)	FL V06 N59	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	LOS coordinates are defined in paragraph 5.2.4.2.

since the last significant event in P20.* R2 shows how much time is left to take marks and perform the final P34 computation before ignition. R3 indicates whether the CMC will accept marks. If R3 equals -00001, then final computations have not been made by the CMC, and marks can be incorporated during some flashing displays. If the astronaut wishes to terminate the marking process and use the current estimate of the state vectors in the CMC for a final P34 solution, he should key PRO in response to a VERB 16 NOUN 45 display. After PRO, no more marks will be incorporated in the CMC state vector. The computer will calculate the maneuver parameters for a final time, display the various other outputs, and then redisplay VERB 16 NOUN 45. After a final computation, the IMU status is indicated in R3. If alignment is unknown, R3 equals -00002, otherwise, the middle gimbal angle (contents of R3) at t_{IG}(TPI) will be shown as a positive number. A second PRO response to VERB 16 NOUN 45 will terminate the program via Routine 00. The astronaut should not attempt to recycle (by keying in VERB 32 ENTR) at this point, because no parameters will change; that is, no marks will be incorporated, and the astronaut will be forced to uselessly wade through the other outputs before reaching Routine 00.

Depending on the mode used, either a VERB 06 NOUN 55 or a VERB 06 NOUN 37 will flash after all but the final VERB 16 NOUN 45 displays. If the time option (E equals 00000) was exercised, the program will compute E for the specified t_{IG}(TPI), and display it as R2 (output 5) in a VERB 06 NOUN 55 display. Registers 1 and 3 will be identical with inputs 2 and 4, supplied by the astronaut. If the E option is exercised, output 7, the computed t_{IG}(TPI), will be flashed in a VERB 06 NOUN 37 display.

After either the NOUN 55 or the NOUN 37 display, the program calculates the $\Delta \underline{v}$ required for the TPI maneuver. When the thrust vector is calculated, the program flashes a VERB 06 NOUN 58 display, containing outputs 8, 9 and 10 in R1, R2 and R3, respectively. Refer to Table 5.2.4-II for an explanation of these outputs, which represent the magnitudes of the initial and final maneuvers of the transfer phase. Output 11, flashed only after final computation, and output 12 show the thrust vector displayed first in the local vertical coordinates, at t_{IG}(TPI), and then in LOS coordinates. (For a description of the local vertical coordinate system, refer to Document No. R-577, paragraph 5.1.4.2.) The LOS coordinate system can be described as follows:

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* Refer to paragraph 4.2.1 for the significance of the number of marks taken. Some examples of significant events in P20 are P20 originally keyed in, W-matrix reinitialized, AVERAGEG terminated, and P76 terminated.

LOS Coordinate System

$$\underline{X}\ (\text{LOS}) = \text{unit}\ (\underline{r}_P\ -\underline{r}_A)$$

$$\underline{Y}\ (\text{LOS}) = \text{unit}\ \left[((\underline{r}_A \times \underline{v}_A) \times \underline{X}\ (\text{LOS}))\times \underline{X}\ (\text{LOS})\right]$$

$$\underline{Z}\ (\text{LOS}) = \text{unit}\ \left[\ \underline{X}\,(\text{LOS}) \times \underline{Y}\ (\text{LOS})\right]$$

In other words, the active-passive LOS is along the +X(LOS) axis. Y(LOS) is perpendicular to X(LOS), in the plane formed by X(LOS) and Y(LV). Z(LOS) completes the right-handed system.

As was mentioned above, VERB 16 NOUN 45 is flashed after final computation, before the program terminates, and R3 equals either -00002 or the positive middle gimbal angle at t_{IG}(TPI).

5.2.4.3 Program Coordination

Like all the rendezvous targeting programs, P34 can be used in conjunction with P20. Although P20 requires that the ISS be running and aligned, P34 does not. SXT marks can be taken via R21 during any P34 flashing display; VHF marks can accumulate throughout the program. Marks are only incorporated, however, during the initial NOUN 55 and NOUN 37 displays and during NOUN 45 and NOUN 59 displays preceding the request for final computation (PRO to FL VERB 16 NOUN 45.)

The P34/P40 or P41 interface is automatic, and need not concern the astronaut.

5.2.4.4 Program Limitations

Under certain conditions, such as a small ΔH_{CDH}, the program may not be able to find the desired E-angle. This will cause a 00611 alarm code to be flashed as part of a VERB 05 NOUN 09 display. If the desired E-angle cannot be found, the procedures outlined in paragraph 5.2.4.5 should be followed. The time option will always produce a solution for rendezvous.

5.2.4.5 Alarms

Alarm 00611 is the only alarm code likely to occur during P34. The circumstances under which alarm 00611 might occur are described in paragraph 5.2.3.4. Unless CDH is poorly performed, this alarm should occur during P33 when the CM pilot is likely to have more time to search for a solution. In a time-critical situation like the period between CDH and TPI, the iteration process used to find t_{IG}(TPI) is usually too lengthy to be used more than once. Therefore, if a 00611 alarm should occur in P34, it is recommended that the CM pilot recycle (by keying in VERB 32 ENTR), use the time option (input 3, E equals 00000), and leave the other inputs unchanged.

5.2.4.6 Restarts

P34 is protected against restarts. If one should occur during P34 operation, no loss of accuracy, but a loss of time—equal at most to the time required for a final computation—would occur.

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5.2.5 P35, Transfer Phase Midcourse (TPM)-CMC

P35 targets a midcourse correction for the transfer phase of the rendezvous sequence. All of the P35 inputs are available in the computer at the time it is selected; the astronaut need not key in anything but P35, itself. The inputs to P35 are as follows:

a. Active and passive vehicle state vectors, as updated by P20, if it is running

b. Time of intercept, as calculated by P34

c. Time of ignition, defined as follows:

    Current time + A

    where A is pad-loaded, or loaded via P27.

d. NN, the conic-precision offset target switch, input in P34 as R1 of NOUN 55.

Given these inputs, P35 targets a midcourse correction using the Lambert routine. It computes the required Lambert target vector and transfer time and displays the required impulsive $\Delta \underline{v}$, both in local vertical coordinates and in LOS coordinates (if the computation was a final computation). P35 also allows the astronaut to monitor the progress of P20 by flashing the standard VERB 16 NOUN 45 display described in paragraph 5.2.4.

Like all the other rendezvous targeting programs, P35 must interface with two other major modes, P20 and P40/P41. P20 can run along with P35. Marks with the optics can be taken and incorporated during any flashing display before final computation is requested by a PRO response to VERB 16 NOUN 45; VHF marks can accumulate until a PRO indicates final computation. P35 must initialize registers for P40/P41 (ECSTEER, for instance), but this is done automatically, without the aid of the astronaut. No alarms are expected during P35.

5.2.5.1 Options

P35 provides one choice. The astronaut must decide whether he wishes a preliminary or a final computation of the midcourse correction $\Delta \underline{v}$ that P40/P41 will use. This decision will be based on mission procedures and the status of Rendezvous Navigation (P20) (i.e., whether sufficient marks have been incorporated or not).

5.2.5.2 P35 Computational Sequence

The P35 computational sequence is not complicated. The inputs are obtained from various computer locations and the target vector is calculated, either conically or using precision offsets, as specified by NN. (Refer to paragraph 5.2.4.) Figure 5.2.5-1 is a flowchart of P35. Tables 5.2.5-I and 5.2.5-II show P35 input and output, respectively.

When P35 is selected, it first enables tracking and mark incorporation by setting TRACK and UPDATE flags. Then the CM computer flashes VERB 16 NOUN 45, the standard monitor for P20. It should be noted here that R2, showing the time from ignition (TFI), displays a positive number the first time VERB 16 NOUN 45 comes up. In actual fact, the time shown is time from ignition of the last maneuver (or maneuver calculation), because the registers containing t_{IG}(TPM) are not loaded until some response is made to VERB 16 NOUN 45. This allows the astronaut to space out the midcourse maneuvers according to mission planning.

After a PRO or VERB 32 ENTR response is made to the VERB 16 NOUN 45 display, a pad-loaded or uplinked increment, A, is added to the time when the response was made to produce the time for the TPM ignition (even if the current cycle is a preliminary computation). Then, the CMC uses the time of intercept computed in P34 to extrapolate the target vector. If NN was nonzero in P34, indicating a certain number of precision offsets, P35 will use that number of precision offsets in computing the target vector. If NN was zero in P34, P35 will compute the target vector using conic integration.

After the target vector and corresponding $\Delta \underline{v}$ have been computed, if the current computation is a final one, P35 flashes the $\Delta \underline{v}$ in local vertical coordinates via VERB 06 NOUN 81. This allows the astronaut to overwrite R2 with $-\dot{Y}$(CSM) computed by R36. Should R2 be changed, P35 will recompute the target vector accordingly. The $\Delta \underline{v}$ is displayed in LOS coordinates, whether the computation was final or not.

The final display, common to all targeting routines, is VERB 16 NOUN 45. If the last computation was preliminary, the CM pilot will probably wait until a few more marks have been incorporated before requesting a final computation. If the last computation was final, keying PRO will allow P35 to exit via R00.

5.2.5.3 Restrictions and Limitations

If input 4, CENTANG, to P34 was greater than 180 deg, the transfer angle from position at t_{IG}(TPM) to the target vector (available from VERB 06 NOUN 52) might be in the range 165 to 195 deg. If it is, P35 will rotate the target vector into the plane of the active vehicle. This will result in the loss of any out-of-plane correction. If the transfer angle is in the range of 165 to 195 deg, it is recommended that the

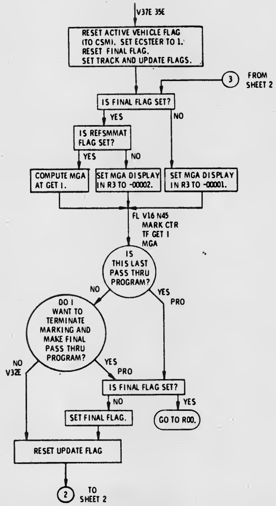

Figure 5.2.5-1. Transfer Phase Midcourse Program (P35) (Sheet 1 of 2)

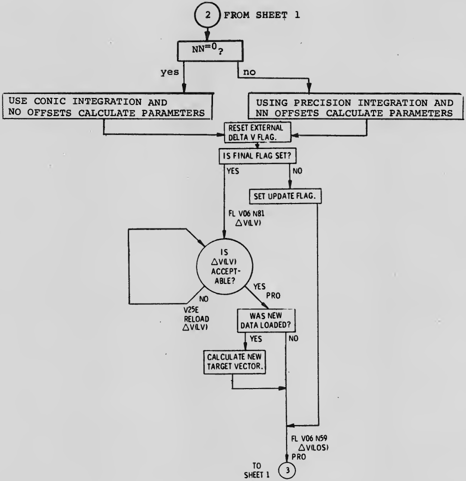

Figure 5.2.5-1. Transfer Phase Midcourse Program (P35) (Sheet 2 of 2)

TABLE 5.2.5-I

P35 INPUT

Input	Identification	Input Source (no inputs are displayed)	Comments
1*	Time of midcourse correction	TIG (TPM) is the time when the current recycle or final computation was requested, plus a pad-loaded or uplinked delay interval, A. A is usually about three minutes.	Given that t_{IG} (TPM) changes with each recycle or final computation (or restart, if one occurs between the request for a recycle or final computation and the corresponding solution), one can expect the calculated maneuver to change somewhat with each computation.
2*	Time of intercept	Calculated by P34 from CENTANG.	
3*	Conic-Precision offset target switch, NN.	If P34 was requested to do conic targeting (R1 of NOUN 55 = 00000), P35 will do the same. If P34 did a certain number of precision offsets, P35 will do the same number.	

*No actual input is required.

TABLE 5.2.5-II

P35 OUTPUT (SHEET 1 OF 2)

Input	Identification	Mnemonic	DSKY	Register	Comments
1	VHF and optics marks incorporated since latest significant event in P20 (i.e., P20 originally selected, W-matrix reinitialized, AVERAGEG or P76 terminated.)	Mark counters	FL V16 N45	R1 xxBxx	A VERB 32 ENTR response to a flashing VERB 16 NOUN 45 display will recycle for a preliminary computation. An initial PRO response will halt incorporation of marks and allow final computation. If it is decided that the final computation cannot be used, a VERB 32 ENTR response will allow a final comp with a slightly later t_{IG}(TPM). Once an initial PRO has been keyed in response to a flashing VERB 16 NOUN 45 display, no more marks will be incorporated until UPDATE flag is once again set--for instance by reselecting P35.
2	Time from ignition	TFI	FL V16 N45	R2 xxBxx min, sec	
3	Final computation; recycle indicator. Middle gimbal angle at t_{IG}(TPM)	Middle gimbal angle	FL V16 N45	R3 xxx.xx deg	If displayed value = -00001, PRO has not been keyed in response to a VERB 16 NOUN 45 flashing display. If PRO has been keyed in response to that display, then a positive number indicates the MGA at t_{IG}(TPM). -00002 indicates IMU alignment is not currently known.
4	Impulsive change in velocity, in Local Vertical Coordinates.	DELTA V(LV)	FL V06 N81	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	Flashed only after final computation. The Y component may be overwritten with $-\dot{Y}$(CSM), calculated by R36 with T(EVENT) = t_{IG}(TPM).

TABLE 5.2.5-II
P35 OUTPUT (SHEET 2 OF 2)

Input	Identification	Mnemonic	DSKY	Register	Comments
5	Impulsive change in velocity vector, in LOS coordinates.	DELTA V(LOS)	FL V06 N59	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	LOS coordinates are defined in paragraph 5.2.4.

maneuver be recalculated about 12 minutes later in the lunar sphere, to eliminate the loss of any out-of-plane correction. A delay allows the transfer angle to become less than 165 deg.

5.2.5.4 Restarts

If a restart occurs during the calculation of the TPM maneuver (after a response to VERB 16 NOUN 45 but before the next display), P35 starts again just after the VERB 16 NOUN 45 display. Since A, the time increment (refer to 5.2.5 c), is added to the current time after the restart protection point in the program, the maneuver will be targeted for a time slightly later than A plus the time of restart occurrence.

5.2.6 P37, Return-to-earth Targeting

Program P37 provides the crew with an onboard means of targeting for a Lambert-aimpoint maneuver that will return the spacecraft to a proper earth-reentry state.[*] Targeting with P37 is wholly independent of earth communication and can be used either for an SPS maneuver (P40) or an RCS maneuver (P41).[**] The program can be utilized to return from (a) earth orbit, (b) trajectories resulting from translunar-injection powered-maneuver failure, (c) translunar coast (outside lunar sphere of influence), and (d) transearth coast, including midcourse corrections (again, outside lunar sphere of influence). (See Figures 5.2.6-1, -2, and -3.)

5.2.6.1 Options and Crew Inputs

P37 has three basic options—minimum fuel, minimum time, and adjusted landing site. For either of the three, the crew enters five inputs via the DSKY and receives fifteen outputs. (See Table 5.2.6-I, and refer to program flow, Figure 5.2.6-4.) The first six outputs present a relatively fast, conic-section solution; the second six (outputs 7-12) present the precision-solution equivalent of the first six, recomputed to consider gravitational perturbations. After keying in VERB 37 ENTR 37 ENTR, the crew enters the first three inputs as requested by the DSKY—desired ignition time (t_{IG}), desired velocity change (Δv_D), and desired reentry angle $[\gamma\,(t_2)_D]$. Whether it is to be a minimum-fuel or a minimum-time return is determined by the input Δv_D. Whether it is to be an adjusted-landing-site return is determined by crew decision to vary certain of the inputs in order to effect a desired change in landing-site longitude.

5.2.6.1.1 Minimum-fuel Option.—For a minimum-fuel return, the crew allows zero to remain in register 2 in response to the DSKY's flashing VERB 06 NOUN 60. A Δv_D of zero signals the program to compute a trajectory requiring the minimum possible velocity change. In addition, from certain earth-orbital conditions (see Figure 5.2.6-5), the crew can further minimize fuel consumption by selecting a shallower entry flight-path angle than would be otherwise automatically computed by the program. That is, in response to VERB 06 NOUN 60, the crew can leave a

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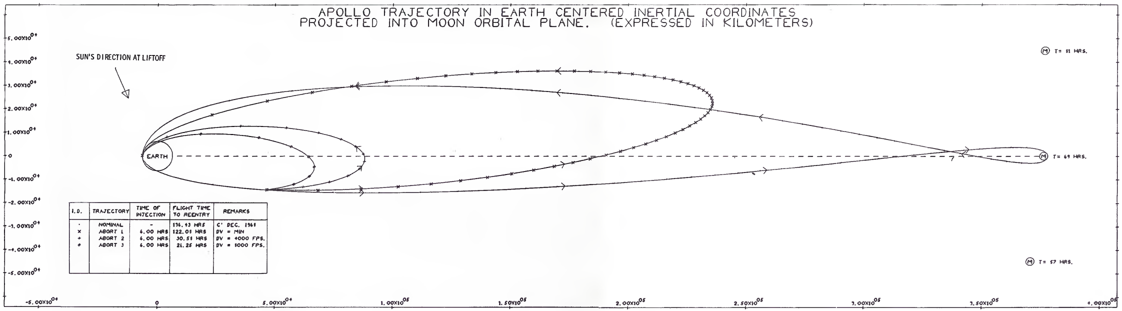
[*] See appropriate GSOP: Section 4, "GNCS Operational Modes," and Section 5 (paragraph 5.4.3), "Guidance Equations."

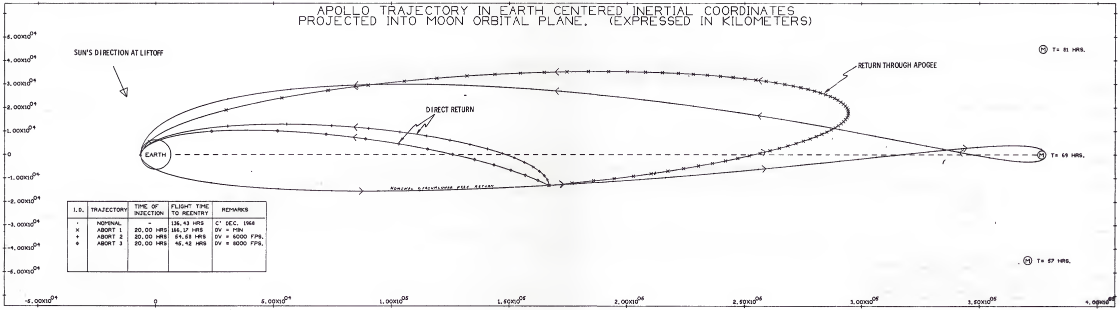
[**] See paragraph 5.2.6.8 for a special application of P37 outputs to returns using the lunar-module propulsion system.



APOLLO TRAJECTORY IN EARTH CENTERED INERTIAL COORDINATES
PROJECTED INTO MOON ORBITAL PLANE. (EXPRESSED IN KILOMETERS)

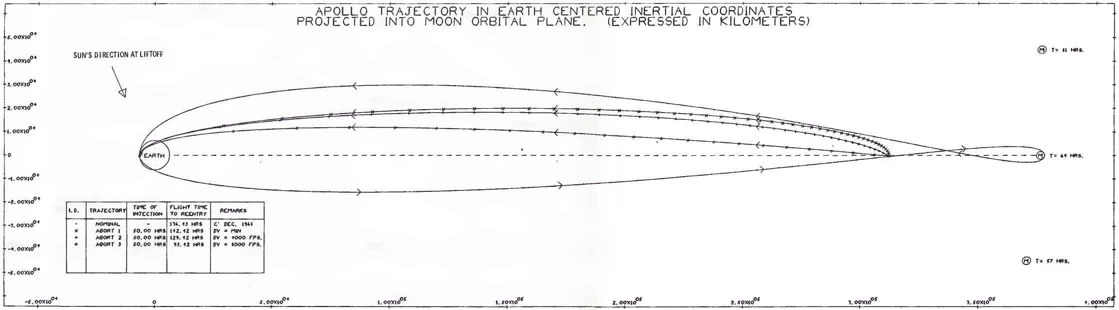
I.D.	TRAJECTORY	TIME OF INJECTION	FLIGHT TIME TO REENTRY	REMARKS
·	NOMINAL	-	136.43 HRS	C' DEC. 1961
×	ABORT 1	6.00 HRS	122.01 HRS	DV = MIN
+	ABORT 2	6.00 HRS	30.51 HRS	DV = 4000 FPS.
◆	ABORT 3	6.00 HRS	21.25 HRS	DV = 8000 FPS.

Figure 5.2.6-1.



I.D.	TRAJECTORY	TIME OF INJECTION	FLIGHT TIME TO REENTRY	REMARKS
·	NOMINAL	-	136.43 HRS	C' DEC. 1968
×	ABORT 1	20.00 HRS	166.17 HRS	DV = MIN
+	ABORT 2	20.00 HRS	54.58 HRS	DV = 6000 FPS.
◆	ABORT 3	20.00 HRS	45.42 HRS	DV = 8000 FPS.

Figure 5.2.6-2. Typical Abort Trajectories for TLI +20 Hours



I.D.	TRAJECTORY	TIME OF INJECTION	FLIGHT TIME TO REENTRY	REMARKS
·	NOMINAL	-	136.43 HRS	C' DEC. 1968
×	ABORT 1	50.00 HRS	142.42 HRS	DV = MIN
+	ABORT 2	50.00 HRS	129.42 HRS	DV = 4000 FPS.
◆	ABORT 3	50.00 HRS	93.42 HRS	DV = 8000 FPS.

Figure 5.2.6-3.

TABLE 5.2.6-I

P37 CREW INPUTS AND PROGRAM OUTPUTS (SHEET 1 OF 2)

Input	Identification	Display Mnemonic	DSKY	Register
1.	Desired Ignition Time (t_{IG})	TIG (GET I)	FL V06 N33	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec
2.	Desired Velocity Change (Δv_D)	VPRED	FL V06 N60	R2 xxxxx. fps
3.	Desired Reentry Angle $[\gamma(t_2)_D]$	GAMMA EI	FL V06 N60	R3 xxx. xx deg*
4.	Vehicle Mass and Number of Jets **			
5.	Desired Propulsion System	SPS RCS	FL V04 N06	R2 00001 (R1 00007) R2 00002 (R1 00007)
Output				
1.	Landing-site Latitude (θ_{LAT})	IMPACT LAT	FL V06 N61	R1 xxx. xx deg*
2.	Landing-site Longitude (θ LONG)	IMPACT LONG	FL V06 N61	R2 xxx. xx deg*
3.	Time of Flight ($t_2 - t_1$, or t_{21})	DELTA T TRANS	FL V06 N39	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec
4.	Velocity at Entry $[v(t_2)]$	VPRED	FL V06 N60	R2 xxxxx. fps
5.	Entry Flight-path Angle $[\gamma(t_2)]$	GAMMA EI	FL V06 N60	R3 oxx. xx deg*
6.	Impulsive Velocity Change ($\Delta \underline{v}$)	DELTA V (LV)	FL V06 N81#	R1 (VX) xxxx. x fps*** R2 (VY) xxxx. x fps*** R3 (VZ) xxxx. x fps***
7–12.	Outputs 1–6 recomputed, giving precision solution			
13.	Ignition Time (t_{IG})	TIG (GET I)	FL V06 N33	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec

zero $\gamma(t_2)_D$ in R3, allowing the program to solve for a flight-path angle obtaining the center of the entry corridor; or by keying into R3 a specified entry angle, the crew can request the program to solve for a shallower $\gamma(t_2)$, requiring less fuel. For example, observe in Figure 5.2.6-5 that at an orbital altitude of 140 n. mi. a change in γ from -3 deg to -2 deg reduces the required Δv by approximately 450 ft/sec.

TABLE 5.2.6-I

P37 CREW INPUTS AND PROGRAM OUTPUTS (SHEET 2 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register
14.	Time from Ignition	TFI (TF GET I)	FL V16 N45	R2 $\underline{\text{xxBxx}}$ min, sec*
15.	Middle-gimbal Angle at Ignition (a_{MG})	MGA	FL V16 N45	R3 $\underline{\text{oxx.xx}}$ deg*

*Sign convention;

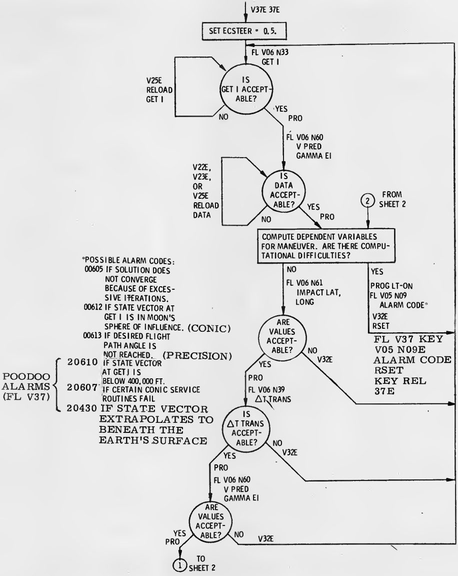
γ--"-" designates below horizontal plane
θ--"+" designates north latitude, east longitude
a_{MG}--"-" indicates IMU not aligned
TFI--"-" indicates before t_{IG}; "+" after t_{IG}.

**Mass data are not specifically requested by the program—must be loaded via Routine 03 before program is allowed to proceed beyond input $\underline{5}$.

***VX is component of impulsive Δv, at t_{IG}, along $(\underline{R}\text{X}\underline{V})\text{X}\underline{R}$
VY is component of impulsive Δv, at t_{IG}, along $\underline{V}\text{X}\underline{R}$
VZ is component of impulsive Δv, at t_{IG}, along $-\underline{R}$.
Where $\underline{R}$ is CSM geocentric radius vector, and $\underline{V}$ is inertial-velocity vector at t_{IG}.

\# The scalar Δv can be observed here by keying VERB 06 NOUN 40 (R2 xxxx.xfps).

NOTE: Offset-target data relative to the Lambert-aimpoint maneuver are not displayed, but are transferred to the appropriate erasables for the applicable powered-flight guidance program.

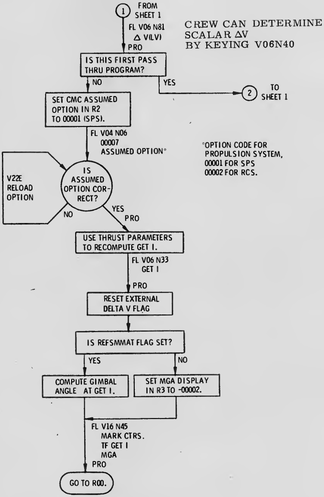


FL V37 KEY
V05 N09E
ALARM CODE
RSET
KEY REL
37E

*POSSIBLE ALARM CODES:
00605 IF SOLUTION DOES NOT CONVERGE BECAUSE OF EXCESSIVE ITERATIONS.
00612 IF STATE VECTOR AT GET I IS IN MOON'S SPHERE OF INFLUENCE. (CONIC)
00613 IF DESIRED FLIGHT PATH ANGLE IS NOT REACHED. (PRECISION)

POODOO ALARMS (FL V37)
20610 IF STATE VECTOR AT GET I IS BELOW 400,000 FT.
20607 IF CERTAIN CONIC SERVICE ROUTINES FAIL
20430 IF STATE VECTOR EXTRAPOLATES TO BENEATH THE EARTH'S SURFACE

Figure 5.2.6-4. Return to Earth Program (P37) (Sheet 1 of 2)



CREW CAN DETERMINE
SCALAR ΔV
BY KEYING V06N40

°OPTION CODE FOR
PROPULSION SYSTEM,
00001 FOR SPS
00002 FOR RCS.

Figure 5. 2. 6-4. Return To Earth Program (P37) (Sheet 2 of 2)

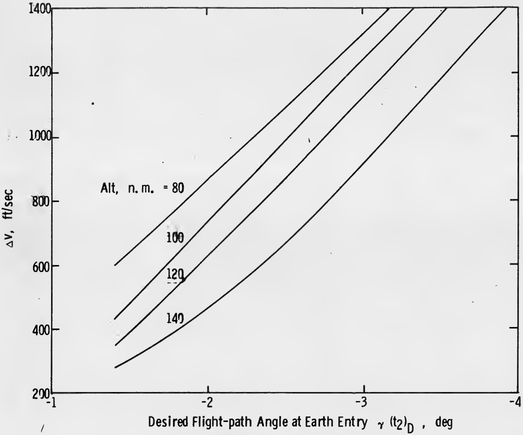


Figure 5. 2. 6-5. Relationship of Δv to Desired Flight-path Angle at Earth Entry: Returns from Near-circular Earth Orbits of Several Altitudes

Normally, minimum-fuel maneuvers executed during transearth coast have only an x-component (local vertical coordinates). Should the pre-maneuver state vector have a value, however, that would result in a velocity at entry $[v(t_2)]$ greater than 38,000 ± 5 fps, the program will automatically compensate for the excess velocity and produce a Δv output having both an x- and a negative z-component, i.e., a decelerating effect.

Another factor for consideration is the possibility that the minimum-fuel solution will specify a Δv that exceeds the fuel-onboard capability. Should this occur during translunar coast, the solution to the problem might be to utilize the free-return feature of the TLI trajectory and to use P37 for midcourse corrections on the way back to earth. (Figure 5.2.6-6 shows the minimum Δv required for a return from various translunar-coast distances.) During transearth coast, the minimum Δv required to adjust the entry angle increases as range decreases. Therefore, a P37 targeted maneuver should be executed as early as possible after exiting the lunar sphere of influence.

5.2.6.1.2 Minimum-Time Return.—For a minimum-time return, the crew keys into register 2 the maximum Δv obtainable with the fuel on-board. Should the Δv input be less than required for a minimum-fuel return, the program will respond as though a zero Δv_D has been entered and will compute a minimum-fuel return. Should the Δv_D input exceed P37-imposed limits, the program will automatically compute a trajectory for the maximum-allowable Δv. For example, should the Δv_D result in a $v(t_2)$ greater than 38,000 ± 5 fps, the program would automatically limit the Δv to a value resulting in a $v(t_2)$ equal to 38,000 ± 5 fps. As with a minimum-fuel return, a pre-maneuver state vector that would result in a $v(t_2)$ greater than 38,000 ± 5 fps will be corrected by a $\Delta \underline{v}$ output having both an x-component and a negative z-component. This has ramifications regarding landing-site selection and will be discussed further under that subject.

5.2.6.1.3 Adjusted-landing-site Return.—In addition to the basic options of a minimum-fuel or a minimum-time return, the crew has a limited capability of varying landing site. The salient characteristics of the capability are as follows:

a) Landing-site values (θ_{LAT}, θ_{LONG}) can either be approximations based on the AUGEKUGL routine (GSOP Section 5, paragraph 5.6.10.2), which determines time and range from entry to landing for a half-lift entry trajectory, or they can be computed using a padloaded value for entry range. (Time, however, would still be based on AUGEKUGL range.) The method used will be determined by the value entered in P37RANGE.

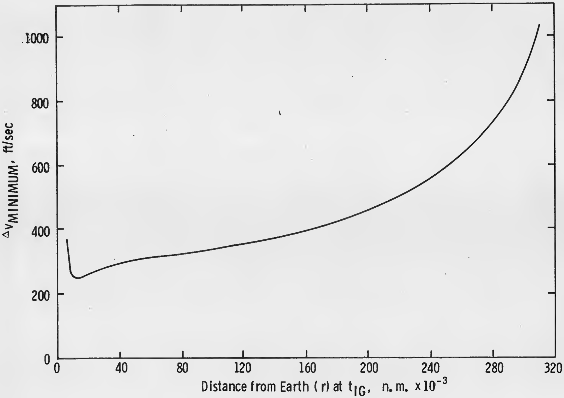


Figure 5.2.6-6 Minimum Fuel Requirements During Translunar Coast

(Table 5.2.6-II gives typical ranges and their octal equivalent. The exact octal value for any range can be computed by converting to octal the product, range times 0.758.) A zero in P37RANGE signals P37 to use AUGEKUGL to compute entry range; a specific value entered in P37RANGE signals P37 to use that value as the entry range. (Figure 5.2.6-7 illustrates AUGEKUGL entry range as a function of entry angle and velocity.)

b) The crew input most effective in varying the landing site when in earth orbit is the desired ignition time (t_{IG}), that most effective when in translunar or transearth coast is the desired velocity change (Δv_D). (See Figure 5.2.6-8.)

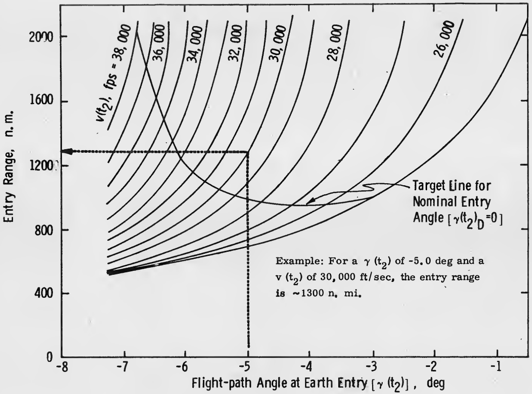
c) From earth orbit, landing-site adjustment is constrained by the minimum t_{21} required for completing pre-entry procedures. For example, during the apogee-to-perigee phase of the orbit (negative flight-path angle), the magnitude of t_{21} is approximately 3-1/2 minutes, which is insufficient for preparing the spacecraft for reentry; during the perigee-to-apogee phase, however, the magnitude of t_{21} is approximately 25 minutes. Therefore, we recommend that, normally, a t_{IG} be selected that will occur during the perigee-to-apogee phase. Should this prove impractical—because of landing site—the crew can extend t_{21} somewhat by selecting a shallower entry angle. (See Figure 5.2.6-9.)

TABLE 5.2.6-II

ENTRY RANGE AND OCTAL EQUIVALENT LOADED IN P37RANGE

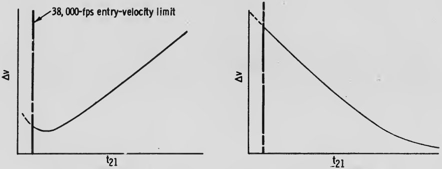
(LOADED BY VERB 21 NOUN 01 ENTR, 3376 ENTR, xxxxx ENTR)

Range, n.mi.	Octal Equivalent
1200	01616
1250	01664
1300	01732
1350	02000
1400	02046
1450	02114
1500	02162
1550	02230
1600	02276
1650	02344
1700	02411
1750	02457
1800	02525



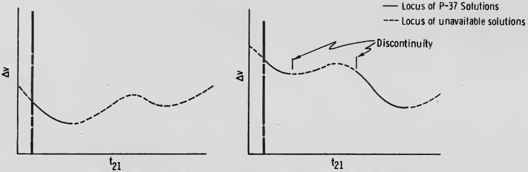
Example: For a $\gamma(t_2)$ of -5.0 deg and a $v(t_2)$ of 30,000 ft/sec, the entry range is ~1300 n. mi.

Figure 5.2.6-7. Range from Entry interface (400,000 ft) to Landing



(a) Transearth Coast

(b) Translunar Coast



(c) Apogee-to-perigee Earth Orbit and Near-in Transearth Coast

(d) Perigee-to-apogee Earth Orbit and Near-in Translunar Coast

Figure 5. 2. 6-8. Locus of Available Solutions for Four Typical Pre-maneuver State Vectors

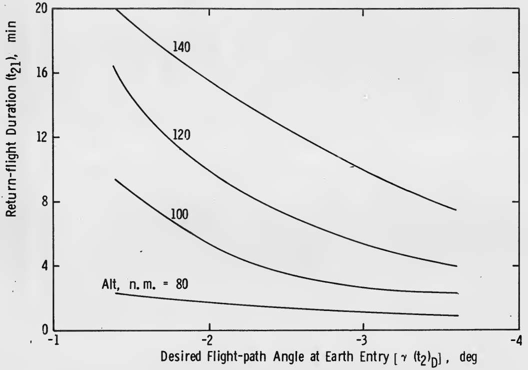


Figure 5.2.6-9. Relationship of Return-flight Duration to Desired Flight-path Angle at Earth Entry: Returns from Near-circular Earth Orbits of Several Altitudes (with Negative Pre-maneuver Flight-path Angles)

d) When return-flight durations (t_{21}) are large, i.e., several days, the precision solution may vary significantly from the conic solution. (See Figure 5.2.6-10.) The procedure recommended in that situation, for determining (1) the sensitivity of landing-site longitude to changes in Δv_D and, thus (2), the required change in Δv_D for effecting the desired adjustment in landing site, will be explained in paragraph 5.2.6.4.

5.2.6.3 Program Outputs and Computation Sequence

Regardless of option, the program computes, first, a conic solution and, second, a precision solution. (Refer to Figure 5.2.6-4.) The conic, two-body solution displays a relatively fast approximation of the return-to-earth targeting information. In arriving at the conic solution, P37 first must extrapolate the existing state vector up to the input t_{IG}. This may take several minutes, depending upon t_{IG}. Once the state-vector has been extrapolated, the conic solution obtains within seconds. The crew can either accept the conic-solution approximations and continue with the precision solution, or the crew can vary the inputs and reiterate, as many times as necessary, for a new set of conic approximations. Except for situations that will be discussed, the conic-solution values will be sufficiently accurate for the crew to determine whether the final (precision) solution will be acceptable. The precision solution may require as little as 2 minutes and as much as 35 minutes—depending upon the trajectory. (See Figure 5.2.6-11.)

5.2.6.3.1 Program Output.—Table 5.2.6-I presents the 15 outputs displayed to the crew. The first six are the dependent variables displayed after the conic solution; the second six (outputs 7–12) are the first six recomputed, giving the precision solution. The latter are followed by a display of the burn data (outputs 13–15).

The dependent variables (outputs 1–12) are determined by crew inputs 1–3 as follows:

1. Landing-site latitude (θ_{LAT}) variability is small and only secondarily dependent upon input variables. (See in-plane-only limitation, paragraph 5.2.6.6.)

2. Landing-site longitude (θ_{LONG}) is the primary dependent variable in landing-site adjustment (paragraph 5.2.6.4).

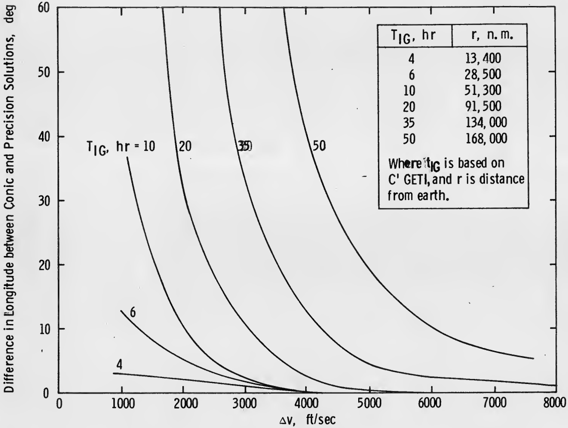


Figure 5. 2. 6-10. Correlation of Conic and Precision Solutions for Longitude: Returns from Translunar Coast

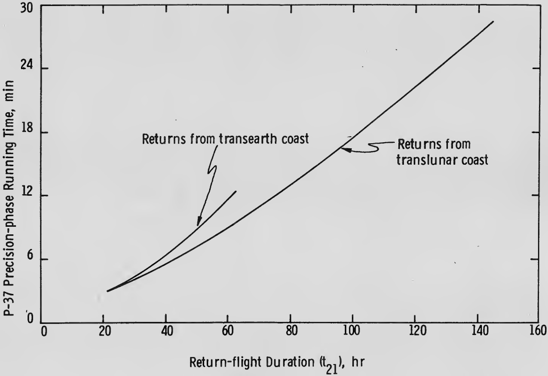


Figure 5.2.6-11. Approximate Relationship of Precision-phase Running Time versus Return-flight Duration

3. Time-of-flight (t_{21}) relative to Δv_D is illustrated for various pre-maneuver distances in Figure 5.2.6-12. Note that for minimum-fuel returns from the early part of an earth-outbound trajectory, the magnitude of t_{21} may be as much as five days for a return-through-apogee solution, but can be much less for a direct-return solution. See special case when t_{21} may be <u>too</u> short when entering from earth orbit—paragraph 5.2.6.1.3(c).

   For a very long t_{21}, there will be a substantial difference in the conic and precision solutions. Although rarely occurring and no cause for alarm, a large difference in conic and precision t_{21} values does introduce a special case when reiterating for landing-site adjustment—discussed in paragraph 5.2.6.4.

4. Inertial velocity at entry $[v(t_2)]$ is program limited within acceptable velocities for a corresponding entry flight-path angle. As a variable, the value of $v(t_2)$ is dependent upon the input Δv_D. Should the crew request a velocity change that will result in an entry velocity exceeding the maximum allowable, the program will adjust the input Δv_D downward to ensure an output $v(t_2)$ that is within the prescribed limits. [Note that both the input scalar Δv_D and the output scalar $v(t_2)$ use the VPRED register (NOUN 60); the Δv_D magnitude, can be observed, however, in VERB 06 NOUN 56 ENTR, register 2.]

5. Entry flight-path angle $[\gamma(t_2)]$ is determined by the input $\gamma(t_2)_D$. An input of zero will cause the program to automatically compute a $\gamma(t_2)$ appropriate for the computed $v(t_2)$. An input other than zero will cause the program to compute a trajectory obtaining the specifically requested entry angle. It should be noted, however, that when a value other than zero is entered, there is no assurance that the resulting trajectory will obtain the entry corridor.

6. Impulsive velocity change ($\Delta \underline{v}$) is determined by the input Δv_D and is the last of the dependent variables, displayed both after the conic and the precision solutions. The display is in local vertical coordinates whose y-component is always zero. (See in-plane-only restriction, paragraph 5.2.6.6.)

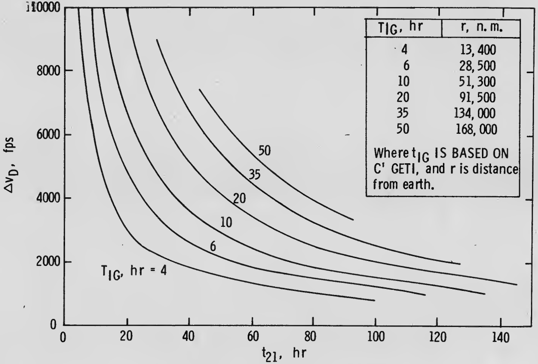


Figure 5. 2. 6-12. Relationship of Δv_D to Time of Flight (t_{21}) During Translunar Coast

The burn data (outputs 13-15) are displayed only after the precision solution is completed and the propulsion system has been selected: The precision time of ignition (t_{IG}) is presented to the nearest centisecond (ground elapsed time); time from ignition (TFI) is presented in minutes and seconds (maximum reading of ±59 min 59 sec); and the middle-gimbal angle (a_{MG}) at ignition is presented to the nearest 0.01 deg. Note that the output t_{IG} will not be exactly the same as the input t_{IG} since the output value is adjusted for a finite thrusting duration calculated on the basis of the propulsion system selected and the mass of the vehicle. Note also that, although TFI overflow is 59 min 59 sec, this in itself implies no limitation on how long in advance of the desired manuever time P37 can be called up. The actual TFI may, in fact, be considerably longer than the maximum indication. The limiting factor in this regard is the requirement that the state vector still be valid. (This requirement applies equally to the question of how many revolutions forward while in earth orbit the program can target an entry: subject to a valid state vector at t_{IG}, the crew can expect the targeting solution to be valid if P37 has proceeded to its conclusion without an alarm.) Finally, the crew should expect the sign value of the middle-gimbal-angle display to always be positive unless the IMU has not been aligned (REFSMMAT flag not set). If the IMU has not been aligned and a_{MG} (or MGA) cannot be computed, the value displayed will be -00002.

5.2.6.3.2 Computation Sequence.—Computation begins after the first three crew inputs into the DSKY. (Refer to Table 5.2.6-I and Figure 5.2.6-4.) Depressing the PRO key on the DSKY then signals the program to proceed with the computation of a conic-section solution, yielding the first six program outputs. By keying in VERB 16 NOUN 38, the crew has the option of monitoring the state-vector time as it extrapolates to t_{IG}. When the state vector reaches t_{IG}, the conic solution will follow within seconds. If NOUN 38 is being monitored, the DSKY will flash KEY REL.

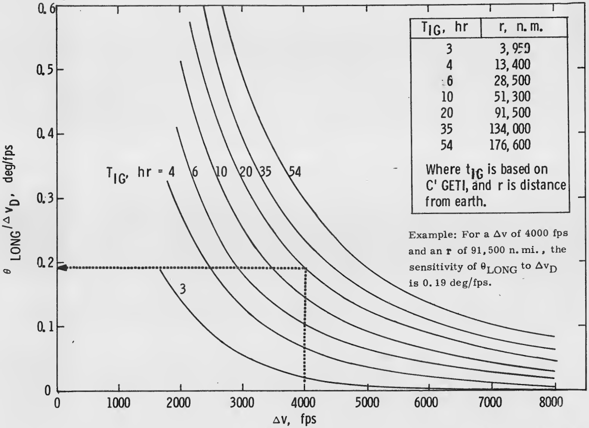
After the conic solution has been accepted by the crew's depressing the PRO key (or reiterated by keying VERB 32 ENTR and loading new inputs), the program proceeds to recompute for a precision solution encompassing all gravitational perturbations. Outputs 7 through 12, corresponding to conic-solution outputs 1 through 6, are then displayed by the DSKY. Note that the elapsed computer time required by the precision solution is roughly proportional to the return-flight (t_{21}); e.g., for a return flight of 6 or 7 days, the precision computation time may be as much as 35 minutes; for a return from an earth orbit or from a near-in transearth trajectory, the computation time can be as little as 2 minutes. Again, by keying in VERB 16 NOUN 38, the crew can monitor the program as it converges to a solution. Normally, the state-vector time will advance from t_{IG} to the time of entry (t_2), "hunt" briefly in the vicinity of t_2, then snap back to t_{IG}, repeating the cycle as many as seven times as the program converges to a solution. Should the state-vector time advance significantly beyond t_2 or snap back to a time earlier than t_{IG}, the crew should suspect that the solution is not converging and that it will be necessary to change t_{IG} and reenter the program. (See "Additional Restrictions," paragraph 5.2.6.6.)

The crew must enter the mass data and select the number of RCS jets (input 4) by executing R03 anytime before proceeding beyond the selection of the desired propulsion system (input 5). After the conic and precision solutions have been computed, displayed, and approved, the DSKY will display (VERB 04 NOUN 06) the option code for the service propulsion system (00001 in R2), which is the CMC-assumed option. Should the crew wish to select the reaction-control-system (RCS) option, the operator would key in VERB 22 ENTR and load (in R2) option code 00002. Before depressing the PRO key, signaling the program to proceed with the computation of t_{IG} (output 13) is the last instance when valid mass data can be entered. This information, however, will not be specifically requested by the program, which will assume as valid the last data entered. Therefore, unless R03 had been executed earlier—and the data were still valid—the crew would now key in VERB 48 ENTR, complete R03, and then continue P37 (by depressing the PRO key). Receiving a PRO signal from the crew, the program will either compute the middle-gimbal angle at ignition (REFSMMAT flag set, IMU aligned) or indicate (-00002 in register 3) to the crew that a_{MG} cannot be computed (REFSMMAT flag not set). If computed, the middle-gimbal angle at ignition will itself be displayed in R3, and the time from ignition displayed in R2. The crew's depressing the PRO key signals P37 to proceed to completion.

5.2.6.4 Procedure for Adjusting Landing Site During Cislunar Coast

For an adjusted-landing-site return from translunar coast, the crew would initially enter the maximum Δv_D available with the fuel onboard—the same as for a minimum-time return. Should the resulting landing site be unacceptable, the crew would recycle the program, adjusting Δv_D input downward, until an acceptable landing site was obtained. To assist in determining the sensitivity of landing-site longitude to variations in Δv_D, the following procedure is recommended—refer to Figures 5.2.6-13 and -14:

1. Reiterate (using Figure 5.2.6-13) the conic solution until it obtains a landing-site longitude ($\theta_{LONG_{C_1}}$) within 15 deg of desired (θ_{LONG_D}).



T_{IG}, hr	r, n. m.
3	3,950
4	13,400
6	28,500
10	51,300
20	91,500
35	134,000
54	176,600

Where t_{IG} is based on C' GETI, and r is distance from earth.

Example: For a Δv of 4000 fps and an r of 91,500 n. mi., the sensitivity of θ_{LONG} to Δv_D is 0.19 deg/fps.

Figure 5.2.6-13. Sensitivity of Landing-site Longitude to Changes in Δv_D: Returns from Translunar Coast

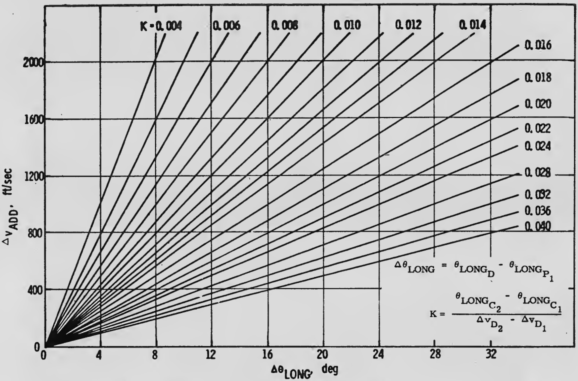


Figure 5.2.6-14a Increase in Δv_D to Produce a Desired Increase in θ_{LONG}: K = 0.04 to 0.004

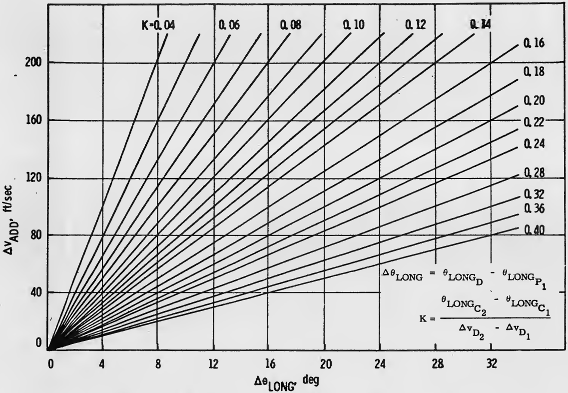


Figure 5.2.6-14b Increase in Δv_D to Produce a Desired Increase in θ_{LONG}: K = 0.4 to 0.04

2. Record $\theta_{LONG_{C_1}}$ and the last Δv_D* input (Δv_{D_1}).
3. Proceed through to a precision solution.
4. Record the precision longitude ($\theta_{LONG_{P_1}}$).
5. Add ±10 fps to Δv_{D_1} (to get Δv_{D_2}), and re-run the conic.
6. Record the Δv_{D_2} and the resulting $\Delta_{LONG_{C_2}}$.
7. Obtain value "K" by dividing by ±10 (viz., $\Delta v_{D_2} - \Delta v_{D_1}$) the difference in $\theta_{LONG_{C_1}}$ and $\theta_{LONG_{C_2}}$.
8. Use "K" to get from Figure 5.2.6-14 the value ($\Delta v_{D_{ADD}}$) that must be added to Δv_{D_1} in order to obtain the required $\Delta\theta_{LONG}$ (viz., $\theta_{LONG_D} - \theta_{LONG_{P_1}}$).
9. Use Δv_{D_3} (i.e., $\Delta v_{D_1} \pm \Delta v_{D_{ADD}}$) to re-run both conic and the precision solution. (Adding $\Delta v_{D_{ADD}}$ moves the landing site eastward; adding $-\Delta v_{D_{ADD}}$ moves the landing site westward.)

For an adjusted-landing-site return from <u>transearth coast</u>, the crew would initially enter a Δv_D input of zero—the same as for a minimum-fuel return. Recording the conic-solution longitude and the scalar Δv (VERB 06 NOUN 40), the crew would then allow the precision solution to complete. Should the precision-solution landing site be unacceptable, the crew would use the plus or minus of the Δv value observed in NOUN 40—rather than the zero Δv_D input—when adding ±10 fps to obtain Δv_{D_2}. (See step 5 of reiteration procedure used for translunar coast.) For example, if the initial Δv_D input yielded an unacceptable landing site, and the value observed in NOUN 40 (R2) were 400 fps, the crew would add (step 5) +10 fps to +400 fps, yielding +410 fps for an eastward adjustment, or would add -10 fps to -400 fps, yielding -410 fps for a westward adjustment. Steps 6, 7, 8, and 9 are performed the same as for translunar coast.

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*Near the upper limits of Δv or near the minimum-fuel Δv, adding or subtracting 10 fps to Δv_{D1} can result in a Δv_{D2} that is outside the program-constrained limits. To detect this, the crew should monitor VERB 06 NOUN 40 (register 2) immediately after the display of the vector Δv (output 6). NOUN 40 will display the scalar value of Δv, which will be exactly equal to Δv_{D2} unless Δv_{D2} is outside the limits. Should the latter occur, the scalar Δv observed in NOUN 40 will be the program-limited value. The program should be allowed to complete the precision solution in order to discover whether the desired landing site is achievable with the limited Δv; if so, reiteration can be continued by adding a value less than ±10 fps to Δv_{D1}, i.e., a value that will not exceed the Δv limits.

5.2.6.5 Program Alarms

In addition to the anticipated outputs, the program will display an alarm under the following conditions:*

a) Alarm code 00612 is displayed if the state vector at t_{IG} is within the lunar sphere of influence.

b) Alarm code 00605 is displayed if the solution will not converge.

c) Alarm code 00613 is displayed if the desired entry flight-path angle is unobtainable.

d) Alarm code 20610 is displayed if the state vector at t_{IG} is below 400,000 ft..

e) Alarm code 20607 is displayed whenever any of certain conic service routines used by P37 fail.

f) Alarm code 20430 is displayed if the state vector extrapolated either to t_{IG} (during conic phase) or to t_2 (during the precision phase) is beneath the earth's surface.

P37 is not capable of targeting a return when the position of the spacecraft at time of ignition is within the lunar sphere of influence (LSI). Should an attempt be made to target such a return, alarm 00612 will alert the crew that the proper solution is not possible. The corrective action is to adjust the t_{IG} input such that the spacecraft will be outside the LSI at ignition. Note that the present spacecraft position is of no consequence: so long as the spacecraft state vector at t_{IG} lies outside of the LSI, the position when P37 is called can be either within the LSI, outside the LSI, or outside but on a trajectory that passes through. Again, since the essential concern is the position at t_{IG}, the corrective action for alarm 00612 is to select a later (or earlier) t_{IG}.

Although we have not been able to simulate a likely condition resulting in a nonconverging solution (alarm code 00605), we have, nevertheless, incorporated iteration counters as a safeguard against the possibility of getting into an infinite

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*Alarms 00612, 00605, and 00613 are indicated by a PROG illumination, a flashing VERB 05 NOUN 09, and a display of the appropriate alarm code. Alarms 20610, 20607, and 20430 are POODOO alarms, indicated by a PROG illumination and a flashing VERB 37. For a POODOO alarm, the operator must key VERB 05 NOUN 09 ENTR for a display of the alarm code. To return to P37, he must depress KEY REL and RSET and then key 37 ENTR.

loop. Should an alarm 00605 occur during the conic computation, the recommended corrective action would be, first, to reiterate using a specified $\gamma(t_2)_D$, i.e., other than zero; if the alarm still occurs, to reiterate using a different t_{IG}. Should an alarm 00605 occur during the precision computation, the recommended corrective action would be to reiterate with an increased Δv_D; the resulting decrease in transit time should require fewer iterations to converge on a solution. Again, the second thing to try would be to change the t_{IG}.

Although it would require lengthy explanation, we have become convinced since the original design of P37 that a condition triggering alarm code 00613 will never occur. Nevertheless, should by some remote and unforeseen circumstance the desired entry flight path not be obtainable, a possible corrective action would be either to increase the Δv_D or to adjust the $\gamma(t_2)_D$.

P37 cannot be used for targeting trajectories begun below 400,000 ft above the Fischer ellipsoid. Accordingly, the DSKY will flash VERB 37, for an alarm code 20610, should a t_{IG} be inadvertently entered that would occur below the earth-entry interface. The recommended corrective action would be to decrease t_{IG} such that it occur above 400,000 ft.

The recommended action for alarm 20607 is to check for valid inputs.

For an alarm 20430 during the conic phase, the crew would select an earlier t_{IG}; an alarm 20430 during the precision phase is rare and would be corrected by increasing Δv_D or adjusting t_{IG} in order to reduce trajectory perturbations caused by the lunar gravitational field.

5.2.6.6 Additional Restrictions

In addition to its being restricted from transfer trajectories begun within the lunar sphere of influence, the limitations of P37 are (1) it does not target trajectories begun from certain positions in the vicinity of the moon (Figure 5.2.6-15), though not within its sphere of influence, and (2) it does not target out-of-plane maneuvers. Regarding trajectories targeted from the vicinity of the moon, the number of variables precludes our defining an exact envelope of no solution. Therefore, for a return from any area approximating that shown in Figure 5.2.6-15, we recommend that VERB 16 NOUN 38 be used to monitor the program as it attempts to converge to a precision solution. Monitoring the state-vector time (as described in paragraph 5.2.6.3.2) is necessary in this instance because, though t_{IG} fall outside the LSI, the post-ignition trajectory would, if the solution converged, pass within the sphere of

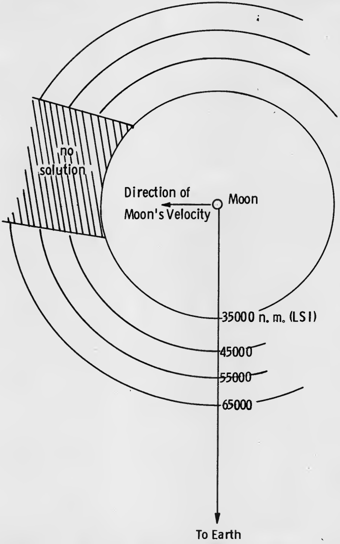

Figure 5.2.6-15. **Area, Near Lunar Sphere of Influence, Where P37 Will Not Converge to a Precision Solution**

influence. The solution does not converge, however, nor is there an alarm; the only indication is (monitoring NOUN 38) the abnormal behavior of state-vector time. The corrective action would be to terminate integration (VERB 96 ENTR) and to reenter the program with an earlier t_{IG}, an increased Δv_D, or both.

The reason that P37 is designed to provide only in-plane solutions is to minimize fuel expenditure and program complexity. The one exception to the in-plane-only solutions is when the spacecraft is in the vicinity of the moon (though outside its sphere of influence) and there is a near collinearity of the r-vector and v-vector, viz., within 1-1/2 deg. In this situation, when the actual plane cannot be determined, an arbitrary plane is defined having the minimum possible inclination, i.e., such that the inclination of the post-maneuver orbit is equal to the angle formed by the pre-maneuver position vector and the earth's equatorial plane. Again, this occurs only when $\underline{r}$ and $\underline{v}$ are nearly collinear.

Also in the category of program limitations are the constraints regarding landing-site adjustment. The in-plane-only limitation is, itself, one constraint on landing site; consequently, the crew has very little control over the landing latitude. The second constraint is related to the discontinuity that exists regarding velocity change and transit time. For some outbound pre-abort trajectories (see Figures 5.2.6-8d and -16), the solution of the return-trajectory problem is multivalued for a given Δv_D; consequently, a small change in Δv_D may result in a change from a direct-return to a return-through-apogee solution. (See Figure 5.2.6-2.) In iterating for landing-site selection, the crew may observe, for a small change in Δv_D, a very large change in t_{21} and, of course, in landing site. As evidenced by Figure 5.2.6-16, the area in which the discontinuity can occur is quite small; encountering it, the crew has the option of iterating either for a suitable landing site within the realm of direct-return solutions or for one within the realm of return-through-apogee solutions. To more precisely locate the discontinuity, the crew can reiterate for a solution using one-half the difference in the two preceding Δv_Ds. The procedure can be repeated, with progressively smaller differences in Δv_D, until the desired result is obtained.

5.2.6.7 Program Coordination

Although the execution of P37 requires only an operational command-module computer (CMC) and does not require the inertial subsystem (ISS) to be on, timing considerations will usually best be served if the ISS is operating and the IMU is aligned before P37 is entered. Considering (1) that the ISS is required to be on for at least 15 minutes before the execution of the thrusting program (P40 or P41), (2) that normally

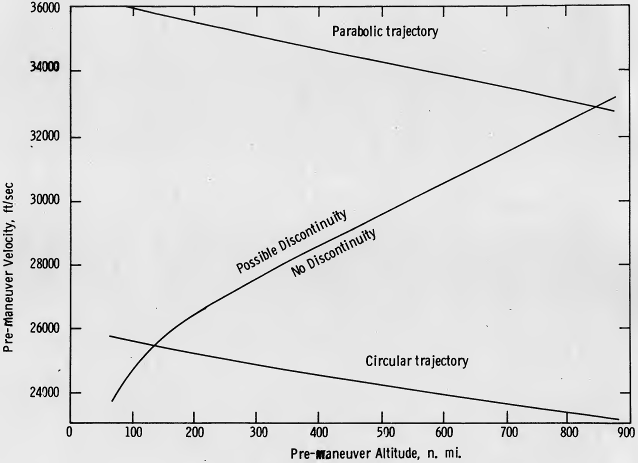

Figure 5.2.6-16. Pre-maneuver Conditions Where a Possible Discontinuity Exists in the Relationship Between Δv and Transfer Time

the prethrust program (P37) requires, at most, 35 to 40 minutes to complete, and (3) that the DAP Data Load Routine (R03) must be performed before the P37 precision solution can be computed, we recommend the following as the normal sequence when timing is critical and an actual burn is anticipated:

a) Perform Autopilot Data Load (R03)
b) Perform Orientation Determination Program (P51)
c) Perform Return-to-earth Targeting (P37)
d) Begin SPS or RCS Thrusting Program (P40 or P41)
e) If the MGA displayed by P37 was greater than 45 deg, exit P40 (or P41) and perform P52 Option A, "Preferred Orientation," as soon as the thrusting program enters the Attitude Maneuver Routine (R60) and displays the desired gimbal angles. (The crew should expect here to observe essentially the same MGA as displayed by P37.) Upon completion of P52, reenter and complete P40 (or P41). If the MGA displayed by P37 (and now R60) was less than 45 deg, but greater than zero, the crew has the option of either accepting the existing alignment, thereby conserving RCS fuel, or entering P52 to perform a "preferred orientation." Accepting the existing alignment, the crew allows the thrusting program to continue; rejecting alignment, the crew proceeds as though the MGA had been greater than 45 deg, i.e., completes Option A of P52 and then reenters the thrusting program at the beginning.

The exception, when the above sequence might not be appropriate, or desired, is when a thrusting maneuver is not intended to immediately follow P37. For example, should the crew wish merely to exercise P37, without intending to use the targeting information for an actual burn, or should the crew intend a burn, but with a several-hour delay before ignition, then P37, requiring only an operational CMC, can be performed before the IMU alignment is determined. [Since IMU realignment (P52) will be necessary should more than 3 hours elapse between IMU alignment determination (P51) and t_{IG}, there is little or no advantage in this case in performing P51 before P37.] An alternate sequence, therefore, might be as follows:

a) Perform P37 through propulsion-system option selection.
b) Perform DAP Data Load Routine (R03) unless no burn is anticipated or R03 has been performed earlier.
c) Continue P37 to completion.
d) Within 3 hours of t_{IG}, perform IMU Orientation Determination Program (P51).

e) Enter SPS or RCS thrusting program (P40 or P41); when the thrusting program enters the Attitude Maneuver Routine (R60) and the DSKY flashes VERB 50 NOUN 18, "Please perform auto maneuver," observe whether the "final desired gimbal angle" is acceptable to the crew and, in any case, less than 45 deg. If the final MGA is not acceptable, exit the thrusting program and perform IMU Realign Program (P52), Option A, "Preferred Orientation." If the final MGA is acceptable to the crew and is less than 45 deg, proceed with R60 and allow the thrusting program to continue to completion.

f) Upon completion of P52 Option A (unacceptable final MGA), reenter and perform SPS or RCS thrusting program (P40 or P41).

Additional factors regarding IMU alignment are related to RCS fuel economy. When a fuel-critical return using RCS thrusting is anticipated, it becomes especially important that as little RCS fuel as possible be used in aligning the IMU. Accordingly, when RCS fuel supply is critical, the crew should avoid, if possible, the necessity of entering P52. One means of avoiding the need for realigning the IMU is to visually orient the spacecraft during P51, such that the spacecraft y-axis will lie approximately normal to the $\underline{v}$, $\underline{r}$ plane, and then to coarse align the IMU to 0,0,0 gimbal angles. P51 can then be completed and the IMU left stabilized at an orientation that should ensure a "final desired middle gimbal angle" of less than 45 deg for any trajectory targeted by P37, which computes only in-plane solutions, i.e., local-vertical thrust-vector component $y = 0$. Again, however, to avoid performing IMU Realignment (P52), P51 must be completed within 1 to 3 hours of t_{IG}.

5.2.6.8 Returns Using Lunar-module Descent Propulsion System (LM DPS)

Should, for some reason, the crew wish to use the LM DPS for the return-to-earth maneuver, the t_{IG} and Δv precision outputs of P37 can be used as the manually entered inputs for targeting an External-Δv burn with P30. There is, however, one important exception: in the vicinity of the moon, when $\underline{r}$ and $\underline{v}$ may be within 1-1/2 deg collinearity it may be necessary for P37 to compute an arbitrary return transfer plane (paragraph 5.2.6.6); the Δv output, in that case, would not be valid for use with P30. (Use P21 to determine flight-path angle (γ) at desired t_{IG}; if γ is within 1-1/2 deg of +90 or -90 deg, the P37 Δv cannot be used with P30.)

5.2.6.9 Restart

P37 is not restart protected. Should a restart occur, the program must be reselected and all inputs re-entered.

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5.2.7–5.2.10 P72–P75 CMC Targeting of LM-active Maneuvers

The CMC programs for targeting a LM-active maneuver are P72–P75, and, with two exceptions,[*] are identical to the LGC P32–P35. Refer, therefore, to paragraphs 5.3.2 through 5.3.5, which describe the differences between the LGC and the CMC rendezvous-targeting programs. The CMC uses P72–P75 to target LM-active maneuvers only if the LM rendezvous radar is malfunctioning. The appropriate P70 program is then used to target the thrusting parameters for a LM-active maneuver; the parameters are voice-linked to the LM for use in the appropriate LGC targeting (P3x) program.

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[*] In the CMC P72, the t_{IG} (CSI) zero-entry option, which causes the LGC to compute a t_{IG} (CSI) coincident with the next apoapsis, is not applicable. Also, the P70 programs do not display a positive number in R3 of NOUN 45—even on the final computational cycle.

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5.2.11 P76, Target Δv—CMC

(TBF)

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SUBSECTION 5.3

LGC TARGETING PROGRAMS

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5.3.1. P30, External $\Delta \underline{v}$—LGC

The LM External $\Delta \underline{v}$ Program is essentially the same as the CSM P30, in which the CSM is the active body. P30 accepts targeting parameters, obtained from sources external to the LGC, for the computation of required variables for the execution of the desired maneuver. Secondly, P30 displays to the crew and the ground those dependent variables necessary to the maneuver for astronaut and ground approval.

The preliminary assumptions are as follows:

a. The target parameters, t_{IG} (time of ignition) and $\Delta \underline{v}_{LV}$ (impulsive $\Delta \underline{v}$ along the local vertical axes) may have been uplinked during a prior execution of the LGC Update Program (P27).

b. Indication is made to the thrusting programs, by setting a flag during P30 operation, that external $\Delta \underline{v}$ steering is to be used.

c. The ISS need not be running or aligned for P30 to run to completion, unless radar use is desired. If so, the ISS and radar should be turned on and the radar should be locked on the CSM by the Rendezvous Navigation Program (P20). In the LM-active case, radar sighting marks will be made automatically at intervals of approximately one minute when the tracking and updating programs are enabled.

5.3.1.1 Procedures

A step by step description of crew procedures relating to P30 during its operation follows. Selection of the program is made by DSKY entry of VERB 37 ENTR 30 ENTR. Immediately, VERB 06 NOUN 33 flashes, with t_{IG} exhibited in registers 1 through 3 (in hours, minutes and seconds)—indicating that the crew is to run a comparison check on the displayed time. The criterion determining the correctness of a parameter is its agreement with values uplinked from the MSFN.

If the displayed t_{IG} is not the desired time, a new time is reloaded, using VERB 25 ENTR and loading the time into registers 1 through 3. Another comparison is made until agreement is reached. When the displayed t_{IG} is acceptable, keying PRO indicates its acceptability to the program. The program then flashes VERB 06 NOUN 81 requesting verification of the impulsive $\Delta \underline{v}$ components exhibited in the registers.

If the displayed components are not satisfactory, new components can be entered into the registers using VERB 25 ENTR; and comparison with crew desired components continues until the satisfactory components are exhibited. At this time, PRO should be keyed. Any PRO response indicates to the program acceptance of the components and leads to the execution of certain internal program functions.

The height of the vehicle at apogee and perigee and the impulsive $\Delta\underline{v}$ at t_{IG} are the next parameters to be exhibited. Consultation with MSFN is made; if the parameters are not acceptable and the LGC Update Program (P27) is needed, the astronaut keys VERB 37 ENTR 00 ENTR followed by VERB 71 ENTR and the program exits to P27. If another program is desired at this point, provision is made for the keying of VERB 37 ENTR xx ENTR, and P30 exits to program number xx. Should it be desirable to recycle through the whole of P30, the crew member should key VERB 37 ENTR 30 ENTR. If the parameters are acceptable, a PRO response calls up the next display.

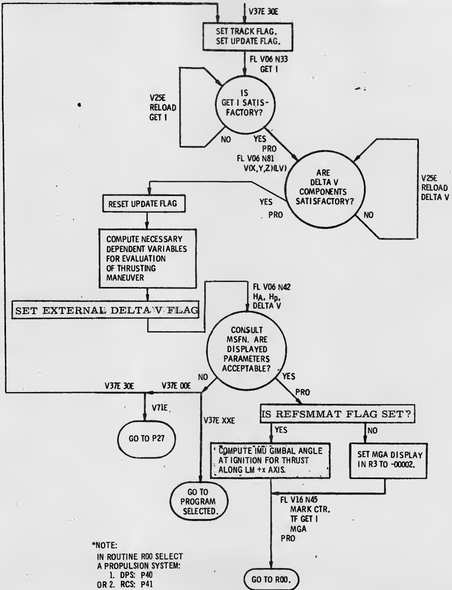
The last display in P30 is a flashing VERB 16 NOUN 45 with the value of the mark counter in R1, time from ignition in R2, and the middle gimbal angle in R3. A PRO response is the next action, and it terminates P30.

5.3.1.2 Computational Sequence and Inputs and Outputs

An event flow diagram of the P30 computational sequence is given in Figure 5.3.1-1. Summaries of the input and output parameters are provided in Tables 5.3.1-I and 5.3.1-II, respectively.

In the LM-active situation, all LGC inputs are uplinked to the CMC for state-vector confirmation. The CMC has the t_{IG} and $\Delta\underline{v}_{LV}$ components, which have been confirmed by the ground computer. If a disagreement should exist among the three, the burn should be postponed until new parameters can be uplinked, or any computer malfunction is diagnosed and corrected. P30 outputs, if satisfactory, are accepted as valid by keying PRO, which loads them into the computer.

The input parameters for P30 are the time of ignition, in hours, minutes and seconds, and the impulsive $\Delta\underline{v}_{LV}$, with the components displayed for confirmation in the registers. Rendezvous radar marks are relevant only if P30 is used during a rendezvous sequence with the standard targeting program exit display VERB 16 NOUN 45. Onboard out-of-plane corrections to the inputs can be loaded with corrections when these parameters are exhibited. A change is entered for each and a PRO response made. Care should be taken not to let any zero vector get into the system; other programs trying to unitize a zero vector run into alarm conditions. Out-of-plane maneuvers must have the following characteristics:



*NOTE:
IN ROUTINE R00 SELECT
A PROPULSION SYSTEM:
1. DPS: P40
OR 2. RCS: P41
OR 3. APS: P42

Figure 5.3.1-1. External Δv Program (P30)

TABLE 5.3.1-I

EXTERNAL $\Delta \underline{v}$ INPUTS (P30)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time of ignition, t_{IG}. *	TIG	FL V06 N33	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec	If the burn is uplinked, these registers will display the uplinked t_{IG}. If an onboard-calculated out-of-plane maneuver is being targeted then T(EVENT) must be loaded.
2.	Impulsive velocity change vector, $\Delta \underline{v}_{LV}$	DELTA V(LV)	FL V06 N81	R1 xxxx. x X R2 xxxx. x Y R3 xxxx. x Z	If the burn is uplinked, these registers will display the uplinked $\Delta \underline{v}$ (LV). If an onboard-calculated out-of-plane maneuver is being targeted, then (0, -Y (LM), 0) must be loaded.

* t_{IG} (TIG) is equivalent to the GET I given in the flowchart.

TABLE 5.3.1-II

EXTERNAL $\Delta \underline{v}$ OUTPUTS (P30)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Apogee altitude above pad radius/apolune above latest landing site radius	APO ALT	FL V06 N42	R1 xxxx. x n. mi.	Maximum number (9999.9), scaling is exceeded.
2.	Perigee altitude above pad radius/ perilune above latest landing site radius	PER ALT	FL V06 N42	R2 xxxx. x n. mi.	Maximum number (9999.9), scaling is exceeded.
3.	Magnitude of impulsive $\Delta \underline{v}$	DELTA V	FL V06 N42	R3 xxxx. x fps	
4.	Rendezvous marks taken	TRK MK CNT	FL V16 N45	R1 xxxxx.	Number of radar marks taken since counter was last zeroed.
5.	Time from ignition	TFI	FL V16 N45	R2 xxBxx: min, sec.	Maximum reading, 59 min., 59 sec; negative before t_{IG}, positive after t_{IG}.
6.	Middle gimbal angle	MGA	FL V16 N45	R3 xxx. xx +degrees if alignment of IMU is known; - 00002, otherwise.	

a. T(EVENT) from R36 must equal t_{IG}.
b. R1, R3 must equal 00000.
c. R2 must equal $-\dot{Y}$(LM).

If an excessive MGA, perhaps greater than 70 deg, occurs in R3 of flashing VERB 16 NOUN 45 (output 6), the astronaut should perform a realignment. If the ISS is not running, or if its alignment is unknown (output 6 will have -00002 in R3), it must be powered up and aligned before the burn. All operations that do not call for any corrective measures before the burn will be executed by depressing the PRO key on the DSKY until the program exits through routine R00 and flashes VERB 37 for another crew action.

5.3.1.3 Exceptions and Restrictions

In the LM-active program, the time for execution of these operations is longer than it is in the CSM-active program, due to the necessity of the LGC voice-link confirmation with the CMC.

If either P40, P41, or P42 is keyed in between two P30 targeting operations for the same burn, the $\Delta \underline{v}_{LV}$ should be reloaded with the original value since the thrusting program will rotate this vector through a central angle. The thrusting program then stores this reloaded value in the original location, eliminating the unrotated vector.

For maneuvers of long duration, the apogee and perigee of an orbit based on a P30 impulsive $\Delta \underline{v}$ will most likely be wrong since the program adds the impulsive $\Delta \underline{v}$ without taking into account accrued orbital degradations. The ground computer, however, does take these degradations into account. Therefore, the LGC - orbit configuration must be periodically updated by the ground. This is especially true after a burn because P30 orbit-change calculations assume an instantaneous $\Delta \underline{v}$ while the actual burn is of finite duration.

The problem arises as a result of the immediate approximation of an impulsive addition to the burn, as opposed to sampled data updating of the changed velocity. This impulsive $\Delta \underline{v}_{LV}$ is input to the computer for display before the burn. The addition of impulsive $\Delta \underline{v}$—not computed by AVERAGEG—can cause a "lunar impact" display in the LGC and the CMC first lunar orbit insertion burn parameters. The LGC orbit configuration, therefore, must be periodically updated by the ground.

5.3.1.4 Restarts and Alarms

P30 is restart protected. There are no alarm conditions.

5.3.2 P32, Coelliptic Sequence Initiation (CSI) Targeting—LGC

The principal difference between the LGC P32 and the CMC P32 lies in the coordination procedures required to verify the LGC outputs by voice link. Refer, therefore, to paragraph 5.2.2 for a discussion of the basic procedures for the CMC with the understanding that in the LGC program the roles of CSM/CMC and LM/LGC are reversed.

A second difference is that the LGC t_{IG}(CSI) input has a zero entry option that causes the LGC program to compute a t_{IG}(CSI) coincident with the next apoapsis.

5.3.2.1 Program Coordination

The LM crew verifies the LGC targeting solution by comparing it with the Abort Guidance System (AGS) solution and the CMC solution by voice link. The CMC and LM solutions should be nearly mirror images, i.e., opposite signs.

The criteria for selecting the correct solution are normally as follows:

1. If all three solutions agree (within mission-specified limits), use the LGC solution.
2. If the CMC and the AGS solutions agree, but the LGC solution disagrees, use the CMC solution.
3. If all three solutions disagree, use the CMC solution unless it is known to be, or suspected of being, unreliable.

5.3.2.2 Procedures

The first input value, t_{IG}(CSI), the time of CSI ignition, is displayed by a flashing VERB 06 NOUN 11. Initially, t_{IG}(CSI) is zero; any value entered by the crew is used as the time of ignition after PRO is keyed.

If PRO is keyed with the zero value, however, P32 computes t_{IG}(CSI) for the next apoapsis. A PRO response incorporates the value into the LGC.

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5.3.3 P33, Constant Delta Altitude (CDH)—LGC

The principal difference between the LGC P33 and the CMC P33 lies in the coordination procedures required to verify the LGC outputs by voice link. Refer, therefore, to paragraph 5.2.3 for a discussion of the basic procedures for the CMC with the understanding that in the LGC program the roles of CSM/CMC and LM/LGC are reversed.

5.3.3.1 Program Coordination

The LM crew verifies the LGC targeting solution by comparing it with the Abort Guidance System (AGS) solution and the CMC solution by voice link. The CMC and LM solutions should be nearly mirror images, i.e., opposite signs.

The criteria for selecting the correct solution are normally as follows:

1. If all three solutions agree (within mission-specified limits), use the LGC solution.
2. If the CMC and the AGS solutions agree, but the LGC solution disagrees, use the CMC solution.
3. If all three solutions disagree, use the CMC solution unless it is known to be, or suspected of being, unreliable.

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5.3.4 P34, Transfer Phase Initiation (TPI) Program—LGC

The principal difference between the LGC P34 and the CMC P34 lies in the coordination procedures required to verify the LGC outputs by voice link. Refer, therefore, to paragraph 5.2.4 for a discussion of the basic procedures for the CMC with the understanding that in the LGC program the roles of CSM/CMC and LM/LGC are reversed.

5.3.4.1 Program Coordination

The LM crew verifies the LGC targeting solution by comparing it with the Abort Guidance System (AGS) solution and the CMC solution by voice link. The CMC and LM solutions should be nearly mirror images, i.e., opposite signs.

The criteria for selecting the correct solution are normally as follows:

1. If all three solutions agree (within mission-specified limits), use the LGC solution.
2. If the CMC and the AGS solutions agree, but the LGC solution disagrees, use the CMC solution.
3. If all three solutions disagree, use the CMC solution unless it is known to be, or suspected of being, unreliable.

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5.3.5 P35, Transfer Phase Midcourse (TPM) Program—LGC

The principal difference between the LGC P35 and the CMC P35 lies in the coordination procedures required to verify the LGC outputs by voice link. Refer, therefore, to paragraph 5.2.5 for a discussion of the basic procedures for the CMC with the understanding that in the LGC program the roles of CSM/CMC and LM/LGC are reversed.

5.3.5.1 Program Coordination

The LM crew verifies the LGC targeting solution by comparing it with the Abort Guidance System (AGS) solution and the CMC solution by voice link. The CMC and LM solutions should be nearly mirror images, i.e., opposite signs.

The criteria for selecting the correct solution are normally as follows:

1. If all three solutions agree (within mission-specified limits), use the LGC solution.
2. If the CMC and the AGS solutions agree, but the LGC solution disagrees, use the CMC solution.
3. If all three solutions disagree, use the CMC solution unless it is known to be, or suspected of being, unreliable.

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5.3.6-5.3.10 LGC P72-P61

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SECTION 6.0

POWERED FLIGHT

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6.1 INTRODUCTION TO POWERED FLIGHT

Seven programs constitute the powered-flight major modes for the command and service module (CSM) and the lunar module (LM).* Two of the seven are monitor programs; three use input data from the targeting programs (refer to section 5.0) to control thrust direction and velocity-to-be-gained during automatic thrusting maneuvers; the remaining two use input data from the targeting programs to coordinate short, manually controlled maneuvers. All provide DSKY displays for the crew to monitor the maneuver's progress.

The command-module computer (CMC) powered-flight programs are as follows:

- P40, the Service Propulsion System (SPS) Maneuver Program—paragraph 6.2.1.
- P41, the Reaction Control system (RCS) Maneuver Program—paragraph 6.2.2
- P47, the Thrust Monitor Program—paragraph 6.2.3.

The lunar-module guidance computer (LGC) powered-flight programs are as follows:

- P40, the Descent Propulsion System (DPS) Maneuver Program—paragraph 6.3.1
- P41, the Reaction Control System (RCS) Maneuver Program—paragraph 6.3.2
- P42, the Ascent Propulsion System (APS) Maneuver Program—paragraph 6.3.3
- P47, the Thrust Monitor Program—paragraph 6.3.4.

The calculations for steering the spacecraft are done in the cross-product steering loop. The name "cross-product" comes from the steering commands that are generated by taking the cross-product of two vectors. The term "steering loop" indicates that the steering computations are done repetitively in a predetermined cycle, using performance feedback and new guidance input to update output values. Refer to Figure 6.1-1, below.

Within the steering loop is a digital autopilot (DAP) loop for controlling the spacecraft attitude during powered flight; the DAP cycles between 10 and 25 times each second. Because DAP performance is different for the different vehicles, the DAP loop

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*In the LM, there are other powered flight programs for ascent and descent.

operation within the larger steering loop is discussed separately in the introductions to the CSM and LM vehicles, subsections 6.2 and 6.3, respectively.

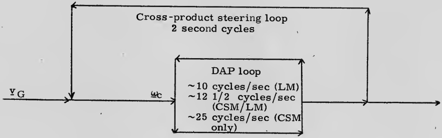

Figure 6.1-1 Steering and DAP Loops

All seven of the powered flight programs use the AVERAGEG Routine for state vector updating. AVERAGEG is discussed in paragraph 6.1.1. The CSM P40 and P41 and the LM P40, P41, and P42 use the cross-product steering subroutine to update the velocity-to-be-gained vector ($\underline{v}_G$); the CSM P40, LM P40, and LM P42 also use the subroutine to generate steering commands to the DAP, compute time from cutoff (t_{go}) and issue engine-off commands. Cross-product steering calculations are discussed in paragraph 6.1.2.

Despite dissimilarities in the powered flight programs, there is a basic pattern common to the logic of all. Figure 6.1-2 shows this basic logic pattern. Figure 6.1-3 presents a typical time line for a CSM P40 maneuver.

6.1.1 AVERAGEG Routine

The AVERAGEG Routine maintains an estimate of the vehicle state vector during noncoasting thrusting maneuvers. AVERAGEG computations are used whenever forces other than gravity are acting on the vehicle (for example, thrusting forces during boost, translunar injection, SPS, RCS, DPS, and APS burns; aerodynamic forces during boost and entry). In contrast with the Coasting Integration Routine, AVERAGEG is used when a short computing time is required.*

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* The Coasting Integration Routine takes longer than AVERAGEG and uses multiple iterations to arrive at a precision solution.

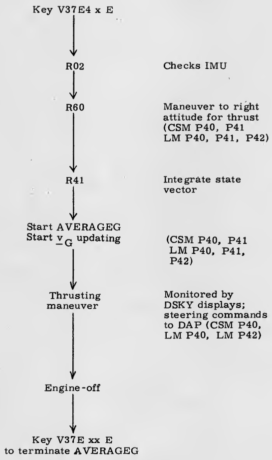


Figure 6.1-2. Powered Flight Logic

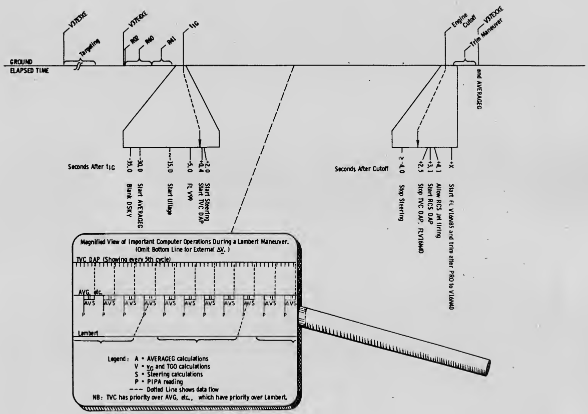


Figure 6.1-3. Typical Time Line for a CSM P40 Maneuver

In a 2-second computation cycle, the AVERAGEG Routine uses input position, velocity, and gravity acceleration vectors, as well as the velocity change measured by the PIPAs, to compute updated position and current gravity acceleration vectors. Updated velocity is then computed using (1) an average of current and past sample gravitational acceleration and (2) applied Δv. These outputs are used as inputs in the next AVERAGEG cycle.

The velocity change measured by the PIPAs is stored in the computer, from which it is read by the AVERAGEG routine. (See above.) But the PIPAs have an inherent bias error. During thrusting, the bias error is small in proportion to the movement measured by the PIPAs. When thrusting terminates, however, the PIPAs continue to measure movement, and the uncompensated bias error becomes large in proportion to the movement measured. Thus, to avoid disproportionate accumulations of bias errors, AVERAGEG should be terminated as soon as possible after thrusting terminates.

The earth-gravity-subroutine computation includes a single oblateness term; the lunar computation includes none. Section 5, GSOP, paragraph 5.3.2 gives details of the computation.

6.1.2 Cross-product Steering Subroutine

The cross-product steering subroutine extrapolates $\underline{v}_G$ for $\underline{v}_G$-updating, generates steering commands to the DAP, computes time from cutoff, and issues engine-off commands. Cross-product steering nulls the input $\underline{v}_G$ by controlling the thrust direction: the combination of properly oriented thrust acceleration and inherent gravitational acceleration eventually nulls the guidance $\underline{v}_G$. Thrust is terminated when the desired velocity increment has been achieved. It is the function of guidance to ensure that nulling the $\underline{v}_G$ will achieve the desired $\underline{v}$.

The general objective of cross-product steering is to align $(\underline{a}_T - c\underline{b})$ with $\underline{v}_G$, where:

$\underline{v}_G = \underline{v}_R - \underline{v}$ = required velocity - actual velocity

$\underline{b} = \frac{d\underline{v}_R}{dt} - \underline{g}$

$\underline{a}_T$ = thrust acceleration

c = a mixing factor empirically chosen to minimize fuel consumption and optimize or control vehicle attitude change during the maneuver. In the LM, c = 0; in the CSM, the nominal values of c are as follows for the programs listed:

P30, P32, P33 (External Δv)	0
P34, P35,	1
P37	1/2

For the CSM P40 and P41 and the LM P40, P41, and P42, the cross-product steering subroutine is used to update the $\underline{v}_G$ vector and to compute DSKY displays for monitoring the maneuver's progress. For the CSM P40, LM P40, and LM P42, the computations are used to generate steering commands and to update the estimate of engine cut-off time. In the P41s, these two functions are performed by the crew with the assistance of the displayed updated $\underline{v}_G$.

The cross-product steering functions are executed every 2 seconds, i.e., every time an updated state vector is provided from AVERAGEG computations. No steering commands are computed until t_{IG} + 2 seconds or during the last 4 seconds of a maneuver. Steering is not implemented for burns of less than 6 seconds (impulsive burns), which are done in attitude hold.

There are two modes of cross-product steering computations—External Δv and Lambert Aimpoint. Figure 6.1.2-1 gives a general flow of the cross-product steering logic.

6.1.2.1 External-Δv Guidance Mode

The External-Δv mode is characterized by a nonrotating thrusting maneuver, i.e., it uses a single thrust direction. The maneuver is done at a fixed attitude except when there is an initial misalignment of thrust, $\underline{v}_G$, and cg (center of gravity); cg motion; or DAP commands to compensate for slosh, etc.

The External-Δv mode is used to control maneuvers in which a constant thrust attitude is desired. Such maneuvers may be targeted in either the CSM or the LM P30, P32, and P33. Examples of External-Δv maneuvers are as follows:

Command and Service Module

Phasing maneuvers	P30
Coelliptic Sequence Initiation (CSI) rescue	P32
Constant Delta Altitude rescue (CDH)	P33
Some out-of-plane maneuvers	P30
Trans-earth injection (TEI)	P30
Lunar orbit insertion (LOI)	P30
Midcourse correction	P30

Lunar Module

Descent orbit insertion (DOI)	P30
Concentric sequence initiation (CSI)	P32
Constant delta height (CDH)	P33
Some out-of-plane maneuvers	P30
CMC—P37 targeted maneuvers using DPS	P30
Abort TEI using DPS/APS	P30

The guidance program accepts input data from the above targeting programs in the form of an impulsive $\Delta \underline{v}$ required in local vertical coodinates at a specified time of ignition (t_{IG}). Since the change of velocity cannot be made instantaneously, the in-plane component of the initial $\underline{v}_G$ is rotated about the angular momentum vector at t_{IG} by half the predicted central angle of the burn. After it has computed this compensated $\Delta \underline{v}$, the program overwrites the contents of NOUN 81 (local vertical Δv required) from the prethrust program. Thus, should the crew call a NOUN 81 display after entering the thrusting program, they will notice that the components of $\Delta \underline{v}$, as displayed in NOUN 81, have changed.

Figure 6.1.2-1 shows how the External-Δv mode fits into the Cross-product Steering Routine.

6.1.2.2 Lambert-aimpoint-guidance Mode

The Lambert-aimpoint-guidance mode controls the spacecraft trajectory such as to intercept a given target position (aimpoint) at a given time. The thrusting maneuver has a built-in rate of change of thrust direction, since the Lambert computations periodically update the value of $\underline{v}_R$ during finite non-impulsive burns; no central angle rotation is required. (Refer to Figure 5.1-3.)

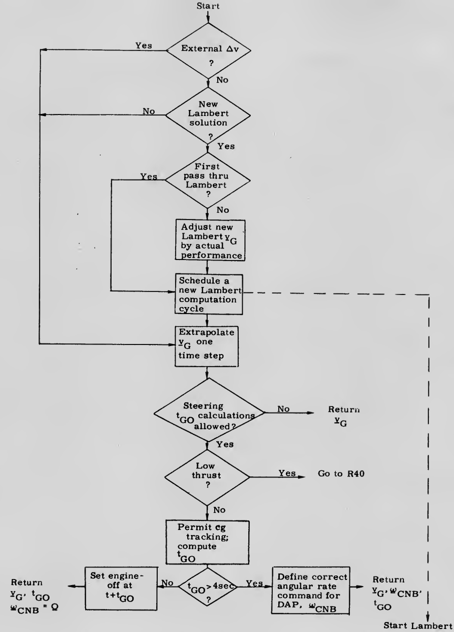


Figure 6.1.2-1. Logic Flow of Cross-product Steering

Such maneuvers may be targeted in the CSM by P34, P35, and P37. In the LM, Lambert-type maneuvers are done using ASTEER guidance. P34 and P35 target for such maneuvers. Examples of CSM Lambert maneuvers are as follows:

Rendezvous intercept	P34
Rendezvous midcourse maneuver	P35
Return-to-earth maneuvers	P37

The typical solution time for the Lambert calculations is 2 to 4 seconds (the COMP ACTY light will be illuminated during the calculations). Since there is often not a new Lambert solution at the beginning of the 2-second cross-product steering cycle, values from the last complete Lambert computation are used to determine $\underline{v}_G$ by extrapolating current values until new data are available from a complete Lambert computation.

In P41, and in the manual trim maneuver of the CSM P40, there is a $\underline{v}_G$-bounce phenomenon that causes the displayed value of $\underline{v}_G$ to change unevenly at the end of a Lambert cycle. This bounce is due to 1-csec time quantization in time-of-flight.

Ordinarily, the Lambert Routine seeks a $\underline{v}_R$ in the plane of the initial and final position vectors ($\underline{r}$ and $\underline{r}_T$). (See Fig. 6.1.2-2 a.) The $\underline{r}_T$ vector (the target vector), however, may be slightly out of the $\underline{r}$-$\underline{v}$ plane. Consequently, the computed $\underline{v}_R$ would be slightly out of $\underline{r}$-$\underline{v}$ plane, resulting in $\underline{v}_G$ having a component perpendicular to the $\underline{r}$-$\underline{v}$ plane. (See Fig. 6.1.2-2 b.) The greater the magnitude of the out-of-plane component, the more energy would be necessary to acquire $\underline{v}_G$. The most serious problem occurs in the 180-deg transfer angle condition (i.e., the angle between $\underline{r}$ and $\underline{r}_T$ is near 180 deg), since the $\underline{r}$-$\underline{r}_T$ plane could be perpendicular to the $\underline{r}$-$\underline{v}_R$ plane and $\underline{v}_G$ could be totally out of plane.

Figure 6. 1. 2-2. Lambert Routine Vectors

A switch is set in the Lambert targeting programs (P34 and P35) to indicate whether $\underline{r}_T$ is within a specified cone angle, ϵ, measured from the 180-deg transfer angle condition. If within this cone angle, $\underline{r}_T$ is rotated into the active vehicle orbital plane, so that excessive plane change and Δv are avoided. In the intercept targeting programs (P34 and P35) the cone angle ϵ is set at 15 deg, and active vehicle transfer angles between 165 deg and 195 deg are normally avoided in the targeting procedure. If a transfer angle condition falling within this 180 ±15-deg sector is either intentionally selected, during the TPI targeting (P34), or is the result of a rendezvous midcourse correction maneuver (P35) during an intercept trajectory targeted for more than 180 deg, the Lambert Routine increases the cone angle ϵ to 45 deg so that the active vehicle transfer angle will not change from inside, to outside, the cone angle during the powered maneuver. Such a condition is undesirable since the intercept trajectory would be retargeted during the powered maneuver. Likewise, if the initial transfer angle falls outside the 15-deg cone angle of P34 and P35, ϵ is decreased to 10 deg to reduce the possibility of the transfer angle changing from outside to inside the cone angle during a powered maneuver.

Figure 6.1.2-1 shows how the Lambert mode fits into the Cross-product Steering Routine. When no new Lambert solution is available, $\underline{v}_G$ is extrapolated from the current $\underline{v}_G$. When a new Lambert solution is available, the computed value of $\underline{v}_G$ is corrected by adding the incremental difference between the calculated, expected change in v and the PIPA-measured $\Delta\underline{v}$. A new Lambert computation is scheduled to begin at the end of the cross-product steering calculations, the corrected Lambert $\underline{v}_G$ is then used as input to the extrapolation of $\underline{v}_G$.

ASTEER is an LGC modification of the Lambert steering concept. It can be used because of the characteristics of lunar orbit rendezvous maneuvers (i.e., for small powered flight maneuvers, variation in the semimajor axis (a) of the desired Lambert soltuion is negligible). ASTEER guidance is like Lambert guidance, except (1) v_G-bounce is eliminated and (2) computation load is reduced (since $\underline{a}$ does not have to be recalculated).

6.2 CMC POWERED FLIGHT PROGRAMS

The Command Module Computer (CMC) has a thrust monitor program (P47) and two thrust control programs—P40 for Service Propulsion System (SPS) maneuvers and P41 for Reaction Control System (RCS) maneuvers. The cross-product steering cycle, which generates steering commands in P40, has been discussed in paragraph 6.1. The digital autopilot (DAP) implements these commands.

During powered flight, the thrust vector control (TVC) DAP controls the spacecraft attitude in accord with steering commands from the cross-product steering computations. Pitch and yaw control of the vehicle is achieved through the deflection of the single gimbaled SPS engine mounted on the service module, while attitude control about the roll axis is provided by the TVC ROLL DAP using the RCS jets.

The TVC DAP computes gimbal-servo commands in response to computed errors between commanded and measured attitudes. The operation takes place as follows:

a. The CMC steering loop computations generate incremental attitude commands in inertial coordinates and transform them into body coordinates.

b. A coupling data unit (CDU) measures the gimbal angles of the inertial measurement unit (IMU) and generates pulses representing small, fixed increments in these angles. These pulses are transmitted to the CMC where they are summed and held in a CDU register.

c. The CDU register is sampled regularly by the DAP program, which back-differences the CDU angles to obtain the incremental variations over each sampling interval.

d. The CDU increments over each sampling interval are then transformed into body coordinates and subtracted from the commanded increments generated by the steering program.

e. The resulting differences represent attitude-error increments, which are then summed to form attitude errors in body coordinates. Small initial attitude errors resulting from an ullage maneuver (RCS thrusting to settle the SPS propellant) prior to SPS thrusting are neglected in the CSM/LM DAP, which zeros the error registers at ignition. This is done to avoid exciting the bending modes by the effects of initial errors. In the CSM, where bending is less of a problem, the errors are correctly initialized.

f. The respective attitude errors are fed to the pitch and yaw compensation filters, whose outputs contribute to the commands to the engine-gimbal servos for pitch and yaw.

g. The total command signal to each engine-gimbal servo is made up of the component from the compensation filter plus another component from a thrust misalignment correction (TMC) loop. The latter component serves to bias the total command so that a zero output from the compensation filter will cause the thrust vector to pass exactly through the center of gravity (cg) when there is no cg motion and no motion of the thrust vector relative to the commanded angle.

The TVC ROLL DAP is designed to provide attitude and rate control about the roll axis by the use of the RCS jets. Its function is strictly attitude hold. The orientation of the CSM about the roll axis is held within a 5-deg deadband throughout the burn. The outer-gimbal angle of the IMU, which is parallel to the vehicle roll axis, is read and processed to yield approximate roll-attitude and roll-rate measurements. A switching logic in the phase plane is then used to generate jet commands to the RCS jets. The switching logic divides the phase plane into three regions: jet firings for negative torque, jet firings for positive torque, and coast. The operating point in the phase plane is computed every 0.5 second and jet firings are commanded only if the 5-degree deadband is exceeded. For successive torque commands of the same sign, jets are fired from alternate quad pairs. Normal procedure, however, is for the crew to disable one quad during a burn, which means that a jet failed on will produce a diverging roll attitude error.

Operation of the TVC DAP during an SPS burn is completely automatic, requiring no inputs from the crew. Before the burn, however, the crew may enter the CSM and LM weights or the estimated engine-trim angles in the pitch and yaw planes. (This entry is required after a vehicle configuration change, such as the LM undocking; at other times it is optional, to be made only if the crew is dissatisfied with the pad-loaded or computed values. The values are displayed in R03. (Refer to paragraph 9.3.1.) Also, by keying in VERB 46 ENTR, the crew can change the CSM/LM compensation filter during a burn. This is a backup mode in case of a slosh instability; it will probably never be used.

The gains for the ROLL DAP and TVC DAP filters are established initially and updated using a small AGC program called TVCMASSPROP. This program, which is called every 10 seconds by TVCEXEC, computes piecewise-linear approximations to the curves of I_{xx}, I_{AVG}, and I_{AVG}/Tl_x versus CSM propellent weight. These curves are given in parametric form, with LM mass as the parameter. TVCEXEC decrements CSMMASS every 10 seconds by subtracting an erasable constant assumed equal to the mass flow over the 10-second period. Also, at the end of the burn, a decrement is made proportional to the time since the last update—thus any burn length will cause CSMMASS to be updated. (Mass change calculations are covered in detail in GSOP paragraph 3.3.4.)

P40 initiates the operations of the TVC DAP after ignition. At 0.5-second intervals, ROLL DAP and a routine to update the FDAI needles are called. Four seconds before the end of the burn, the engine shutdown sequence is begun. After SPS engine shutdown, there is a 2.5-second delay while the TVC DAP continues to function as the thrust level decays. RCS jet firings start approximately 1.5 seconds later. At the end of the burn, there is an automatic update of the engine trim estimates from the thrust misalignment correction (TMC) loop, to be used for the next burn.

The performance of the TVC DAP is monitored via the FDAI attitude-error needles. Needle updates are made every 0.5 second. During changeover from RCS to TVC, there is a short period (0.5 to 1 second) during which the needles will be zeroed. After this period, in the CSM configuration the pitch and yaw errors are reestablished with the values left by the RCS DAP. For the CSM/LM, the needles are not reestablished with the RCS errors.

In addition to the FDAI attitude-error needles, the crew can also monitor the Stabilization and Control System (SCS) rate needles and the engine gimbal-position-indicator (GPI) needles. Following the completion of the burn, the residual cross-axis velocity components are displayed on the DSKY in NOUN 85. Although when the ROLL DAP calls for jet-firings, the logic assumes the firing of alternate pairs of jets to minimize the effect of jet failures; operationally only one jet pair is enabled by the crew. This ensures that the crew will notice if a jet fails on (the roll error will diverge), and the failed jet can then be disabled.

The RCS autopilot is in control of the spacecraft during the trim maneuver of P40 providing rotational control and during P41 providing translational as well as rotational control. The RCS autopilot converts an input desired thrust attitude to output jet firings and rotational acceleration by means of a phase-plane switching logic and jet-firing logic. On each side of the desired attitude is a deadband, i.e., an area of allowable angular deviation. If the actual thrust attitude exceeds the deadband, jets are fired to bring the attitude back inside the deadband. Under manual control, moving the rotational hand controller changes the input desired attitude. As a result, the DAP perceives an attitude error relative to the new desired attitude and fires RCS jets to maintain the attitude within the deadband about the new desired attitude.

BLANK

6.2.1 P40, Service Propulsion System (SPS) Maneuver Program—CMC

The powered flight guidance program, P40, handles the timing of SPS maneuvers. During burns, P40 maintains the CSM state vector, guides the thrust direction so as to achieve the desired velocity at the end of the maneuver, and provides the crew with a monitor of the maneuver's progress. P40—which may be used when a change-of-orbit maneuver is required—and the SPS are used for big burns with a manually controlled RCS trim maneuver at the end.

For a GNCS-controlled maneuver, P40 is used for a large velocity-to-be-gained; i.e., when $|\underline{v}_G|$ is greater than, or equal to,

$$\frac{F_{SPS}}{m} \cdot \Delta t_{MIN}$$

In the expression above, F_{SPS} is the thrust of the SPS engine (about 20,500 lb), m is the mass of the total vehicle (including the LM if it is attached), and Δt_{MIN} is the minimum burn time for which the particular SPS engine being considered has been successfully tested. Currently, Δt_{MIN} equals 0.5 sec.

A prethrust program, P3x, establishes the parameters needed for thrust control guidance. After the appropriate P3x has been performed, the astronaut must not select another P3x, P7x, or P23 before the burn. These programs use some of the same variable computer storage locations and would destroy the thrusting parameters established by the original P3x for this burn. Since mark incorporation would change the current state vector without correspondingly changing the thrusting parameters, P20 should not be selected between P3x and P40. If P20 had been previously selected, however, it may continue to run in the background. (The mark incorporation function is turned off by P3x.)

P40 uses the AVERAGEG routine for state vector updating, and cross-product steering for inputs to the TVC DAP, which controls the spacecraft attitude by positioning the engine bell during the burn.

6.2.1.1 State Vector Updating (AVERAGEG)

To keep the state vector up to date, the AVERAGEG routine takes into account two kinds of acceleration effects:

a. Gravity—by averaging the gravitational acceleration vector over 2-sec increments of time

b. Thrusting—by discrete velocity increments as measured by the PIPAs.

The state vector is updated by AVERAGEG every 2 seconds. AVERAGEG is used during burns because of its speed in updating. It should be terminated as soon as possible after the burn, however, to avoid accumulation of PIPA bias errors. Refer to subsection 6.1 for a more detailed discussion of AVERAGEG.

6.2.1.2 Cross-Product Steering (External $\Delta\underline{v}$ and Lambert Aimpoint)

Cross-product steering is used to guide the thrust direction. The two modes, External $\Delta\underline{v}$ and Lambert aimpoint, use the cross-product steering concept to control the thrust direction along the velocity-to-be-gained ($\underline{v}_G$) vector and to terminate thrust when the desired velocity increment has been achieved. The two modes differ in method of computing $\underline{v}_G$. External $\Delta\underline{v}$ is characterized by a non-rotating burn and therefore uses a single initial value of $\underline{v}_G$ in its computations. Lambert aimpoint periodically recomputes $\underline{v}_R$ (required velocity) to achieve an intercept with the specified target vector at the specified time.

In External $\Delta\underline{v}$, since the change of velocity cannot be made instantaneously, the routine uses a compensated inplane velocity to compute $\underline{v}_G$ rather than the actual desired-velocity-change vector.

The 2-second cycles of the cross-product steering functions often do not allow enough time to complete a Lambert computation in each cycle. Consequently, values from the last complete Lambert computation are used to determine $\underline{v}_G$ by extrapolating current values until new data are available from a complete Lambert computation. For a detailed explanation of External $\Delta\underline{v}$ and Lambert aimpoint, refer to subsection 6.1.

6.2.1.3 P40 Procedures

Tables 6.2.1-I and -II show P40 displays and extended verbs, respectively. Figure 6.2.1-1 is the program flowchart. Before entering P40, the Autopilot Data Load Routine (R03) and a prethrust program (P3x) must be performed. In addition, the IMU must be powered up and aligned.

The crew selects P40 (via the DSKY) at a time, specified by crew procedures, to allow sufficient time before ignition for prethrust activities, such as arming the

TABLE 6.2.1-I

DISPLAYS ASSOCIATED WITH P40 (SHEET 1 OF 2)

DSKY	Initiated By	Purpose	Condition	Register
V05 N09E	Astronaut	Verify PROG alarm	00205 bad PIPA reading detected 00210 ISS not on 00220 IMU orientation unknown 01301 arc-sine or arc-cosine argument too large 01407 velocity-to-be-gained increasing 01703 time of ignition slipped	R1 xxxxx* R2 xxxxx R3 xxxxx
FL V50 N18	R60	Display required gimbal angles	OGA-roll IGA - pitch MGA - yaw	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
V06 N18	R60	Display of final gimbal angles	OGA IGA MGA	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
FL V50 N25	P40	Please perform SPS gimbal test drive option	00204 gimbal drive test option	R1 00204
V06 N40	P40	Display	Time from t_{IG} Velocity to-be-gained Sum of acquired velocity	R1 xxBxx min, sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V99 N40	P40	Request SPS engine-on enable	---	---
FL V97 N40	R40	Low thrust detected	---	---
FL V16 N40	P40	Burn complete	Time from cutoff Remaining $\underline{v}_G$ Sum of velocity acquired	R1 xxBxx min, sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V16 N85	P40	Display remaining $\underline{v}_G$	Components of $\underline{v}_G$	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec

*The alarm codes are displayed as follows:
R1 contains the first alarm following error reset.
R2 contains the second alarm following error reset.
R3 contains the most recent alarm.

TABLE 6.2.1-I

DISPLAYS ASSOCIATED WITH P40 (SHEET 2 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
FL V16 N44	R30	Display orbital parameters (R30)	Apogee altitude Perigee altitude Time of free fall	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min, sec
FL V16 N54	R31	Display	Range Range rate Theta	R1 xxx. xx n. mi. R2 xxxx. x ft/sec R3 xxx. xx deg

TABLE 6.2.1-II

EXTENDED VERBS FOR USE WITH P40

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters	DSKY displays apogee, perigee; and time of free fall
83 ENTR	Do R31	Display rendezvous parameters	DSKY displays range, range rate and theta, the angle between local horizontal and the spacecraft X-axis

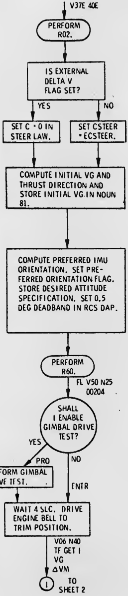


Figure 6.2.1-1. SPS Maneuver Program (P40) (Sheet 1 of 3)

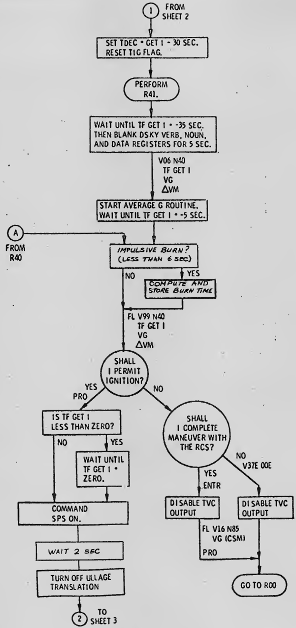
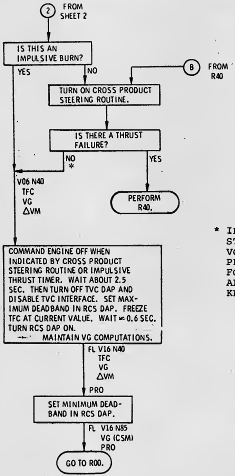


Figure 6. 2. 1-1. SPS Maneuver Program (P40) (Sheet 2 of 3)



* IF CROSS PRODUCT
STEERING DETECTS
VG INCREASING
PROG LT--ON.
FOR DISPLAY OF
ALARM CODE 1407
KEY V5N9E.

Figure 6.2.1-1. SPS Maneuver Program (P40) (Sheet 3 of 3)

SPS and TVC, and performing R60. The program performs the IMU Status Check Routine (R02) and illuminates the PROG light if the ISS is off (alarm code equals 00210) or the IMU orientation is unknown (alarm code equals 00220).

At the completion of R02, the program computes the initial $\underline{v}_G$ and thrust direction and the preferred orientation matrix and then enters the Attitude Maneuver Routine (R60) and flashes VERB 50 NOUN 18. The desired gimbal angles are displayed to 0.01 deg in the following registers:

R1 = OGA, roll
R2 = IGA, pitch
R3 = MGA, yaw.

If the PROG light goes on at this point and the alarm code is 01301, the desired gimbal angles are indeterminate because the initial $\underline{v}_G$ is collinear with the stable member Y-axis. A maneuver to the desired attitude would produce gimbal lock.

If the crew chooses to have the attitude maneuver performed by the autopilot, the SC CONT switch must be placed in CMC, the CMC mode switch in AUTO, and then PRO keyed in response to VERB 50 NOUN 18, signaling the RCS DAP to begin the maneuver via R60.

During the maneuver, a non-flashing VERB 06 NOUN 18 displays the final gimbal angles, and the crew monitors the maneuver on the FDAI ball and needles. If gimbal lock is approached, or if it is desired to perform the entire maneuver manually, the crew uses the RHC to complete the maneuver. (Once the RHC is removed from detent, the automatic maneuvering routine ceases and can be re-initiated by responding with a PRO to the flashing VERB 50 NOUN 18.) A VERB 50 NOUN 18 display comes up upon completion of the R60 maneuver. The crew can then switch to SCS control and verify manual TVC. To exit from R60, the crew keys ENTR on VERB 50 NOUN 18.

Upon completion (or termination) of R60, the DSKY displays a flashing VERB 50 NOUN 25 with R1 containing 00204 (i.e., please perform SPS gimbal drive test option). The crew now arms the SPS and TVC. If the time to ignition is too short to allow the test to be performed, the crew can key ENTR. Normally, the crew keys PRO and monitors the test on the gimbal position indicator (GPI). In 2-second intervals, the SPS pitch gimbal is driven from 0 deg to +2 deg, from +2 deg to -2 deg, and from -2 deg to 0 deg. The SPS yaw gimbal then undergoes the same process.

After a 4-second delay, the program drives the engine bell to the trim position. Then the DSKY displays (and repeats every second) VERB 06 NOUN 40; the registers contain the following:

R1 = time from t_{IG}
R2 = magnitude of velocity-to-be-gained
R3 = sum of velocity increments acquired so far.

R1 is negative until t_{IG}. R2 initially contains the total velocity-to-be-gained and decreases as the maneuver proceeds. R3 should remain close to zero until ullage begins.

The program at this time enters the State Vector Integration Routine (R41), which integrates the CSM state vector ahead to t_{IG}-30 seconds. If R41 is not completed before t_{IG} -42.5 seconds, a program alarm (code 01703) is generated and the time of ignition is slipped until the integration is completed.

At t_{IG} -35 seconds, the DSKY is blanked for 5 seconds, then the VERB 06 NOUN 40 display returns. This is the beginning of the AVERAGEG and v_G updating cycles. From t_{IG} -30 until t_{IG} -25 seconds, the crew should watch R3 of the DSKY to be sure it does not exceed 2.0 ft/sec—a condition that indicates excessive PIPA bias and possible termination of the burn.

The crew should begin ullage shortly before t_{IG}—at a time determined from tables, depending on SPS fuel loading and the vehicle configurations. At this time, R3 will start to increase.

At t_{IG}-5 seconds, the DSKY display changes to flashing VERB 99 NOUN 40, requesting the SPS engine ignition go-ahead signal. The program provides the crew with the following three choices:

a. Avoiding the burn altogether by keying VERB 34 ENTR or by selecting a new program (VERB 37 ENTR xx ENTR)
b. Completing the maneuver under RCS power by keying ENTR
c. Going ahead with the SPS burn by keying PRO.

The program commands SPS ignition at t_{IG} and displays a non-flashing VERB 06 NOUN 40. The SPS THRUST light goes on, and the crew will feel an acceleration of approximately 0.2 to 1.0 g. If the crew fails to key PRO before t_{IG}, it may still PRO and the engine will light instantly.

During the burn, the astronaut should avoid using extended verbs since a VERB 97 display (low thrust) could be masked (i.e., not displayed on DSKY). In the Lambert mode, the computer may not have enough VAC area to perform both the Lambert computations and the extended verb. R1 displays time from engine cutoff. If R2 is increasing or if the PROG light goes on and alarm code 01407 occurs, there was probably an error in the initial attitude maneuver.

The crew can monitor the pitch and yaw attitude errors, as determined by the TVC autopilot, on the FDAI needles.

During the burn, if the system should detect a bad PIPA reading, the program will store an alarm code of 00205. The astronaut should switch to SCS control. If low thrust is detected by the computer, the program enters the Thrust Fail Routine (R40). The DSKY displays flashing VERB 97 NOUN 40 requesting action on thrust failure. (R40 is discussed in detail in paragraph 6.2.1.5.1.)

At cutoff time (t_{CO}), the program shuts off the SPS engine and the SPS THRUST light goes out. The DSKY displays a flashing VERB 16 NOUN 40 to indicate completion of the SPS burn; the crew replies by keying PRO. After 2 seconds, the DSKY displays a flashing VERB 16 NOUN 85 (the three components of the remaining $\underline{v}_G$, in control coordinates). The crew should use the RHC and THC to null the remaining $\underline{v}_G$ to a value specified in the checklist. The crew keys PRO to get to the flashing VERB 37.

The crew may desire to review the post-burn orbital parameters (R30), or it may desire to review the range and range rate to the LM (R31/R34).

AVERAGEG will continue running until a new major mode is selected; therefore this selection must be made immediately to avoid accumulation of PIPA bias errors.

6.2.1.4 Time Lines

Figure 6.2.1-2 relates the P40 flowchart to crew observance and response.

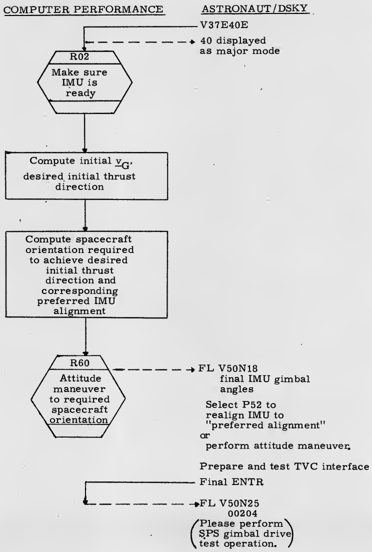


Figure 6. 2. 1-2. Time Lines of SPS Maneuver Program (P40)
(Sheet 1 of 4)

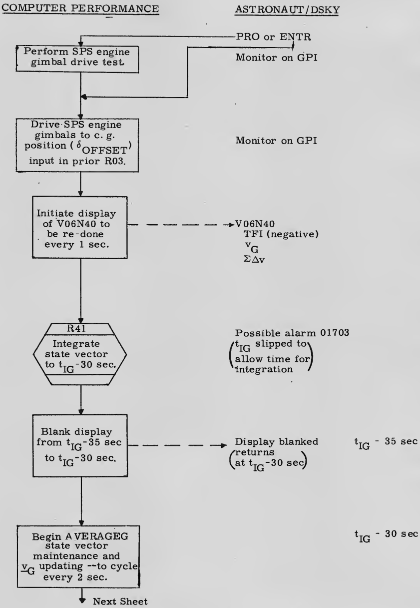


Figure 6.2.1-2. Time Lines of SPS Maneuver Program (P40)
(Sheet 2 of 4)

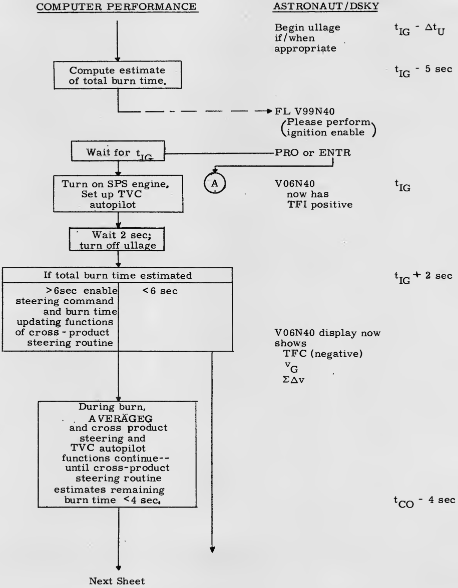


Figure 6.2.1-2. Time Lines of SPS Maneuver Program (P40) (Sheet 3 of 4)

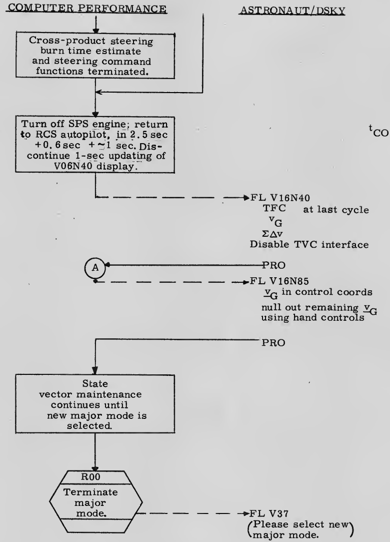


Figure 6.2.1-2. Time Lines of SPS Manuever Program (P40)
(Sheet 4 of 4)

6.2.1.5 Routines Associated with P40

6.2.1.5.1 SPS Thrust Fail Routine.—The SPS Thrust Fail Routine (R40) is automatically selected by P40 when low thrust is detected. Figure 6.2.1-3 gives a brief logical flow of R40. A flashing VERB 97 NOUN 40 notifies the crew of the thrust fail. If the engine comes back on at full strength, the crew can key PRO to continue the burn. To perform a manual thrust, the crew turns the DIRECT THRUST switch to ON and keys PRO.

To terminate the burn and attempt re-ignition or to attempt the maneuver by RCS power, the crew should key ENTR. Control will be returned to P40, where the time from t_{IG} display (R1) will be set to 59 min 59 sec, and the VERB 99 flash (occurring in about 2.8 seconds from return of control to P40) will behave as in a late ignition. The crew should key PRO for immediate ignition. The crew may choose to switch control of the burn immediately to the SCS. To terminate the burn altogether, the crew keys VERB 34 ENTR and turns the ΔV THRUST-A and -B switches to OFF when a new major mode has been requested.

6.2.1.5.2 State Vector Integration Routine.—Figure 6.2.1-4 is a flowchart of the State Vector Integration Routine (R41). R41 is automatically selected by P40, P41, P47, P61, and P62. The purpose of this routine is to integrate the state vector ahead to the time that the AVERAGEG routine will be turned on by the thrusting program. If the state vector integration cannot be completed before the specified time, a program alarm occurs (alarm code equals 01703) and the t_{IG} is slipped.

6.2.1.6 Alarms

A list of alarm codes which may occur in P40 follows; detailed description of procedures to follow upon occurrence of these alarms is given below.

a. Alarm code 00205 occurs if a bad PIPA reading is detected.
b. Alarm code 00210 occurs if the ISS is not on.
c. Alarm code 00220 occurs if the IMU orientation is not known.
d. Alarm code 01301 occurs if the arc-sine or arc-cosine argument is too large.
e. Alarm code 01407 occurs if the velocity-to-be-gained is increasing.
f. Alarm code 01703 occurs if the t_{IG} is slipped.

Alarm code 00205 may occur during the thrusting maneuver. The crew should switch to SCS control.

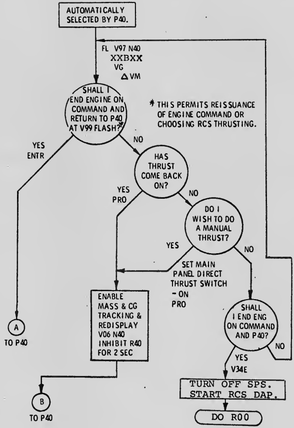


Figure 6.2.1-3. SPS Thrust Fail Routine (R40)

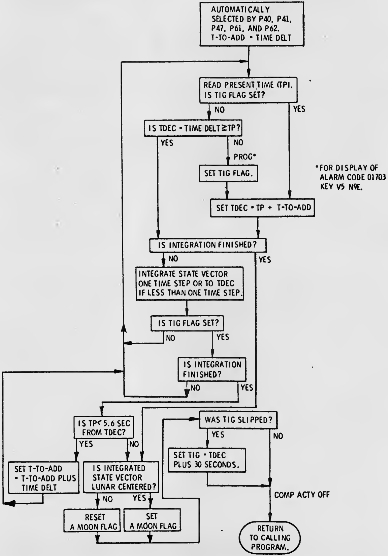


Figure 6.2.1-4. State Vector Integration Routine (R41)

Alarm codes 00210 and 00220 may occur immediately after the program is entered and the IMU Status Check Routine is called. They appear as PROG alarms on the DSKY when the crew keys VERB 05 NOUN 09 ENTR to identify the abnormality. When the alarm is identified, the crew depresses KEY REL and RSET and responds to flashing VERB 37.

Alarm code 01301 may occur during R60. After verifying the alarm, the crew selects P52 to realign the IMU and then reselects P40.

Alarm code 01407 may occur during an SPS burn, indicating that the angle between v_G and the thrust direction vector is greater than 90 deg. Crew procedures should be consulted about recovery.

Alarm code 01703 may occur during R41 of P40. After verifying the alarm, the crew will note a discontinuity in the contents of DSKY R1 (i.e., time from t_{IG}). The value on the Digital Event Timer will no longer be valid. No crew action is necessary.

6.2.1.7 Restarts

Should a restart occur during P40, the RESTART light would go on; the crew would probably not notice any other effects.

6.2.2 P41, Reaction Control System (RCS) Maneuver Program—CMC

P41, one of the powered flight guidance programs, can be used to handle the timing of short, manually controlled RCS burns whenever a change-of-orbit maneuver is required. During these burns, P41 maintains the CSM state vector, controls spacecraft attitude—to achieve the desired velocity at the end of the maneuver—and provides the crew with a monitor of the maneuver's progress.

P41 uses the AVERAGEG routine for state vector updating and the steering routines (i.e., Lambert Aimpoint or External $\Delta \underline{v}$) to compute DSKY displays. (Refer to subsection 6.1.)

The crew's first choice about a powered flight maneuver must be which of the powered flight programs to use. When a GNCS-controlled maneuver is desired, the choice of program usually depends on the magnitude of velocity-to-be-gained (i.e., on the amount of energy required to accomplish the maneuver). P41 is chosen if $|\underline{v}_G|$ is less than,

$$\frac{F_{SPS}}{m} \cdot \Delta t_{MIN}$$

In the above expression, F_{SPS} is the thrust of the SPS engine (about 20,500 lb), m is the mass of the total vehicle (including the LM if it is attached), and Δt_{MIN} is the minimum burn time for which the particular SPS engine being considered has been successfully tested. Currently, Δt_{MIN} equals 0.5 sec. The maximum $\underline{v}_G$ that can be acquired by an RCS burn (P41) can be determined by:

$$\left|\underline{v}_G\right| = \frac{w_{prop}}{w_{tot}} \; g_E \; ISP_{RCS}$$

where w_{prop} is the weight of RCS fuel available, w_{tot} is the total weight of the vehicle, g_E is gravitational acceleration at the earth's surface, and

$$ISP_{RCS} = \frac{F_{RCS}}{\dot{w}_{prop}} = 276.45 \text{ sec}$$

A prethrust program, P3x, establishes the parameters needed for thrust control guidance. After the appropriate P3x has been performed, the astronaut must not select another P3x, P7x, or P23 before the burn. These programs use some of the same variable computer storage locations and would destroy the thrusting parameters established by the original P3x for this burn. Since mark incorporation would change the current state vector without correspondingly changing the thrusting parameters, P20 should not be selected between P3x and P41. If P20 had been previously selected, however, it may continue to run in the background. (The mark incorporation function is turned off by P3x.)

6.2.2.1 P41 Procedures

Tables 6.2.2-I and -II show P41 displays and extended verbs, respectively. Figure 6.2.2-1 is a flowchart of P41.

Before entering P41, the Autopilot Data Load Routine (R03) and a prethrust program (P3x) must be performed. In addition, the IMU must be powered up and aligned.

When the crew selects P41, the program first performs the IMU Status Check Routine (R02) and illuminates the PROG light if the ISS is off (alarm code is 00210) or if the IMU orientation is not known (alarm code is 00220). P41 then computes the initial thrust direction and the preferred attitude matrix.

At the completion of R02, the program enters the Attitude Maneuver Routine (R60), flashes VERB 50 NOUN 18, and displays the desired gimbal angles to 0.01 deg in the registers as follows:

R1 = OGA, roll
R2 = IGA, pitch
R3 = MGA, yaw.

The crew has the option of performing (i.e., keying PRO) or bypassing (i.e., keying ENTR) this maneuver in P41. If the PROG light goes on at this point and the alarm code is 01301, the desired gimbal angles are indeterminate because the initial $\underline{v}_G$ is collinear with the stable member y-axis. A maneuver to the desired attitude would produce gimbal lock.

If the yaw angle is not small enough to avoid approaching gimbal lock, the crew can select P52 to do the required preferred realignment. If the yaw angle is small enough, the crew can perform the attitude maneuver automatically or manually. If

TABLE 6.2.2-I

DISPLAYS ASSOCIATED WITH P41

DSKY	Initiated by	Purpose	Condition	Register
V05 N09E	Astronaut	Verify PROG alarm	00205 Bad PIPA reading detected 00210 ISS not on 00220 IMU orientation unknown 01301 arc-sine or arc-cosine argument too large 01703 time of ignition slipped	R1 xxxxx R2 xxxxx R3 xxxxx *
FL V50 N18	R60	Display required gimbal angles	OGA - roll IGA - pitch MGA - yaw	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
V06 N18	R60	Display of final gimbal angles	OGA IGA MGA	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
FL V16 N85	P41	Display remaining v_G	Components of $\underline{v}_G$	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V16 N44	R30	Display orbital parameters	Apogee altitude Perigee altitude Time of free fall	R1 xxxx.x n.mi. R2 xxxx.x n.mi. R3 xxBxx min,sec
V06 N85	P41	Display v_G	Three components of $\underline{v}_G$ to be acquired, in control coordinates	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V16 N54	R31	Display	Range Range rate Theta	R1 xxx.xx n.mi. R2 xxxx.x ft/sec R3 xxx.xx deg

* The alarm codes are displayed as follows:

R1 = First alarm following error reset
R2 = Second alarm following error reset
R3 = Most recent alarm.

TABLE 6.2.2-II

EXTENDED VERBS FOR USE WITH P41

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters	DSKY displays apogee, perigee; and time of free fall
83 ENTR	Do R31	Display rendezvous parameters	DSKY displays range, range rate and theta, the angle between local horizontal and the spacecraft X-axis

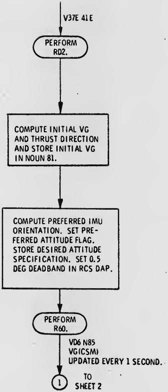


Figure 6.2.2-1. RCS Manuever Program (P41) (Sheet 1 of 2)

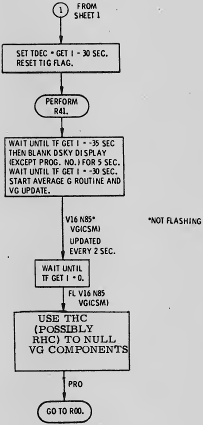


Figure 6.2.2-1. RCS Manuever Program (P41) (Sheet 2 of 2)

the maneuver is performed by the autopilot, the crew places the SC CONT switch in CMC, the CMC MODE switch in AUTO, and then keys PRO to VERB 50 NOUN 18, signaling the RCS DAP to begin the maneuver via R60.

During the maneuver, a non-flashing VERB 06 NOUN 18 displays the final gimbal angles, and the crew monitors the maneuver on the FDAI ball and needles. If gimbal lock is approached, or if the entire maneuver is done manually, the crew uses the RHC to complete the maneuver. (Once the RHC is removed from detent, the automatic maneuvering routine ceases and can be reinitiated only by keying PRO in response to the flashing VERB 50 NOUN 18.) A VERB 50 NOUN 18 display occurs upon completion of the R60 maneuver. To exit from R60, the crew keys ENTR in response to VERB 50 NOUN 18.

Upon completion (or termination) of R60, the DSKY displays (and repeats every second) VERB 06 NOUN 85; the three registers contain the three components of $\underline{v}_G$, in control coordinates. The total velocity to be acquired during the maneuver is displayed and decreases when the maneuver begins. Nominally, the crew places SC CONT in CMC and CMC MODE in AUTO or HOLD.

The program at this time enters the State Vector Integration Routine (R41) which integrates the CSM state vector ahead to t_{IG}-30 seconds. If R41 cannot be completed before t_{IG}-42.5, a program alarm (code 01703) is generated and the time of ignition is slipped. R41 is explained in more detail in paragraph 6.2.1.5.2.

At t_{IG}-35, the DSKY is blanked for 5 seconds, then the VERB 16 NOUN 85 display will start to monitor the same register data. If $\underline{v}_G$ updating is being executed in the External $\Delta\underline{v}$ mode, a change of more than 0.4 ft/sec in any component during the period t_{IG}-30 to t_{IG} indicates excessive PIPA bias.

At t_{IG}, the program flashes VERB 16 NOUN 85. The crew, using the RHC and THC, should null the velocity-to-be-gained to a value specified in the checklist. Upon completion of thrusting, the crew keys PRO to end major mode P41.

The crew may select the Orbital Parameters Display (VERB 82 ENTR) to check apogee altitude, perigee altitude, and time of free-fall. If R2—showing perigee altitude—is greater than 49.4 n. mi. (near earth) or 5.8 n. mi. (near the moon), R3—showing time of free-fall—should read minus 59 minutes 59 seconds. The crew key PRO to return to the flashing VERB 37 display.

The crew can key VERB 83 ENTR to monitor the range, range rate, and the angle between local horizontal and the spacecraft X-axis.

AVERAGEG will continue running until a new major mode is selected. Therefore, immediate new-mode selection is imperative to avoid accumulation of PIPA bias errors.

6.2.2.2 Time Lines

The time lines shown in Figure 6.2.2-2 relate the program flowchart to crew observance and response.

6.2.2.3 Alarms

The alarm codes which may occur in P41 are listed below and a detailed explanation of each follows:

a. Alarm code 00205 occurs when a bad PIPA reading is detected.
b. Alarm code 00210 occurs if the ISS is not on.
c. Alarm code 00220 occurs if the IMU orientation is not known.
d. Alarm code 01301 occurs if the arc-sine or arc-cosine argument is too large.
e. Alarm code 01703 occurs if the time of ignition is slipped.

Alarm code 00205 may occur during the thrusting maneuver. The maneuver should then probably be terminated since the display and AVERAGEG state vector maintenance will no longer be valid.

Alarm code 01301 may occur during R60. After verifying the alarm (i.e., keying in VERB 05 NOUN 09 ENTR) the crew should select P52 to realign the IMU. Then P41 may be reselected.

For a detailed explanation of the occurrence of alarm codes 00210 and 00220 and 01703, refer to paragraph 6.2.1.6.

6.2.2.4 Restarts

Should a restart occur during P41, the RESTART light on the DSKY will be illuminated. No other effects will be noticed by the crew.

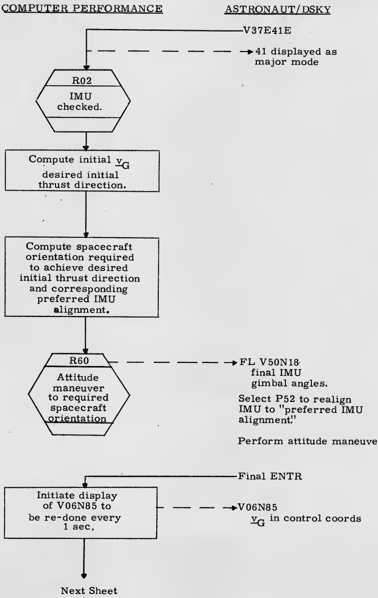


Figure 6.2.2-2. Time Lines of RCS Maneuver Program (P41) (Sheet 1 of 2)

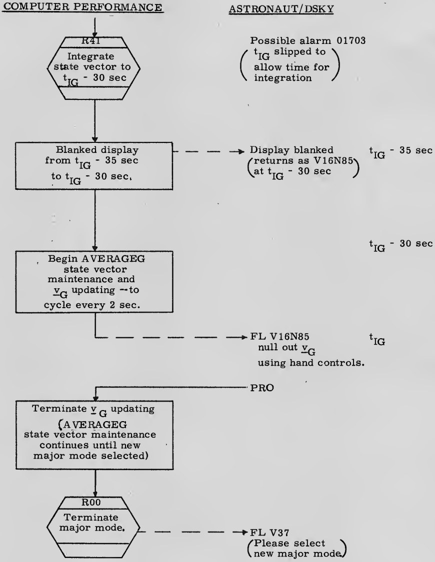


Figure 6.2.2-2. Time Lines of RCS Maneuver Program (P41) (Sheet 2 of 2)

6.2.3 P47, Thrust Monitor Program—CMC

P47, the powered flight monitor program, maintains the CSM state vector during a thrusting maneuver not controlled by the GNCS and provides a monitor of the maneuver's progress for the crew. For example, the trans-lunar insertion (TLI) maneuver is done using the SIVB; the final docking maneuver in rendezvous is done using THC manual control; in case of an SPS engine failure during the second lunar orbit insertion (LOI2) maneuver, or late in the first lunar orbit insertion (LOI1) maneuver (when enough fuel has been used to make a sufficiently light vehicle), the LM DPS or APS engine can be used to initiate a return to earth.

The program uses the AVERAGEG routine for state vector updating. (For an explanation of AVERAGEG use, refer to subsection 6.1.)

6.2.3.1 P47 Procedures

Tables 6.2.3-I and -II present the displays and extended verbs associated with P47. Figure 6.2.3-1 is the program flowchart. Before entering P47, the CMC and the IMU must be on and aligned.

Upon selection of P47, shortly before t_{IG}, the program performs the IMU Status Check Routine (R02) and illuminates the PROG light if the ISS is off (i.e., alarm code is 00210) or the IMU orientation is unknown (alarm code is 00220).

At the completion of R02, the program enters the State Vector Integration Routine (R41), which integrates the CSM state vector ahead to a specified number of seconds (ϵ). In ϵ **seconds**, the AVERAGEG cycle begins. (Refer to paragraph 6.2.1.5.2 for a description of R41.)

The DSKY displays a flashing VERB 16 NOUN 83 with the three components of acquired $\Delta \underline{v}$, in control coordinates. The registers contain zeros initially; the contents are updated every 2 seconds.

While the thrusting maneuver is performed, the crew must monitor the FDAI ball to avoid gimbal lock. If the PROG light goes on during the maneuver, the occurrence of an alarm code 00205 indicates the detection of a bad PIPA reading. If the crew wishes to recycle the display (zeroing the registers), VERB 32 ENTR can be keyed.

To terminate major mode P47, the crew keys PRO. The DSKY then flashes VERB 37, requesting the selection of a new major mode. It is important to respond to

TABLE 6.2.3-I

DISPLAYS ASSOCIATED WITH P47

DSKY	Initiated by	Purpose	Condition	Register
V05 N09E	Astronaut	Verify PROG alarm	00205 Bad PIPA reading detected 00210 ISS not on 00220 IMU orientation unknown	R1 xxxxx R2 xxxxx R3 xxxxx*
FL V16 N83	P47	Display $\Delta \underline{v}$ acquired	Three components in control coordinates	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V16 N44	R30	Display orbital parameters	Apogee altitude Perigee altitude Time of free fall	R1 xxxx.x n.mi. R2 xxxx.x n.mi. R3 xxBxxmin,sec
FL V16 N54	R31	Display	Range Range rate Theta	R1 xxx.xx n.mi. R2 xxxx.x ft/sec R3 xxx.xx deg
FL V16 N53	R34	Display	Range Range rate Phi	R1 xxx.xx n.mi. R2 xxxx.x ft/sec R3 xxx.xx deg
V16 N62	Astronaut	Display	Velocity Rate of altitude change Altitude	R1 xxxxx. ft/sec R2 xxxxx. ft/sec R3 xxxx.x n.mi.

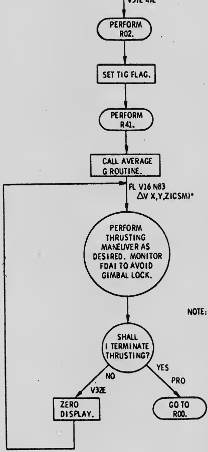
* The alarm codes are displayed as follows:

R1 = First alarm following error reset
R2 = Second alarm following error reset
R3 = Most recent alarm

TABLE 6.2.3-II

EXTENDED VERBS FOR USE WITH P47

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters	DSKY displays apogee, perigee; and time of free fall
83 ENTR	Do R31	Display first set of rendezvous parameters	DSKY displays range, range rate and theta, the angle between local horizontal and the spacecraft X-axis
85 ENTR	Do R34	Display second set of rendezvous parameters	DSKY displays range, range rate and phi, the angle between local horizontal and the sextant SLOS



* R1, R2, AND R3 READ 00000 INITIALLY. AFTER STARTING THEY ARE UPDATED EVERY 2 SECONDS.

NOTE: FOR DISPLAY OF RANGE, RANGE RATE, AND THETA, KEY V83E TO CALL ROUTINE R31.

FOR DISPLAY OF RANGE, RANGE RATE, AND PHI KEY V85E TO CALL ROUTINE R34

FOR DISPLAY OF VI, H-DOT & H KEY V16 N62E

FOR DISPLAY OF APOGEE, PERIGEE, TIME OF FREE FALL, KEY V82E TO CALL R30.

Figure 6.2.3-1. Thrust Monitor Program (P47) this immediately to terminate AVERAGEG and thus avoid accumulation of PIPA bias errors.

6.2.3.2 Time Lines

The time lines shown in Figure 6.2.3-2 relate the program flowchart to crew observance and response.

6.2.3.3 Alarms

The PROG alarm codes associated with P47 are listed below. A detailed description of each follows.

a. Alarm code 00205 occurs if a bad PIPA reading is detected.
b. Alarm code 00210 occurs if the ISS is not on.
c. Alarm code 00220 occurs if the IMU orientation is not known.

Alarm code 00205 may occur during the thrusting maneuver. The maneuver should be terminated since the display and AVERAGEG state vector maintenance will no longer be valid.

For detailed explanations of alarm codes 00210 and 00220, refer to paragraph 6.2.1.6.

6.2.3.4 Restarts

Should a computer restart occur, the RESTART light on the DSKY would be illuminated; no other effect would be noticed by the crew.

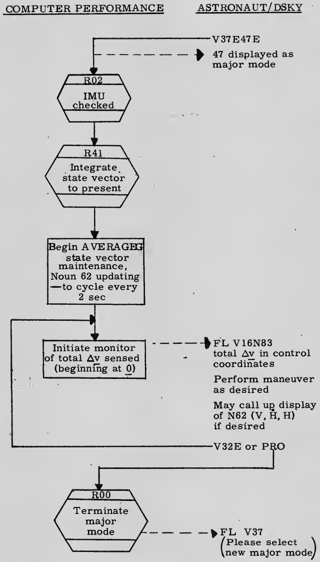


Figure 6.2.3-2. Time Lines of Thrust Monitor (P47)

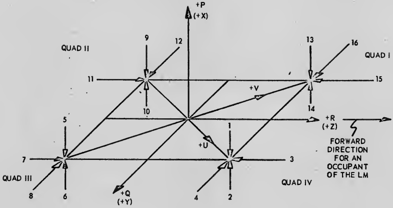
6.3 LGC POWERED FLIGHT PROGRAMS

The Lunar Module Guidance Computer (LGC) has a program that monitors thrust (P47) and three programs that control thrust—P40 for DPS maneuvers, P41 for RCS maneuvers, and P42 for APS maneuvers. The cross-product steering cycle, which generates steering commands in P40 and P42, is discussed in subsection 6.1. The digital autopilot (DAP) implements these commands. The LM DAP is described in detail in Section 3 of the Luminary GSOP.

The LM DAP is designed to control attitude and translation for three vehicle configurations—LM descent, LM ascent, and CSM-docked. During powered flight the LM DAP controls the spacecraft attitude according to steering commands from the cross-product steering computations. In the LM descent configuration, control of the vehicle is achieved with the 16 jets of the RCS (as illustrated in Figure 6.3-1) and through the deflection of the throttleable, gimbaled DPS engine. Since the LM ascent stage has a fixed, constant-thrust engine installed near the centerline of the ascent stage, attitude control in the ascent stage is provided by the RCS jets.

Every two seconds, the steering computations compute a new desired attitude. An interface routine between the LM DAP and the guidance equations issues the rotation rate commands to bring the measured thrust direction into alignment with the desired thrust direction. The LM DAP has two control modes for gimbaling the descent engine: Attitude Control and Acceleration Nulling Control. The Acceleration Nulling mode is used to trim the thrust direction so as to null the offset angular accelerations. It accomplishes this by keeping the thrust vector of the descent engine locked onto the shifting center of gravity of the LM. An initial alignment of the descent engine reduces the attitude transient caused by thrust offsets at ignition. At the end of the burn, the trim-gimbal drives are turned off, leaving the engine thrust axis approximately aligned through the center of gravity. For subsequent ignitions with the same vehicle configuration, realignment is not necessary. The Attitude Control mode is used to move the thrust vector from the center of gravity to maintain full attitude control whenever the flight situation imposes only mild requirements on the LM DAP. The trim-gimbal drive directions are selected by the LGC to zero the attitude error, rate, and acceleration about a given axis simultaneously. When the trim-gimbal control system operates in the Attitude Control mode, the U and V RCS jets (as shown in Figure 6.3-1) are ordinarily inactive.

During powered flight, the LM mass is decremented every two seconds according to the measured velocity change and the assumed main-engine specific impulses. The mass-dependent control gains are then recomputed as a function of the



KEY

——▷ JETS ASSOCIATED WITH RCS FUEL SYSTEM A (JETS 2, 4, 5, 8, 10, 11, 13, AND 15)

——▶ JETS ASSOCIATED WITH RCS FUEL SYSTEM B (JETS 1, 3, 6, 7, 9, 12, 14, AND 16)

NOTES:

1. THE ARROWS INDICATE THRUST DIRECTION, NOT EXHAUST VELOCITY.
2. SEE FIG. 3.1-S, GSOP FOR THE RELATIONSHIP OF THE RCS JETS AND CONTROL AXES DEPICTED HERE TO THE LM VEHICLE
3. IN CASE OF FAILED JETS, THE ASTRONAUT DISABLES JETS IN PAIRS AS FOLLOWS:

   1,3 5,8 9,12 13,15
   2,4 6,7 10,11 14,16
4. THE P, Q, AND R DESIGNATIONS FOR THE CONTROL AXES ARE USED IN CONNECTION WITH ROTATION, WHEREAS THE X, Y, AND Z DESIGNATIONS ARE USED IN CONNECTION WITH TRANSLATION.

Figure 6.3-1. The 16 Jets of the RCS and Their Thrust Directions decremented mass. Since the mass properties of the vehicle are continually changing, the LM DAP using the automatic mass-update method should maintain reasonable estimates during the varying conditions of powered flight.

Operation of the LM DAP during powered flight is completely automatic, requiring no crew inputs. Before the burn, however, the crew can enter control parameters via the DAP Data Load Routine (R03). Refer to paragraph 9.3.1. During a docked-DPS maneuver, in order to prevent excessive thermal impingement of the U and V RCS jet plumes upon the vehicle, the crew keys VERB 65 ENTR into the DSKY to inhibit RCS control about the U- and V-axes; control is maintained by the trim-gimbal system in the Attitude Control mode.

The performance of the LM DAP may be monitored by calling (via VERB 61) the Mode I displays on the FDAI attitude-error needles. Mode I displays the difference between current CDU angles desired and the actual CDU angles; the comparison is made on each DAP pass, that is, every 0.1 sec. The usual FDAI display is Mode II, the difference between the desired gimbal angles (stored in NOUN 22) and the actual gimbal angles. The Mode II display is selected automatically at the beginning of R60.

BLANK

6.3.1 P40, Descent Propulsion System Maneuver Program—LGC

The powered flight guidance program, P40, coordinates the timing of some Descent Propulsion System (DPS) maneuvers, maintains the LM state vector, controls the thrust direction so as to achieve the desired velocity at the end of the maneuver, and provides the crew with a monitor of the maneuver's progress.* The LM P40 behaves much like the CSM P40. (Refer to paragraph 6.2.1.)

The descent engine is gimbaled for thrust vector control. The PGNCS automatically issues on and off commands and gimbal drive actuator commands to the descent engine. The automatic on and off commands can be overridden manually.

Several limitations exist on the use of the DPS engine. Some of these limitations are listed and discussed here, though the following list is not exhaustive.**

a. The descent engine must not be started more than 20 times.

b. The first descent engine firing must last at least 30 seconds to ensure full pressurization of the ullage space in the propellant tanks.

c. Normal throttle profile for all descent engine starts is at 10 percent throttle setting for 26 seconds—a nominal value that can be changed (by the crew, if necessary)—to permit corrective gimbaling without introducing large attitude transients or possible loss of control because the thrust vector at engine start may not be directed through the LM center of gravity.

d. The landing gear must be deployed before descent engine firing. If the landing gear is not deployed, it will be in the path of the descent engine plume and will be damaged.

A targeting program, P3x, will establish the parameters needed for thrust control guidance. After the appropriate P3x has been performed, the astronaut must not select another P3x or P7x before the burn. These programs use some of the same variable computer storage locations and would destroy the thrusting parameters established by the original P3x for this burn.

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* The DPS Maneuver Program is not used during powered descent or during P70, the DPS Abort Program.

** A more complete list can be found in the APOLLO Operations Handbook, Lunar Module, Volume I, Document No. LMA790-3-LM5.

P40 uses the AVERAGEG routine for state vector updating and cross-product steering for guiding the thrust direction. AVERAGEG and cross-product steering are discussed in subsection 6.1.

6.3.1.1 P40 Procedures

Tables 6.3.1-I and -II show P40 displays and extended verbs, respectively. Figure 6.3.1-1 is the program flowchart. Before entering P40, the following must be performed:

a. LGC turned on
b. R03, Autopilot Data Load Routine
c. P3x, a prethrust program
d. ISS on for at least 15 minutes
e. IMU at a known orientation.

Crew procedures specify how long before DPS ignition the crew must select P40, via the DSKY, to allow sufficient time for performing the necessary routines before ignition. P40 first checks for the presence of the DPS. If the DPS has been staged, the DSKY will flash VERB 05 NOUN 09 and display alarm code 01706. The crew can respond by keying in VERB 34 ENTR to terminate P40.

The program next enters the IMU Status Check Routine (R02), as in the CSM P40. Upon completion of R02, the program computes the initial thrust direction of $\underline{v}_G$, and the preferred IMU orientation, and then enters the Attitude Maneuver Routine (R60). This routine is similar to the CSM R60 (refer to paragraph 6.2.1.3) except that the PGNS MODE CONTROL switch (on the STAB/CONT panel) is in the AUTO position for an automatic maneuver and that the NOUN 18 display shows FDAI angles rather than gimbal angles. There is a possibility of a 01301 alarm during the maneuver if the arc-sine or arc-cosine argument is too large. Alarm 00401 indicates that the final gimbal angles would be in gimbal lock.

Upon completion (or termination) of R60, the program checks whether the GUID CONT switch has been set to PGNS, the PGNS MODE CONTROL switch to AUTO and the THR CONT switch to AUTO. If these settings (i.e., modes) have not been selected, the DSKY flashes VERB 50 NOUN 25 with R1 containing 00203. If the crew prefer not to select these modes during the thrusting maneuver, they can key ENTR. Otherwise, the crew can place the GUID CONT switch in the PGNS position, the PGNS MODE CONTROL switch to AUTO, the THR CONT switch to AUTO, and key PRO.

TABLE 6.3.1-I

DISPLAYS ASSOCIATED WITH P40 (SHEET 1 OF 2)

DSKY	Initiated by	Purpose	Condition		Registers
			Alarm Code	Condition	
V05 N09E	Astronaut	Verify PROG alarm	00210	IMU not on	R1 xxxxx * R2 xxxxx R3 xxxxx
			00220	IMU orientation unknown	
			00401	Desired gimbal angles yield gimbal lock	
			01301	Arc sine or arc cosine argument too large	
			01407	v_G increasing	
			01703	t_{IG} slipped	
FL V05 N09	P40	Display alarm	01706	DPS staged	R1 xxxxx * R2 xxxxx R3 xxxxx
FL V50 N18	R60	Display FDAI angles; request maneuver	FDAIX - roll FDAIY - pitch FDAIZ - yaw		R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
V06 N18	R60	Display FDAI angles	FDAIX - roll FDAIY - pitch FDAIZ - yaw		R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
FL V50 N25	P40	Please select PGNS auto mode	00203		R1 00203
V06 N40	P40	Display	Time from t_{IG} v_G magnitude Sum of acquired velocity		R1 xxBxx min, sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V99 N40	P40	Request DPS engine-on enable	---		---

* The alarm codes are displayed as follows:
R1 = First alarm following error reset
R2 = Second alarm following error reset
R3 = Most recent alarm

TABLE 6. 3. 1-I

DISPLAYS ASSOCIATED WITH P40 (SHEET 2 OF 2)

DSKY	Initiated by	Purpose	Condition	Registers
FL V97 N40	R40	Low thrust detected	---	---
FL V16 N40	P40	Display final values	Time from cutoff at last cycle Remaining v_G magnitude Sum of acquired velocity	R1 xxBxx min, sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec
FL V16 N85	P40	Display remaining $\underline{v}_G$	Components of $\underline{v}_G$ in LM body axes	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec
V06 N86	Astronaut	On call display of $\underline{v}_G$	$\underline{v}_G$ components in local vertical coordinates	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec

TABLE 6.3.1-II

EXTENDED VERBS FOR USE WITH P40

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters (apogee, perigee, time of free fall)	FL V16 N44 R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min, sec
83 ENTR	Do R31	Display rendezvous parameters (range; range rate; theta, the angle between local horizontal and the LM +Z-axis)	FL V16 N54 R1 xxx. xx n. mi. R2 xxxx. x ft/sec R3 xxx. xx deg

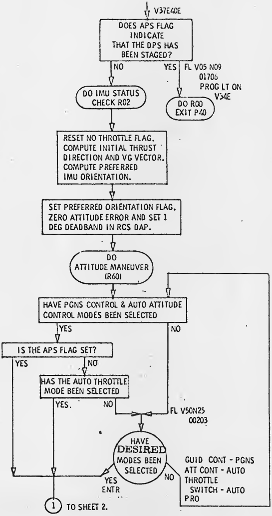

Figure 6.3.1-1. DPS Maneuver Program (P40)(Sheet 1 of 4)

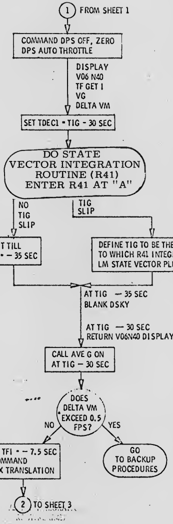

Figure 6.3.1-1. DPS Maneuver Program (P40)(Sheet 2 of 4)

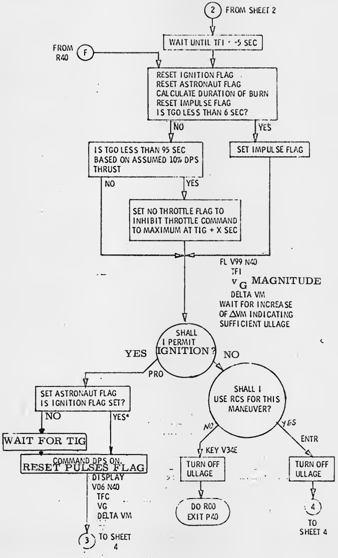

Figure 6.3.1-1. DPS Maneuver Program (P40)(Sheet 3 of 4)

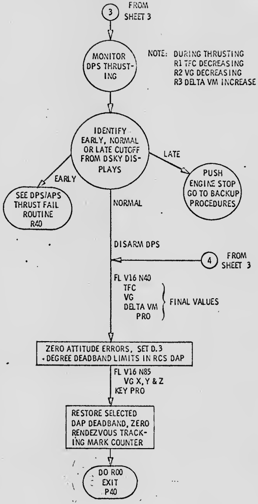

Figure 6.3.1-1. DPS Maneuver Program (P40)(Sheet 4 of 4)

Next, the program commands the DPS off, zeros the DPS auto throttle and displays VERB 06 NOUN 40, with the registers containing the following:

R1 = time from DPS ignition
R2 = magnitude of velocity-to-be-gained (v_G)
R3 = magnitude of $\Delta \underline{v}$

The program next enters the State Vector Integration Routine (R41), which integrates the LM state vector ahead to t_{IG} -30 seconds. Although this routine differs slightly from its CSM counterpart, the crew would be unaware of any differences. Other than the illumination of the COMP ACTY light, the only visible sign that R41 is running is a possible alarm code 01703 indicating that t_{IG} has been slipped to allow sufficient time to complete integration. Should this alarm occur, the new value of t_{IG} will be used for the time-to-ignition displayed in R1 of VERB 06 NOUN 40 after integration has been completed. Next, the crew will verify or set the thrust translation controller (TTCA) to the MIN THRUST position. The crew will arm the DPS and check the thrust indicator to be certain the auto throttle command is zeroed.

At t_{IG} -35 seconds the DSKY will be blank for 5 seconds. At t_{IG} -29 (R1 = -00B29), the VERB 06 NOUN 40 display will return, indicating the start of the AVERAGEG $\underline{v}_G$ update. For the next 15 seconds, the crew should watch R3 to see that it does not exceed 0.5 ft/sec, which would indicate excessive PIPA bias errors. If excessive PIPA errors are so indicated, the crew should go to backup procedures.

Ullage (that is, +X translation to force fuel to the back end of the tanks) begins at t_{IG} -7.5 seconds. At t_{IG} -5 seconds, the program flashes VERB 99 NOUN 40 to request "please perform engine-on enable." After sufficient ullage, as indicated by an increase in Δv (R3), the crew permits DPS ignition by keying PRO. Should the crew choose not to permit ignition, they may avoid the burn altogether by keying VERB 34 ENTR or complete the maneuver with the RCS jets by keying ENTR.

If the crew have chosen to permit ignition, the VERB 06 NOUN 40 display returns until t_{IG}. After ignition, R1 will contain the time from cutoff (TFC), which is initially calculated and displayed based on 10 percent DPS thrust. This display will count down with elapsed time until TVC steering is initiated, after which TFC is recalculated, based on actual thrust every 2 seconds by the guidance equations. The TFC display is updated every 1 second. If the burn is to be impulsive (i.e., less than 6 sec), it will be done with fixed engine gimbal angles. If TFC at ignition is less than 95 seconds, maximum throttle will not be commanded. The crew can identify early, normal, or late engine cutoff from assessment of DSKY displays. If engine cutoff is late, the crew can depress the engine STOP pushbutton and go to backup procedures. An early cutoff would be detected by the program, which would then transfer control to R40, the Thrust Fail Routine. After normal cutoff, the crew disarm the DPS.

The DSKY flashes VERB 16 NOUN 40 to request proceed. The crew can record the register values of VERB 16 NOUN 40 as desired and key PRO. The DSKY flashes VERB 16 NOUN 85 to request response and displays the components of the residual velocity-to-be-gained, resolved along the LM body axes. The $\underline{v}_G$ vector will be updated by the cross product steering during each 2-second computation cycle. If they choose, the crew can use the TTCA to null the $\underline{v}_G$ components. After the maneuver is completed, the Orbital Parameters Display Routine (R30) can be selected (VERB 82 ENTR) to check for reasonable pericenter. To exit P40, the crew key PRO in response to the flashing VERB 16 NOUN 85.

AVERAGEG will continue running until a new major mode is selected. Therefore, immediate new mode selection is imperative to avoid accumulation of PIPA bias errors.

6.3.1.2 Routines Associated with P40

6.3.1.2.1 DPS/APS Thrust Fail Routine.—The DPS/APS Thrust Fail Routine (R40) is automatically called during P40 and P42. Figure 3.3.1-1 gives a brief logical flow of R40. When low thrust (thrust below the minimum threshold value of each 2-second cycle) is detected, flashing VERB 97 NOUN 40 notifies the crew of the thrust fail. (No steering is present at this point.) The crew can verify LGC interpretation of thrust failure by keying PRO. To terminate the maneuver, the crew key VERB 34 ENTR. To attempt to complete the burn, the crew key ENTR which will return control to P40 or P42.

The threshold value for the $\Delta \underline{v}$ comparison has the following values:

a. DPS with docked CSM = 12 cm/sec
b. DPS with LM alone = 36 cm/sec
c. APS with LM alone = 308 cm/sec

A more detailed explanation of R40 is given in paragraph 3.3.2.2.3.

6.3.1.2.2 State Vector Integration Routine.—Figure 6.3.1-2 is a flowchart of the State Vector Integration Routine (R41). R41 is automatically selected by P40, P41, P42, P47, P12, and P63. The purpose of this routine is to integrate the state vector

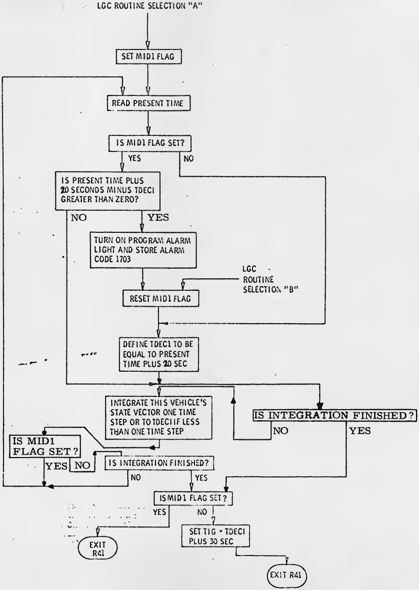

Figure 6.3.1-2. State Vector Integration Routine (R41)

ahead to the time that the AVERAGEG routine will be turned on by the thrusting program. R41 allows 20 seconds in the LM for completion of integration as opposed to 12.5 seconds in the CSM. If the state vector integration cannot be completed before the specified time, a program alarm occurs (alarm code 01703) and the t_{IG} is slipped. P47 enters R41 at B and omits any specification of the time.

6.3.1.3 Alarms

A list of alarm codes that may occur in P40 follows, with a detailed description for remedying the alarms:

a. Alarm code 00210 occurs if the IMU is not operating.
b. Alarm code 00220 occurs if the IMU orientation is unknown.
c. Alarm code 00401 occurs if the desired gimbal angles would yield gimbal lock.
d. Alarm code 01301 occurs if an arc-sine or arc-cosine argument is too large.
e. Alarm code 01407 occurs if the velocity-to-be-gained is increasing.
f. Alarm code 01703 occurs if the t_{IG} is slipped.
g. Alarm code 01706 occurs if P40 is selected, but the DPS has been staged.

Alarm codes 00210 and 00220 may occur immediately after P40 calls the IMU Status Check Routine; they appear as PROG alarms on the DSKY. The crew must key VERB 05 NOUN 09 ENTR to identify the abnormality, depress KEY REL and RSET when the alarm is identified, and respond to flashing VERB 37.

Alarm code 00401 may occur during R60 if the computed desired gimbal angles would produce gimbal lock (i.e., MGA ≥ 70 deg). The crew can maneuver if the maximum middle gimbal angle is less than 85 degrees, or the crew can realign the IMU.

Alarm code 01301 may also occur during R60. It is intended for testing and debugging and is not likely to occur in flight.

Alarm code 01407 may occur during thrusting. The crew should terminate thrusting and check orbital parameters.

Alarm code 01703 may occur during R41. After the COMP ACTY light goes out, the crew will note a discontinuity in the contents of DSKY R1 (i.e., time from t_{IG}).

The value on the Digital Event Timer will no longer be valid. No crew action is necessary unless called for by mission procedures.

Alarm code 01706 is a main alarm, signaled by a flashing VERB 05 NOUN 09. This alarm indicates that the wrong thrusting program has been chosen for the vehicle configuration; i.e., the DPS has been staged for P40 or has not been staged for P42. The crew should key VERB 34 ENTR to terminate P40.

6.3.1.4 Restarts

Should a restart occur, the RESTART light on the DSKY would be illuminated. A restart will terminate automatic attitude maneuvers (R60). The crew can recover by keying PRO in response to the flashing VERB 50 NOUN 18 that returns to the DSKY after the restart.

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6.3.2 P41, Reaction Control System Maneuver Program —LGC

P41, one of the powered flight guidance programs, can be used to coordinate the timing of short, manually controlled Reaction Control System (RCS) burns whenever a change-of-orbit maneuver is required. During these burns, P41 maintains the LM state vector and provides the crew with a monitor of the maneuver's progress. A prethrust program, P3x, establishes the parameters needed for thrust control.

P41 uses the AVERAGEG routine for state-vector updating and the $\underline{v}_G$ updating cycles to compute DSKY displays. (Refer to subsection 6.1.)

6.3.2.1 P41 Procedures

Tables 6.3.2-I and -II show P41 displays and extended verbs, respectively. Figure 6.3.2-1 is a flowchart of P41.

Before entering P41, the following must be performed:

a. LGC turned on
b. R03, Autopilot Data Load routine
c. P3x, a prethrust program
d. ISS on for at least 15 minutes
e. IMU at a known orientation.

When the crew select P41, the program performs the IMU Status Check Routine (R02) and illuminates the PROG light if the IMU is not operating (alarm code 00210) or if the IMU orientation is not known (alarm code 00220). At the completion of R02, the program computes the initial thrust direction of v_G and the preferred IMU orientation and then enters the Attitude Maneuver Routine (R60). R60 is similar to the CSM R60 except that the PGNS MODE CONTROL switch (on the STAB/CONT panel) is in the AUTO position for an automatic maneuver, and the NOUN 18 display shows FDAI angles rather than gimbal angles. There is a possibility of a 00401 alarm, indicating that the final gimbal angles would produce gimbal lock. A 01301 alarm would indicate an arc-sine or arc-cosine argument that is too large.

Upon completion (or termination) of R60, the DSKY displays (and updates every 1 second) VERB 16 NOUN 85; the three registers contain the three components of $\underline{v}_G$ in LM body axes.

TABLE 6.3.2-I

DISPLAYS ASSOCIATED WITH P41

DSKY	Initiated by	Purpose	Description	Registers
V05 N09 E	Astronaut	Verify PROG alarm	Alarm Code — Condition 00210 — IMU not on 00220 — IMU orientation unknown 00401 — Desired gimbal angles yield gimbal lock 01301 — Arc-sine or arc-cosine argument too large 01703 — t_{IG} slipped	R1 xxxxx * R2 xxxxx R3 xxxxx
FL V50 N18	R60	Display FDAI angles	FDAIX - roll FDAIY - pitch FDAIZ - yaw	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
V06 N18	R60	Display FDAI angles	FDAIX - roll FDAIY - pitch FDAIZ - yaw	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
V16 N85	P41	Display $\underline{v}_G$	Components of $\underline{v}_G$ in LM body axes	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V16 N85	P41	Signals t_{IG}	---	---
V06 N86	Astronaut	On call display of $\underline{v}_G$	$\underline{v}_G$ components in local vertical coordinates	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec

* The alarm codes are displayed as follows:

R1 = First alarm following error reset
R2 = Second alarm following error reset
R3 = Most recent alarm

TABLE 6.3.2-II
EXTENDED VERBS FOR USE WITH P41

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters (apogee, perigee, time of free fall)	FL V16 N44 R1 = xxxx. x n. mi. R2 = xxxx. x n. mi. R3 = xxBxx min, sec
83 ENTR	Do R31	Display rendezvous parameters (range; range rate; theta, the angle between local horizontal and the LM+Z-axis)	FL V16 N54 R1 = xxx. xx n. mi. R2 = xxxx. x ft/sec R3 = xxx. xx deg

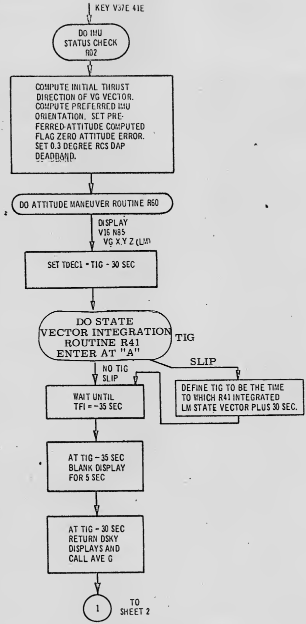

Figure 6.3.2-1. Reaction Control System Maneuver Program (P41) (Sheet 1 of 2)

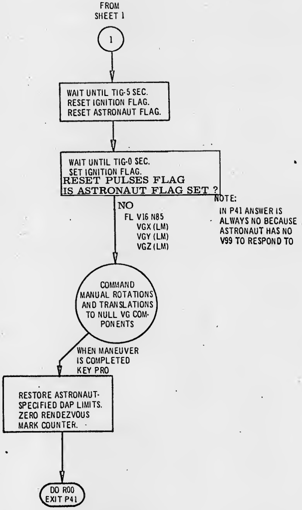

Figure 6.3.2-1. Reaction Control System Maneuver Program (P41) (Sheet 2 of 2)

The program next enters the State Vector Integration Routine, which integrates the LM state vector ahead to t_{IG} -30 seconds. (Refer to paragraph 6.3.1.2.2.) Other than the COMP ACTY light, the only visible sign that the routine is being performed would be the possible occurrence of alarm 01703 indicating t_{IG} has been slipped to allow sufficient time to complete integration. The new t_{IG} will be used for the time-of-ignition displayed in R1 of VERB 06 NOUN 40 after integration has been completed.

At t_{IG} -35 seconds, the DSKY will be blanked for 5 seconds, after which time the DSKY displays return, indicating the start of AVERAGEG and the $\underline{v}_G$ updating cycles.

At t_{IG}, the DSKY will flash VERB 16 NOUN 85 to request response. The crew should null the residual $\underline{v}_G$ by using the manual controls. Upon completion of thrusting, the crew key PRO to end major mode P41.

The crew can select the Orbital Parameters Display (VERB 82 ENTR) to check for reasonable pericenter. The crew key PRO to return to the flashing VERB 37 display.

AVERAGEG will continue running until a new major mode is selected. Therefore, immediate new-mode selection is imperative to avoid accumulation of PIPA bias errors.

6.3.2.2 Alarms

The alarm codes that may occur in P41 are listed below; a detailed explanation of each is given in paragraph 6.3.1.3:

a. Alarm code 00210 occurs if the IMU is not on.
b. Alarm code 00220 occurs if the IMU orientation is unknown.
c. Alarm code 00401 occurs if the desired gimbal angles would yield gimbal lock.
d. Alarm code 01301 occurs if an arc-sine or arc-cosine argument is too large.
e. Alarm code 01703 occurs if the time-of-ignition is slipped.

6.3.2.3 Restarts

Should a restart occur during P41, the RESTART light on the DSKY would be illuminated. A restart will terminate automatic attitude maneuvers (R60). The crew can recover by keying PRO in response to the flashing VERB 50 NOUN 18 that returns to the DSKY after the restart.

6.3.3 P42, Ascent Propulsion System Maneuver Program—LGC

The powered flight guidance program, P42, coordinates the timing of some Ascent Propulsion System (APS) maneuvers, maintains the LM state vector, guides and controls the thrust direction—so as to achieve the desired velocity at the end of the maneuver, and provides the crew with a monitor of the maneuver's progress. The LM P42 behaves much as the LM P40. (Refer to paragraph 6.3.1.)

The ascent engine is neither throttleable nor gimbaled. The PGNCS automatically issues on and off commands to the ascent engine. These commands can be overridden by the crew.

There are several limitations to the use of the ascent engine of which the following is a partial list.*

a. The ascent engine must not be started more than 35 times.
b. The APS must not remain pressurized longer than 24 hours. If this limit is exceeded, the pressure regulator assemblies may not operate.
c. The ascent engine combustion chamber must not be subjected to more than 460 seconds of engine operation. Exceeding this limit will cause the engine to operate with a severely charred combustion chamber, resulting in burn-through.

A targeting program, P3x, will establish the parameters needed for thrust control guidance. After the appropriate P3x has been performed, the astronaut must not select another P3x or a P7x before the burn. These programs use some of the same variable computer storage locations and would destroy the thrusting parameters established by the original P3x for this burn.

P42 uses the AVERAGEG routine for state vector updating and cross-product steering for guiding the thrust direction. AVERAGEG and cross-product steering are discussed in subsection 6.1.

6.3.3.1 P42 Procedures

Tables 6.3.3-I and -II show P42 displays and extended verbs, respectively. Figure

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* A more complete list can be found in the APOLLO Operations Handbook, Lunar Module, Volume I, Document No. LMA790-3-LM5.

TABLE 6.3.3-I

DISPLAYS ASSOCIATED WITH P42 (SHEET 1 OF 2)

DSKY	Initiated by	Purpose	Condition		Registers
			Alarm Code	Condition	
V05 N09E	Astronaut	Verify PROG alarm	00210 00220 00401 01301 01407 01703	IMU not on IMU orientation unknown Desired gimbal angles yield gimbal lock Arc sine or arc cosine argument too large $\underline{v}_G$ increasing t_{IG} slipped	R1 xxxxx* R2 xxxxx R3 xxxxx
FL V05 N09	P42	Display alarm	01706	DPS not staged	R1 xxxxx* R2 xxxxx R3 xxxxx
FL V50 N18	R60	Display FDAI angles to request maneuver	FDAIX - FDAIY - FDAIZ -	roll pitch yaw	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
V06 N18	R60	Display FDAI angles	FDAIX - FDAIY - FDAIZ -	roll pitch yaw	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
FL V50 N25	P42	Please select PGNS AUTO mode	00203		R1 00203
V06 N40	P42	Display	Time from t_{IG} v_G magnitude Sum of acquired velocity		R1 xxBxx min, sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec

* The alarm codes are displayed as follows:

R1 = First alarm following error reset
R2 = Second alarm following error reset
R3 = Most recent alarm

TABLE 6.3.3-I
DISPLAYS ASSOCIATED WITH P42 (SHEET 2 OF 2)

DSKY	Initiated by	Purpose	Condition	Registers
FL V99 N40	P42	Request APS engine-on enable	---	---
FL V97 N40	R40	Low thrust detected	---	---
FL V16 N40	P42	Display final values	Time from cutoff at last cycle Remaining v_G magnitude Sum of acquired velocity	R1 xxBxx min, sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec
FL V16 N85	P42	Display remaining $\underline{v}_G$	Components of $\underline{v}_G$ in LM body axes	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec
V06 N86	Astronaut	On call display of $\underline{v}_G$	$\underline{v}_G$ components in local vertical	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec

TABLE 6.3.3-II
EXTENDED VERBS FOR USE WITH P42

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters (apogee, perigee, time of free fall)	FL V16 N44 R1 = xxxx. x n. mi. R2 = xxxx. x n. mi. R3 = xxBxx min, sec
83 ENTR	Do R31	Display rendezvous parameters (range, range rate; and theta, the angle between local horizontal and LM + Z-axis)	FL V16 N54 R1 = xxx. xx n. mi. R2 = xxxx. x ft/sec R3 = xxx. xx deg

6.3.3-1 is the program flowchart. Before entering P42, the following must be performed:

a. LGC turned on
b. R03, Autopilot Data Load Routine
c. P3x, a prethrust program
d. ISS on for at least 15 minutes
e. IMU at a known orientation.

Crew procedures specify how long before APS ignition the crew must select P42 to allow sufficient time for performing the necessary routines. The program first checks for the presence of the DPS. If the DPS has not been staged, the DSKY will flash VERB 05 NOUN 09 and display alarm code 01706. The crew have two choices: they can terminate P42 by keying VERB 34 ENTR, or they can key PRO and stage the DPS in the time interval between t_{IG} -30 seconds and t_{IG}. The DPS is staged by depressing either the STAGE or the ABORT STAGE pushbuttons.

The program next enters the IMU Status Check Routine (R02) as in the CSM P40. Upon completion of R02, the program computes the initial thrust direction of $\underline{v}_G$ and the preferred IMU orientation and then enters the Attitude Maneuver Routine (R60). This routine is similar to the CSM R60 except that the PGNS MODE CONTROL switch (on the STAB/CONT panel) is in the AUTO position for an automatic maneuver and that the NOUN 18 display shows FDAI angles rather than gimbal angles. There is a possibility of a 00401 alarm, indicating that the final or initial gimbal angles would yield gimbal lock. A 01301 alarm would indicate an arc-sine or arc-cosine argument is too large.

Upon completion (or termination) of R60, the program checks whether PGNS CONT and AUTO ATT CONT modes have been selected (and whether THR CONT is in AUTO if the DPS has not been staged). If they have not been selected, the DSKY flashes VERB 50 NOUN 25 with R1 containing 00203. If the crew prefer not to select these modes during the thrusting maneuver, they can key ENTR. Otherwise they would place the GUID CONT switch in the PGNS position and the PGNS MODE CONTROL switch in the AUTO position (the THR CONT in AUTO if the DPS has not been staged) and key PRO.

Next the program commands the APS off and displays VERB 06 NOUN 40, with the registers containing the following:

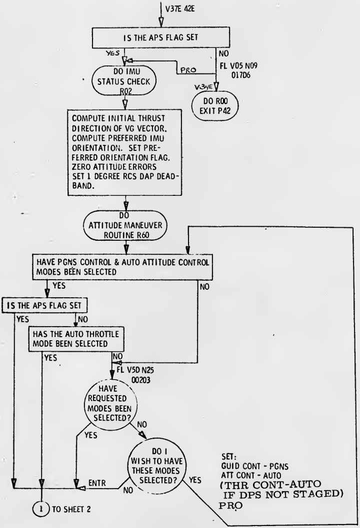

Figure 6.3.3-1. APS Maneuver Program (P42) (Sheet 1 of 3)

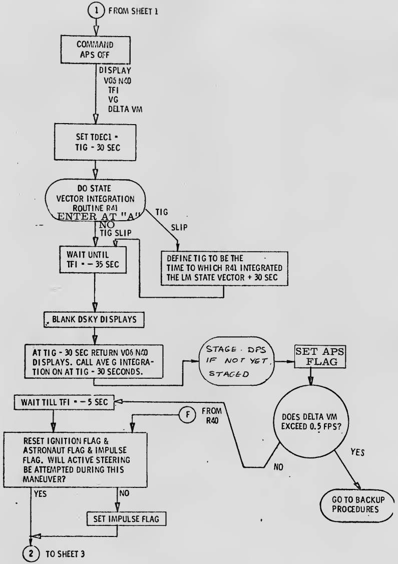

Figure 6.3.3-1. APS Maneuver Program (P42) (Sheet 2 of 3)

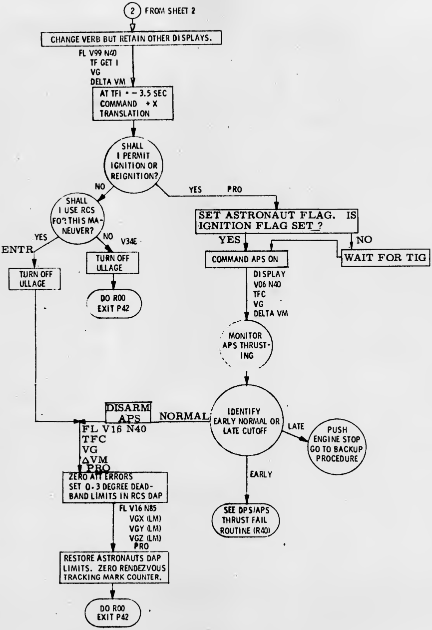

Figure 6.3.3-1. APS Maneuver Program (P42) (Sheet 3 of 3)

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R1 = time from t_{IG}
R2 = magnitude of velocity-to-be-gained
R3 = magnitude of $\Delta \underline{v}$

The program next enters the State Vector Integration Routine (refer to paragraph 6.3.1.2.2), which integrates the LM state vector ahead to t_{IG} -30 seconds. Although this routine differs slightly from its CSM counterpart, the crew would be unaware of any differences. Other than the COMP ACTY light, the only visible sign that R41 is running is the possible occurrence of an alarm (alarm code 01703), indicating t_{IG} has been slipped to allow sufficient time to complete integration. The new t_{IG} will be used for the time-to-ignition displayed in R1 of VERB 06 NOUN 40 after integration has been completed.

At t_{IG} -35 seconds, the DSKY will be blank for 5 seconds. At t_{IG} -29 (R1 = -00B29), the VERB 06 NOUN 40 display will return, indicating the start of AVERAGEG and cross-product steering cycles. For the next 15 seconds, the crew should watch R3 to see that it does not exceed 0.5 ft/sec, which would indicate excessive PIPA bias errors. If excessive PIPA bias errors are so detected, the crew should go to backup procedures.

If the DPS has not been staged, the crew must stage it between t_{IG} -30 seconds and t_{IG}.

At t_{IG} -5, the program flashes VERB 99 NOUN 40 to request "please perform engine-on enable." At t_{IG} -3.5 seconds, ullage begins. After sufficient ullage, as indicated by an increase in R3, the crew permit APS ignition by keying PRO. Should the crew choose not to permit ignition, they may avoid the burn altogether by keying VERB 34 ENTR or complete the maneuver with the RCS jets by keying ENTR.

If the astronaut has chosen to permit ignition, the VERB 06 NOUN 40 display returns until t_{IG}. After ignition, R1 will contain time from cutoff (TFC), which is initially calculated and displayed. This display will count down with elapsed time until TVC steering is initiated, when TFC is recalculated every 2 seconds by the guidance equations. The display of TFC is updated every 1 second. If the burn is to be impulsive (i.e., TFC $<$ 6 sec), it will be done with no steering.

The crew can identify early, normal, or late engine cutoff from assessment of DSKY displays. If engine cutoff is late, the crew can depress the engine STOP pushbutton and go to backup procedures. An early cutoff would be detected by the program, which would then transfer control to R40, the Thrust Fail Routine (paragraph 6.3.1.2.1). After normal cutoff, the crew disarm the APS.

The DSKY flashes VERB 16 NOUN 40 to request proceed. The crew can record the register values as desired and key PRO.

The DSKY flashes VERB 16 NOUN 85, to request response, and displays the components of the current velocity-to-be-gained resolved along the LM axes. The $\underline{v}_G$ vector will be updated by the cross-product steering computations every 2-second cycle. The crew can null the $\underline{v}_G$ components using manual controls if they choose. At this point, the Orbital Parameters Display Routine (R30) can be selected (VERB 82 ENTR) to check for reasonable pericenter. To exit P42, the crew key PRO in response to the flashing VERB 16 NOUN 85.

AVERAGEG will continue running until a new major mode is selected. Therefore, immediate new-mode selection is imperative to avoid accumulation of PIPA bias errors.

6.3.3.2 Alarms

A list of alarm codes that may occur in P42 follows; a detailed description is given in paragraph 6.3.1.3:

a. Alarm code 00210 occurs if the IMU is not operating.
b. Alarm code 00220 occurs if the IMU orientation is unknown.
c. Alarm code 00401 occurs if the desired gimbal angles would yield gimbal lock.
d. Alarm code 01301 occurs if an arc-sine or arc-cosine argument is too large.
e. Alarm code 01407 occurs if the velocity-to-be-gained is increasing.
f. Alarm code 01703 occurs if t_{IG} is slipped.
g. Alarm code 01706 occurs if P42 is selected but the DPS has not been staged. The crew may choose to continue P42, staging the DPS between t_{IG} - 30 seconds and t_{IG}, by responding to the flashing display with PRO.

6.3.3.3 Restarts

Should a restart occur, the RESTART light on the DSKY would be illuminated. A restart will terminate automatic attitude maneuvers (R60). The crew can recover by keying PRO in response to the flashing VERB 50 NOUN 18 that returns to the DSKY after the restart.

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6.3.4 P47, Thrust Monitor Program—LGC

P47, the powered flight monitor program, maintains the LM state vector during a thrusting maneuver not controlled by the GNCS and provides a monitor of the maneuver's progress for the crew. The program uses the AVERAGEG routine for state vector updating. (For an explanation of AVERAGEG use, refer to subsection 6.1.) There is no important difference between the thrust monitor programs for the CSM and the LM.

6.3.4.1 P47 Procedures

Tables 6.3.4-I and -II present the displays and extended verbs associated with P47. Figure 6.3.4-1 is the program flowchart. Before entering P47, the LGC and the ISS must be on—the latter for at least 15 minutes.

Upon selection of P47, shortly before t_{IG}, the program performs the IMU Status Check Routine (R02) and illuminates the PROG light if the ISS is off (i.e., alarm code 00210) or the IMU orientation is unknown (alarm code 00220).

At the completion of R02, the program enters the State Vector Integration Routine (R41), which integrates the LM state vector ahead to 20 seconds from the start of last time step. The AVERAGEG cycle begins at that time. (Refer to paragraph 6. 3. 1. 2. 2 for a description of R41.)

The DSKY displays a flashing VERB 16 NOUN 83 with the three components of acquired $\Delta \underline{v}$ in control coordinates. The registers contain zeros initially; the contents are updated every 2 seconds.

While the thrusting maneuver is performed, the crew must monitor the FDAI ball to avoid gimbal lock. At the end of the maneuver, the crew can recycle the display (zeroing the registers), by keying in VERB 32 ENTR.

To terminate major mode P47, the crew key PRO. The DSKY then flashes VERB 37, requesting the selection of a new major mode. It is important to respond to this immediately to terminate AVERAGEG and thus to avoid accumulation of PIPA bias errors.

TABLE 6.3.4-I

DISPLAYS ASSOCIATED WITH P47

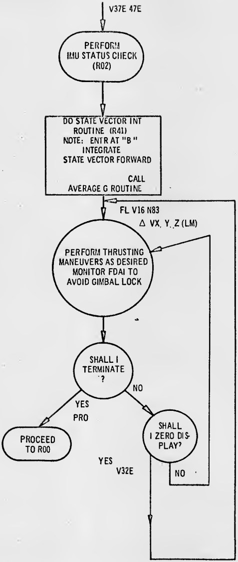
DSKY	Initiated by	Purpose	Condition	Register
V05 N09E	Astronaut	Verify PROG alarm	00210 ISS not on 00220 IMU orientation unknown	R1 xxxxx * R2 xxxxx R3 xxxxx
FL V16 N83	P47	Display $\Delta \underline{v}$ acquired	Three components in control coordinates	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec

* The alarm codes are displayed as follows:
R1 = First alarm following error reset
R2 = Second alarm following error reset
R3 = Most recent alarm

TABLE 6.3.4-II

EXTENDED VERBS FOR USE WITH P47

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters (apogee; perigee; and time of free fall)	FL V16 N44 R1 = xxxx. x n. mi. R2 = xxxx. x n. mi. R3 = xxBxx min, sec
83 ENTR	Do R31	Display rendezvous parameters (range, range rate and theta, the angle between local horizontal and the LM+Z-axis)	FL V16 N54 R1 = xxx. xx n. mi. R2 = xxxx. x ft/sec R3 = xxx. xx deg



NOTE: R1, R2, AND R3 READ 00000 INITIALLY. THEY ARE UPDATED EVERY 2 SECONDS.

Figure 6.3.4-1. Thrust Monitor Program (P47)

6.3.4.2 Alarms

The PROG alarm codes associated with P47 are listed below. A detailed description of each is given in paragraph 6.3.1.3.

a. Alarm code 00210 occurs if the ISS is not on.
b. Alarm code 00220 occurs if the IMU orientation is not known.

6.3.4.3 Restarts

Should a restart occur, the RESTART light on the DSKY would be illuminated; no other effects would be noticed by the crew.

SECTION 7.0

ALIGNMENT

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SUBSECTION 7.1

INTRODUCTION
(TBF)

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SUBSECTION 7.2

CMC ALIGNMENT PROGRAMS

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7.2.1 P51, IMU Orientation Determination Program—CMC

The IMU Orientation Determination Program (P51) is used during free fall to determine the present stable member orientation with respect to the Basic Reference Coordinate System and the associated REFSMMAT. This is accomplished by sighting on two navigation stars, or known celestial bodies, with the scanning telescope (SCT) or the sextant (SXT). [Only the star line of sight (SLOS) is used when the crew performs celestial body sightings and marking using the SXT.] Determining the stable member orientation with respect to the Basic Reference Coordinate system requires the transformation matrix REFSMMAT.

$$\text{REFSMMAT} = \begin{bmatrix} \underline{u}_{XSM}^{T} \\ \underline{u}_{YSM}^{T} \\ \underline{u}_{ZSM}^{T} \end{bmatrix}$$

where $\underline{u}_{XSM}$, $\underline{u}_{YSM}$, and $\underline{u}_{ZSM}$ define the orientations of the stable member axes with respect to the Basic Reference Coordinate System.

The crew acquire the desired celestial bodies by maneuvering the spacecraft and the optics until the bodies are visible in the optical devices. Upon acquiring the celestial bodies, the crew perform the sighting by centering the SCT or SXT SLOS on the celestial body, and then depressing the MARK pushbutton. Taking the mark causes the measurement time, the optics CDU angles, and the inertial CDU angles to be recorded in the command module computer (CMC). The LOS vector in IMU stable member coordinates is also computed.

When the sighting, marking, and computations have been accomplished on two celestial bodies, the CMC computes the angle between the two vectors. This angle is then compared with the angle between the unit LOS vectors, in basic reference coordinates, stored in the CMC; the difference is displayed to the crew in order that they can either accept the information, or reject it and repeat the orientation determination.

The displays during the IMU orientation determination are listed on Table 7.2.1-I.

7.2.1.1 Related Routines

P51 has the following two related routines:

a. The Sighting Mark Routine (R53)
b. The Sighting Data Display Routine (R54)

TABLE 7. 2. 1-I

PROGRAM DISPLAY (P51)

DSKY	Initiated by	Purpose	Condition	Register(s)
FL V06 N88	R53	Display Planet Position Vector	XPL YPL ZPL	R1 .xxxxx R2 .xxxxx R3 .xxxxx
FL V01 N71	R53	Display Celestial Body Code	00 (any planet) 01/45 star (from celestial body code list) 46 sun 47 earth 50 moon	R1 oooxx octal R2 Blank R3 Blank
FL V50 N25	P51 and R53	Request Please Perform 1 Celestial body Acquisition 2 Terminate Mark Sequences	00015 00016	R1 oooxx R2 Blank R3 Blank
FL V51 N blank	R53	Request Please Mark	—	R1 Blank R2 Blank R3 Blank
V41 N22	P51	Display Coarse align Verb/ICDU angles	All zeros for coarse align	R1 00000 R2 00000 R3 00000
FL V06 N05	R54	Display Sighting Angle Difference	Difference between actual and measured star angles	R1 xxx. xx R2 Blank R3 Blank

The Sighting Mark Routine (R53) is called automatically by P51 and is used to request and process marks (using the SCT and SXT) on the celestial bodies determined by the crew. The routine causes five angles (three inertial and two optical) and the mark time to be stored. The routine also determines LOS vectors to the celestial body if the celestial body is the sun, earth, or moon (code 46, 47, or 50 respectively). R53 also obtains stored information from the star ephemeris and allows the crew to load planet position vectors by putting up a flashing VERB 06 NOUN 88 display.

The Sighting Data Display Routine (R54) compares and displays the difference angle between the actual (stored data) and measured (derived from mark angles) lines of sight.

7.2.1.2 Options

To complete P51, the crew have the option of using either the SCT or the SXT in determining the orientation. The procedure is the same for both, although using the SXT, which has a narrower field of view (1.8 degrees as compared to 60 degrees for the SCT), makes it more difficult to acquire celestial bodies. The normal procedure would be to acquire the star, planet, or other celestial body using the SCT; then to use the SXT SLOS for marking, because it provides greater accuracy (within 10 sec) and a narrower field of view.

7.2.1.3 Logical Flow Description

P51 is selected by the crew by keying in VERB 37 ENTR 51 ENTR. (See Figure 7.2.1-1.) The crew should then monitor the DSKY to ensure that the program was properly entered. If the program was initialized without the Inertial Subsystem (ISS) being on, the PROG alarm light comes on. (See paragraph 7.2.1.4, alarm code 00210.) With the ISS on, the first display the crew see is a flashing VERB 50 NOUN 25 with a 00015 code in register R1. (See Table 7.2.1-I.) This display requests the crew to "please perform celestial body acquisition." The crew must decide which two celestial bodies they will acquire, and either maneuver the CSM such that the bodies are visible in the SCT field of view or maneuver the CSM to position the inner gimbal axis in the preferred direction (X_{SM} axis in the thrust direction).

While maneuvering the CSM, however, the crew must ensure that gimbal lock is not impending by monitoring the Flight Director Attitude Indicator (FDAI) ball. Gimbal lock occurs when the middle gimbal angle exceeds ±85 degrees from zero. The gimbal lock warning light, however, is illuminated when the angle exceeds 70 degrees from zero. If 85 degrees is exceeded, the CMC automatically commands a

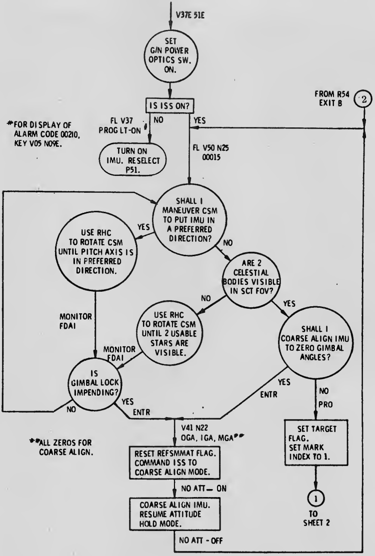


Figure 7. 2. 1-1 IMU Orientation Determination Program (P51) (Sheet 1 of 2)

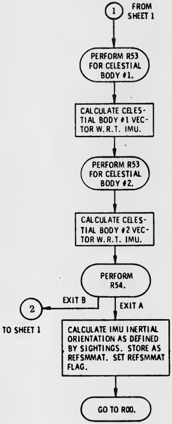


Figure 7.2.1-1 IMU Orientation Determination Program (P51) (Sheet 2 of 2)

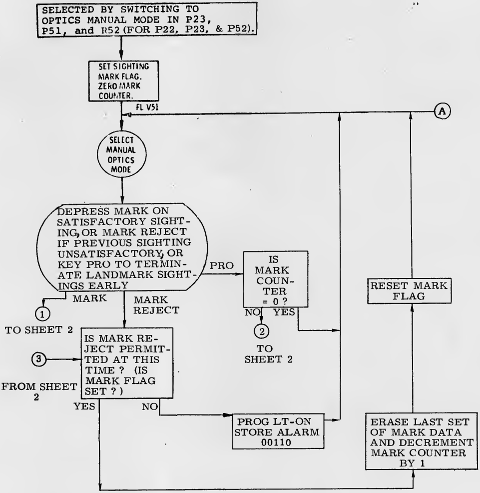
coarse align to prevent gimbal oscillation. If gimbal lock is not impending and the crew do not desire to coarse-align the IMU, they can key in PRO and go directly into the Sighting Mark Routine (R53). If gimbal lock is impending, or if the crew desire, they can coarse-align the IMU to gimbal angles of 0, 0, 0. If the crew choose the latter, they can key in ENTR. In this case a VERB 41 NOUN 22 is displayed on the DSKY (see Table 7.2.1-I) with zeros in all three registers. The NO ATT light comes on indicating that the IMU is in the process of zeroing all three gimbals (in the Coarse Align Mode). When the NO ATT light goes off, the VERB 50 NOUN 25 display comes up again, giving the crew the same choices they had the first time the display came up. This time, however, celestial bodies are probably in the SCT field of view and the IMU has been coarse-aligned to 0, 0, 0, so the crew can key in PRO. If the desired celestial bodies are not in the SCT field of view, the CSM must again be maneuvered to acquire them. The program then sets the mark index (a register indicating the minimum number of marks required) to one and enters R53.

Upon entering the Sighting Mark Routine R53 (see Figure 7.2.1-2), the CMC sets the SIGHTING MARK flag to prevent interruption of the routine, and zeros the mark counter (a register to keep track of the number of marks). A flashing VERB 51 is displayed requesting a "please mark." The crew should select the manual optics mode and, with the use of the Rotational Hand Controller (RHC), sight on the celestial body. (The manual optics mode is used because auto optics positioning is only used in P20, P22, P23, and P52.) When the sighting is satisfactorily accomplished, the crew have the following three choices:

a. Depress the MARK REJECT pushbutton,
b. Depress the MARK pushbutton, or
c. Key in PRO.

Depressing the MARK REJECT pushbutton before any marks have been taken causes the PROG alarm light to come on and alarm code 00110 to be stored. (See paragraph 7. 2. 1. 4.) If a mark had been taken previously and the MARK REJECT pushbutton is depressed, the last set of mark data (five angles and mark time) would be erased and the mark counter decremented by one. The program would then recycle to the flashing VERB 51 to take a new mark.

Depressing the MARK pushbutton stores the five angles (three ICDU and two OCDU) and the exact time the mark was taken, and increments the mark counter by one. The program then determines if the mark counter is



MARK INDEX = 1 FOR P23, P51, P52.
MARK INDEX = 5 FOR P22.

Figure 7.2.1-2 Sighting Mark Routine (R53) (Sheet 1 of 3)

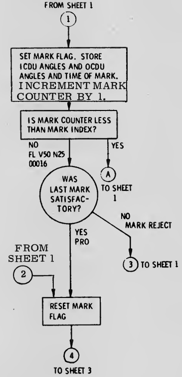


Figure 7.2.1-2 Sighting Mark Routine (R53) (Sheet 2 of 3)

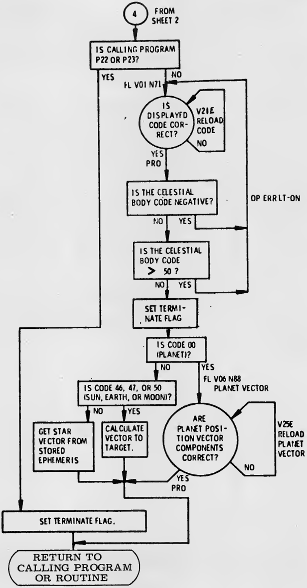


Figure 7.2.1-2 Sighting Mark Routine (R53) (Sheet 3 of 3)

less than the mark index (set to 1 by P51 before entering R53). If it is less than the index, the program recycles to take an additional mark. If the mark counter is not less than the mark index, a flashing VERB 50 NOUN 25 comes up (see Table 7.2.1-I) with a 00016 option code in R1, indicating the request to "Please terminate mark sequence."

Keying PRO causes the mark counter to be checked to ensure that it is not zero. If it is zero, the VERB 51 continues to flash and a mark must be taken. If it is not zero, the program resets the MARK flag, checks to determine that the calling program was not P22 or P23, and then puts up a flashing VERB 01 NOUN 71. (See Table 7.2.1-I.) This is the same sequence of events that occurs if the crew—determining that the mark was satisfactory—key in PRO on the flashing VERB 50 NOUN 25 display (terminate mark sequence) above. If the crew determine that the mark was unsatisfactory, the MARK REJECT pushbutton should be depressed. Depressing the MARK REJECT pushbutton causes the last set of mark data to be erased, the MARK flag to be reset, and the flashing VERB 51 to be put up again to inform the crew that a new mark must be taken.

When a satisfactory mark has been taken, the flashing VERB 01 NOUN 71 display comes up, indicating the code for the celestial body just marked on. If the code is incorrect, the crew should key in VERB 21 ENTR and load the proper celestial body code in R1. The program then checks the code to determine if: (a) it is a star, (b) a planet, or (c) if it is the sun, moon or earth.

If the code is a star (01/45 octal), the vector data are obtained from the ephemeris stored in the CMC. If the code is the sun, earth, or moon, 46, 47, or 50 respectively, the CMC computes the vector to the celestial body. If the code is 00, a flashing VERB 06 NOUN 88 (see Table 7.2.1-I) requests the crew to load the data for the x-, y-, and z-unit position vectors for the planet. In this case, the crew can key in VERB 25 ENTR and load the proper x-, y-, and z-unit position vectors.

In all three cases, (star, planet, or sun, moon, or earth) the routine is exited and control is returned to the calling program (P51).

Using the data computed from the marking sequence and the stored or known data, the CMC computes the measured vector to the celestial body with respect to present orientation of the IMU. This whole process is repeated for a second celestial body. Then the two vectors are tested by calling the Sighting Data Display Routine (R54).

The Sighting Data Display Routine (see Figure 7.2.1-3) calculates the angular difference between the actual (stored data) and the measured (derived from mark angles) LOS vectors and displays this difference angle via a flashing VERB 06 NOUN 05. If the angle difference is within acceptable limits (less than 0.05 degree), the crew should key in PRO; the calling program, P51, calculates the IMU inertial orientation with respect to the celestial body coordinates defined by the two celestial bodies used for marking. These data are stored as the present platform orientation (REFSMMAT). If the angular difference is not within acceptable limits, the crew should key in VERB 32 ENTR (recycle) and return to the flashing VERB 50 NOUN 25 display at the start of P51, requesting celestial body acquisition (option code 00015), and the orientation determination is performed again.

7.2.1.4 Program Alarms

In addition to the anticipated outputs, the program displays a PROG alarm light and stores an alarm code for display to the crew. Keying in VERB 05 NOUN 09 allows the program to display an alarm code in R1, R2, and R3. (R1 displays the first alarm code to occur after the last RSET, R2 the second, and R3 the last.) Keying in RSET turns off the PROG alarm light on the DSKY if the condition causing the alarm has been corrected. After correcting the alarm condition and keying in RSET, keying in KEY REL allows the program to pick up from the point of interruption. The alarm codes and conditions causing them are as follows:

a. Alarm 00110 is displayed if a mark reject has been attempted with no marks to reject.
b. Alarm code 00112 is displayed if a mark reject is not being accepted.
c. Alarm codes 00114 or 00122 are displayed if a mark has been made but not requested by the CMC.
d. Alarm code 00210 is displayed if the IMU is not operating when P51 is entered.
e. Alarm codes 00211 and 00217 are displayed if, at the end of coarse align ISS mode, the gimbals are not within 2 deg of the desired values.
f. Alarm code 31207 is displayed if no vector accumulator (VAC) areas are available for processing of mark data.
g. Alarm code 31211 is displayed when there is an illegal interrupt of an extended verb.

The inertial subsystem (ISS) must be on, and may be either at a known or unknown orientation in order to perform the IMU Orientation Determination Program (P51).

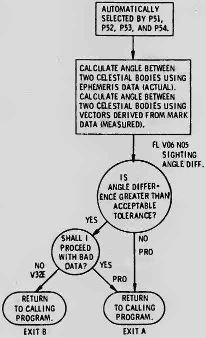


Figure 7. 2. 1-3 Sighting Data Display Routine (R54)

If the ISS is not on, alarm code 00210 alerts the crew to turn on the IMU and, following a 15-minute warmup period, reselect P51 by keying in VERB 37 ENTR 51 ENTR. If, while in the process of sighting and marking on celestial bodies, the crew should press the MARK REJECT pushbutton and no marks have been taken to reject, the PROG alarm light comes on. The crew can key in VERB 05 NOUN 09 ENTR and determine, by monitoring the DSKY, that illumination of the PROG alarm light was caused by alarm code 00110.

If an extended verb is keyed into the DSKY while R53 is in process, the OPR ERR light comes on and the extended verb is rejected.

The alarm code displayed could also be 31207, indicating that no VAC areas are available for storing parameters for computation and mark information. This alarm occurs if all VAC areas are being used by previous programs. If this alarm occurs, the computer does an automatic restart, releases all the VAC areas, and recycles to the beginning of the Sighting Mark Routine (R53).

Alarm code 00112 is stored when the MARK REJECT pushbutton has been depressed and R53 cannot accept marks at this time because the routine is processing previous mark or mark reject data. Alarm 00122 is stored if the MARK pushbutton has been depressed unnecessarily. If this occurs, the alarm should be reset and the mark or mark reject attempted again.

Alarm code 00114 is stored if the MARK pushbutton has been depressed when the CMC is not flashing VERB 51. This alarm occurs when the mark counter has been decremented to the point where it is zero.

7.2.1.5 Restrictions and Limitations

The restrictions and limitations peculiar to P51 are listed below.

a. For more accurate results in determining the IMU orientation, the crew should select celestial bodies that are greater than 30 degrees apart.
b. Before performing the IMU Orientation Determination Program, the IMU should be turned on and allowed to warm up for at least 15 minutes.
c. The celestial body codes selected should not be greater than 50, octal.
d. Only one mark per celestial body is required in order to complete P51.
e. Do not cage the IMU during flight as damage to the IRIGs may result.

7.2.1.6 Program Coordination and Procedures

There is really no best time to perform P51. It is strictly an orientation determination program and is used when it is necessary to calculate a new REFSMMAT. All programs that require REFSMMAT in their computational sequence might first require performance of P51.

If it is necessary to perform P51, enough time should be allowed for completion of the program (i.e., 15-minute IMU warmup, if necessary, plus time required by the crew for sighting and marking), prior to the time that the REFSMMAT is required.

7.2.1.7 Restarts

P51 is restart-protected. Should a restart occur, the program returns to one of several predetermined points depending on where in the program the restart occurs. The program then continues to completion.

7.2.2 P52, IMU Realignment—CSM

The IMU Realignment Program is initiated by the CSM crew to move the IMU stable member from one known inertial orientation to another. P52 (Figure 7.2.2-1) serves two basic purposes: (a) to eliminate, as much as possible, the uncertainty in the knowledge of the stable member's orientation in inertial space arising from uncompensated gyro drift; and (b) to move the stable member into an inertial orientation that is more convenient than its currently known orientation. P52 calculates the orientation of the stable member with respect to a desired orientation (REFSMMAT, preferred, nominal, or landing site) and calculates the gimbal angle changes required to move the stable member into the desired orientation. To determine the orientation of the stable member with respect to the Basic Reference Coordinate System, the astronaut must execute P51, the IMU Orientation Determination Program (paragraph 7.2.1).

The coordinate systems used by P52 to define the stable member's orientation in relation to inertial space and in relation to the CSM are listed below:[*]

a. Basic Reference Coordinate System
b. Vehicle or Body Coordinate System
c. Navigation Base Coordinate System
d. Earth-Fixed Coordinate System
e. Moon-Fixed Coordinate System
f. Stable Member or Platform Coordinate System, which has four types of alignment:
    1. Preferred Alignment
    2. Nominal Alignment (local vertical)
    3. Landing Site Alignment
    4. REFSMMAT Alignment

g. Sextant Base Coordinate System.

REFSMMAT is the name of an important coordinate transformation matrix used by the computer programs to define the orientation of the stable member. This is the matrix required to transform a vector from the Basic Reference Coordinate System

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[*] Refer to subsection 7.1 for a definition and discussion of coordinate systems and coordinate transformations.

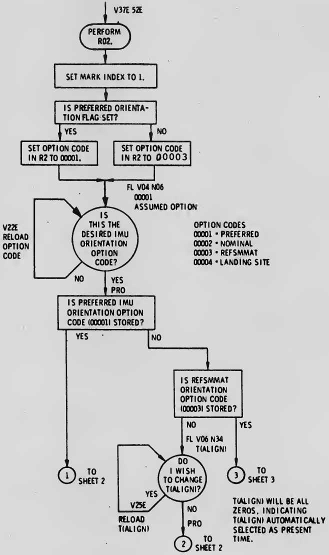


Figure 7. 2. 2-1. IMU Realignment Program (P52) (Sheet 1 of 4)

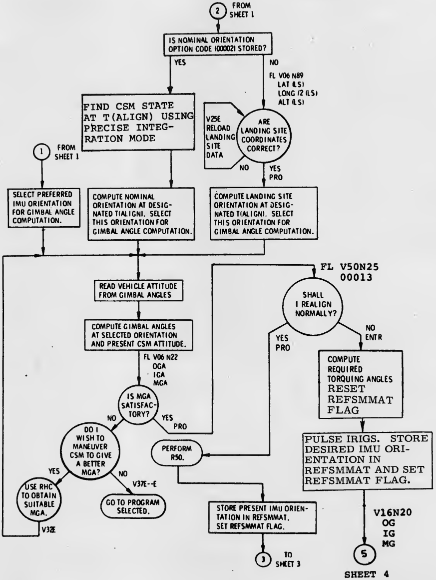


Figure 7. 2. 2-1. IMU Realignment Program (P52) (Sheet 2 of 4)

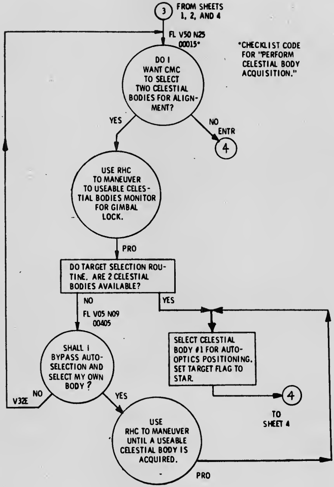


Figure 7.2.2-1. IMU Realignment Program (P52) (Sheet 3 of 4)

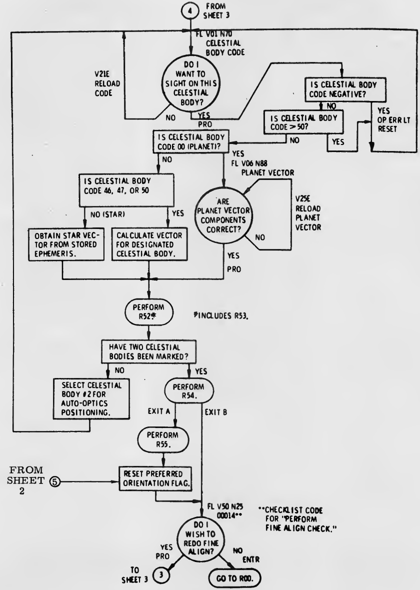


Figure 7. 2. 2-1. IMU Realignment Program (P52) (Sheet 4 of 4)

to the Stable Member Coordinate system. When REFSMMAT is in storage and valid, the REFSMMAT flag is set, which informs all other programs that the inertial attitude of the stable member and the spacecraft is known by the computer. If REFSMMAT is invalid or is not known, the REFSMMAT flag is reset (cleared). Then any program which tests this flag (such as P20 or P30) will be informed that REFSMMAT is invalid.

Another matrix used, but not generated, by P52 is associated with the preferred stable member alignment defined above. This matrix describes the stable member orientation which will produce an FDAI indication of (0,0,0) for a desired vehicle attitude, and is either calculated and stored by P40 or P41 (the SPS and RCS Thrust Programs), or loaded into storage by P27 (the CMC Update Program). The preferred orientation can be used, for example, to establish an orientation for the vehicle roll axis for Passive Thermal Control (Barbecue). The PREFERRED flag is set or reset by the thrust programs, depending on whether or not a preferred alignment matrix is in storage.

In the nominal and landing site alignments, the desired stable member orientation is calculated by P52. For the landing site alignment, the crew must supply to P52, via the DSKY, the time of alignment, and the coordinates of the lunar landing site, in latitude, half-longitude, and altitude. This information is required so that P52 can determine the inertial orientation of the landing site vector.

If the crew chooses nominal alignment, only the time of alignment is required, so that the program can extrapolate the spacecraft state vector up to the time specified, and use the extrapolated radius vector as a stable member minus z-axis alignment direction. Once the present and desired stable member orientations are known, P52 calculates the gimbal angle changes required to bring about the realignment.

At this point, the stable member can be repositioned in one of two ways: coarse alignment (ISS in coarse-align mode) to within about one deg of the exact alignment desired; or pulse torquing (ISS in fine-align mode) to within about one arc-min of the exact alignment desired. If the crew chooses coarse alignment, the inertial orientation of the stable member is then verified by sightings with the scanning telescope or sextant, and any small differences between the actual and desired stable member alignments are removed by pulse torquing the gyros through the angles required (fine alignment).

If the crew has chosen REFSMMAT alignment, coarse alignment is bypassed; the astronaut carries out only star sightings and fine alignment.

During P52, the crew sees displays of the gimbal angles, which are calculated corresponding to the alignment desired. If these angles indicate the risk that the stable member will be positioned into gimbal lock (middle gimbal angle of 85 deg or more), the crew can maneuver the spacecraft and recycle within the program to calculate the gimbal angles based on a new spacecraft attitude. (Refer to paragraph 7.2.2.3.2 below.)

In the event that the sextant (SXT), scanning telescope (SCT), or MARK button is not usable, the crew has recourse to the Backup IMU Realignment Program, P54 (paragraph 7.2.4), which operates in conjunction with the crew optical alignment sight (COAS).

7.2.2.1 Related Routines

Six routines are related to the IMU Realignment Program; five of these are called automatically by P52 at various stages of the realignment. The routines are as follows:

a. IMU Status Check Routine (R02)
b. Coarse Align Routine (R50)
c. Automatic Optics Positioning Routine (R52)
d. Sighting Mark Routine (R53) (called by R52 when crew places Optics Mode switch in MAN)
e. Sighting Data Display Routine (R54)
f. Gyro Torquing Routine (R55).

The IMU Status Check Routine (R02) (Figure 7.2.2-2) informs the crew if the IMU is powered down, or if there is no valid REFSMMAT in the CMC. The Coarse Align Routine (R50) (Figure 7.2.2-3) calculates the present CSM inertial orientation, the required IMU gimbal angles at the proposed orientation option, and proceeds to coarse align the IMU to within about one deg of the exact orientation desired, if the required gimbal angle changes are greater than one deg. The Auto Optics Positioning Routine (R52) (Figure 7.2.2-4) obtains the vector for the designated celestial body in Basic Reference Coordinates and calculates the required SXT shaft and trunnion angles to bring the body into the SXT field-of-view. It then drives the shaft and trunnion CDUs to enable the crew to see the celestial body desired. When the crew places the Optics Mode switch from CMC to MAN, R52 calls the Sighting Mark Routine (R53) (Figure 7.2.2-5). R53 stores the ICDU angles, the OCDU angles, and the time of mark when the crew presses the MARK button on the optics control panel. The Sighting Data Display Routine (R54) (Figure 7.2.2-6) calculates the actual angle between the two celestial bodies marked, using celestial body data from one of the following: star tables from CMC storage; planet unit position vector (N88); or sun, earth, or moon position vectors from previous P52 calculations. R54 then calculates the angle between these same bodies using the sighting data supplied by R53. R54 finally calculates and displays the difference between the actual and observed angles for the crew's judgement concerning the accuracy of the sightings taken in R53. The Gyro Torquing Routine (R55) (Figure 7.2.2-7) calculates and displays, for crew approval, the gyro torquing angles required to bring the stable member into precise alignment with the stable member orientation vectors calculated by P52 for the option selected. R55 then pulses the IRIGs through the desired angles.

7.2.2.2 IMU Realignment Program Options

The first display the crew sees in P52 is a CMC request to choose one of four alignment options provided by the program (flashing VERB 04 NOUN 06): Preferred; Nominal; Landing Site; and REFSMMAT. The functions of these options are described here.

7.2.2.2.1 Preferred Alignment.—One of the purposes of the SPS and RCS thrust programs (P40 and P41, paragraphs 6.2.1 and 6.2.2) is to calculate and store the direction (in inertial space) along which the vehicle X-axis is to be aligned for an upcoming burn. (This preferred direction may also be uplinked via P27.) The preferred option in P52 then treats this vehicle orientation as a desired stable member orientation (i.e., as a future REFSMMAT). P52 calculates the gimbal angle changes required to coarse align the stable member to within about one deg of this desired alignment. When coarse alignment is accomplished, the preferred orientation is stored as the present REFSMMAT. SXT sightings and pulse torquing are then executed to remove any errors in the stable member's alignment to the new REFSMMAT.

When the stable member X-axis is parallel to the vehicle X-axis, it is also very nearly parallel to the SPS thrust vector. In this orientation, gyro drift effects due to thrust acceleration are minimized. In addition, spacecraft roll control becomes, essentially, control of the outer gimbal angle.

In preferred alignment, the stable member provides the basis for a convenient FDAI display. By observing a (0,0,0) gimbal angle indication, the crew can verify that the spacecraft X-axis is in the proper orientation for the powered maneuver.

It should be noted that the orientation for a Passive Thermal Control (Barbecue) maneuver can also be uplinked and treated as a preferred orientation.

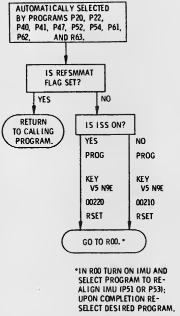


Figure 7. 2. 2-2. IMU Status Check Routine (R02)

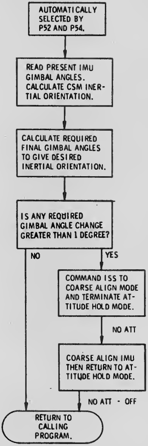
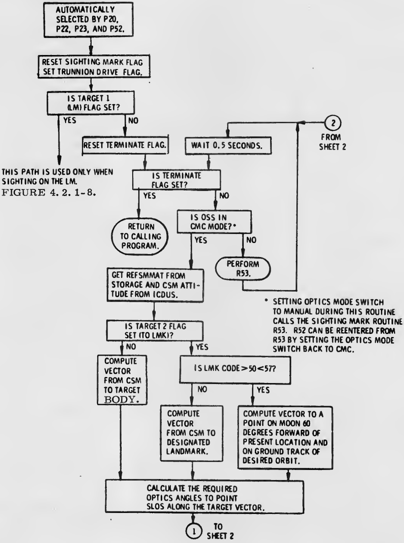
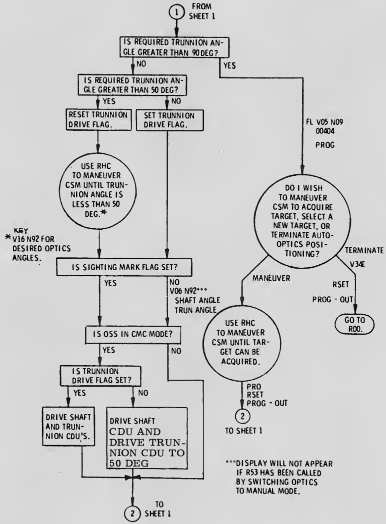


Figure 7. 2. 2-3. Coarse Align Routine (R50)



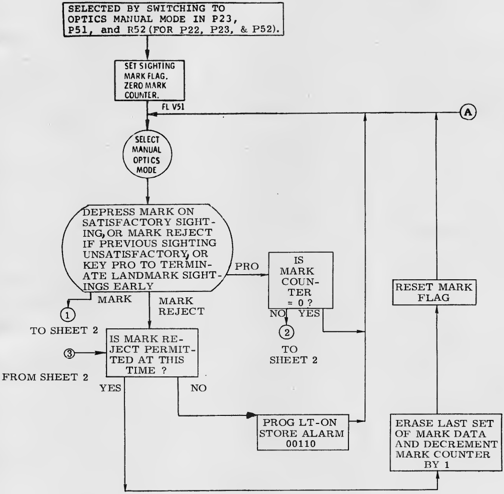
* SETTING OPTICS MODE SWITCH TO MANUAL DURING THIS ROUTINE CALLS THE SIGHTING MARK ROUTINE R53. R52 CAN BE REENTERED FROM R53 BY SETTING THE OPTICS MODE SWITCH BACK TO CMC.

Figure 7. 2. 2-4. Automatic Optics Positioning Routine (R52) (Sheet 1 of 2)



***DISPLAY WILL NOT APPEAR IF R53 HAS BEEN CALLED BY SWITCHING OPTICS TO MANUAL MODE.

Figure 7. 2. 2-4. Automatic Optics Positioning Routine (R52) (Sheet 2 of 2)



MARK INDEX = 1 FOR CELESTIAL BODY (P23, P51, P52)
MARK INDEX = 5 FOR LANDMARK (P22)

Figure 7. 2. 2-5. Sighting Mark Routine (R53) (Sheet 1 of 3)

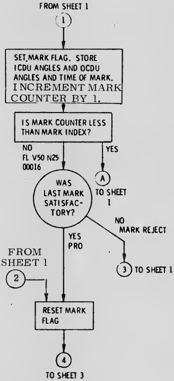
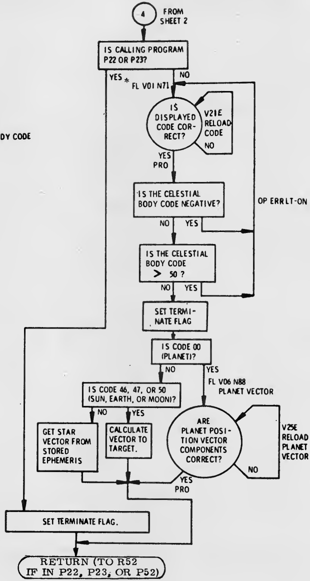


Figure 7. 2. 2-5. Sighting Mark Routine (R53) (Sheet 2 of 3)



* CELESTIAL BODY CODE

Figure 7. 2. 2-5. Sighting Mark Routine (R53) (Sheet 3 of 3)

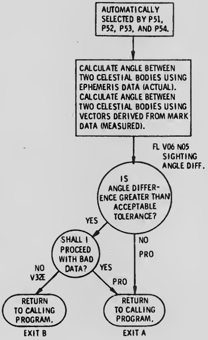


Figure 7. 2. 2-6. Sighting Data Display Routine (R54)

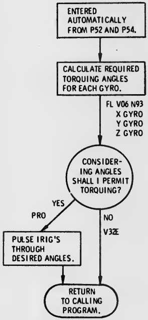


Figure 7. 2. 2-7. Gyro Torquing Routine (R55)

7.2.2.2.2 Nominal Alignment.—The nominal alignment option provides the spacecraft with the onboard capability to compute a stable member orientation that is independent of powered flight considerations (P40 and P41), and that is not related to the present REFSMMAT. Nominal orientation defines a heads-up, wings-level attitude for the spacecraft; it is dependent only on the CSM state vector and provides the basis for a convenient FDAI artificial horizon display while in orbit.

After the crew chooses the nominal orientation, the time of alignment is keyed in. P52 then calls a routine to integrate the vehicle's state vector up to the time specified, and then calculates the gimbal angles required to orient the stable member z-axis along the radius vector just computed, using the present vehicle attitude. The crew then proceeds with normal or pulse torque coarse alignment, then star sightings and fine alignment, to complete the program. This alignment option is less commonly used than the landing site option (paragraph 7.2.2.2.4).

7.2.2.2.3 REFSMMAT Alignment.—If three or four hours have elapsed since the stable member was realigned, normal uncompensated gyro drift will have made the stable member's actual orientation different from the stored REFSMMAT by about 0.03 deg per axis. If a critical maneuver is upcoming, the stable member orientation in the Basic Reference Coordinate System must then be realigned through SXT sightings made on stars or planets whose Basic Reference coordinates are known. P52 determines the present stable member orientation with respect to the desired stable member orientation. The program can then calculate the stable member fine alignment torquing angles required to return the stable member to the REFSMMAT orientation.

The REFSMMAT option in P52 does not call the Coarse Align Routine (R50), because R50's purpose is to realign the stable member from the present REFSMMAT orientation to a desired REFSMMAT (for examples, preferred, nominal, or landing site inertial orientation). For the REFSMMAT option, the present and desired REFSMMATS are identical.

Once the stable member's orientation error from REFSMMAT is known, the Gyro Torquing Routine, R55 (Figure 7.2.2-7), is called by P52 to perform the stable member fine alignment. In R55, the gyro stabilization loops remain closed during the pulse torquing operation, and the stable member remains inertially referenced at all times. The spacecraft is not required to maintain a constant attitude during fine alignment, and will move to follow the torqued gyros if the Digital Autopilot (DAP) is on.

7.2.2.2.4 Landing Site Alignment.—The P52 landing site option is used to align the CSM stable member X-axis parallel to the vector describing the lunar landing site in Basic Reference coordinates, at the predicted time of lunar landing or launch.

At lunar touchdown, the LM stable member must be in the landing site orientation in order to be of use to the Abort Guidance System. To facilitate LM stable member alignment after docked LM ISS power-up, the CSM and LM may be given the same REFSMMAT. To accomplish this, the CSM stable member is aligned to the landing site option. The LM IMU gimbals are then aligned to values based on the docking ring angle and the CSM gimbal angle values, giving the two vehicles the same REFSMMAT—without requiring the LM crew to use the alignment optical telescope to determine their initial stable member orientation. Paragraph 7.3.2 discusses LM IMU realignment.

If the landing site option has been selected for the CSM P52, the crew must key in the time of alignment (i.e., time of landing) and the landing site latitude, half-longitude, and altitude. The CMC then extrapolates the landing site vector's inertial orientation up to the time of alignment, and the realignment process continues through coarse alignment, star sightings, and fine alignment.

7.2.2.2.5 Coarse and Fine Stable Member Positioning. —After the crew has selected an alignment option, P52 computes the gimbal angles which would be required to bring the stable member into the desired inertial orientation if the spacecraft were to maintain its present attitude. The outer, middle, and inner gimbal angles at the new stable member orientation are displayed to the crew (flashing VERB 06 NOUN 22 of Figure 7.2.2-1, sheet 2). The program then requests the crew to choose between the normal and the gyro torque methods of coarse alignment of the stable member to its new orientation (flashing VERB 50 NOUN 25, Checklist code 00013).

The term "coarse alignment" here refers to stable member repositioning without the aid of SXT sightings. Coarse alignment can be accomplished with the ISS in the coarse align mode (normal coarse alignment) or in the fine align mode (pulse torque coarse alignment). "Fine alignment" means stable member repositioning using the fine align ISS mode and orientation information derived from SXT sightings.

The normal coarse alignment option allows the stable member to be quickly aligned to a new position with a limited degree of accuracy. During the time that the stable member is being coarse aligned by the normal method, the gyro stablization loops, which keep the stable member inertially referenced, are opened. If the spacecraft attitude is changing during this alignment, the final stable member orientation will not be the actual orientation desired, since the computer cannot keep track of the inertial orientation of the spacecraft while the gyro stabilization loops are opened. The accuracy of the normal method of coarse alignment is thus dependent on the spacecraft attitude changes, if any, during coarse alignment, and, at best, is limited to about one deg. Alignment to any gimbal angle with this method takes about 15 sec. Once normal coarse alignment has taken place, the crew will have to accurately determine the new stable member orientation with respect to the desired orientation by P52's celestial body sights. The SXT can determine star directions to within about 0.01 deg; the SCT has an accuracy of about 0.05 deg.

Gyro torquing coarse alignment is an alternate astronaut response to Checklist code 00013 of flashing VERB 50 NOUN 25 above. The fine align ISS mode can be used to bring the stable member into more precise alignment with the orientation desired than is available with the coarse align ISS mode. The fine align ISS mode allows the computer to position the stable member to a predetermined gimbal angle within about 40 arc-sec. During pulse torquing, the ISS gyro stabilization loops remain closed, allowing the IMU to remain sensitive to the spacecraft inertial attitude changes at all times during the process of stable member repositioning.

The disadvantage of the fine align ISS mode is that it is slow. The larger the gimbal angle changes, the longer it takes to bring the stable member into the desired orientation (about 2 sec per deg of torquing, one axis at a time).

7.2.2.3 P52 Computational Sequence

The following paragraphs discuss the calculations and crew procedures that take place during the progress of P52 (Figure 7.2.2-1). Table 7.2.2-I lists the P52 displays.

7.2.2.3.1 Program Initiation.—The CSM crew initiates P52 by keying VERB 37 ENTR 52 ENTR into the DSKY. P52 then calls the IMU Status Check Routine, R02 (Figure 7.2.2-2), which checks to see if the REFSMMAT flag is set. If the REFSMMAT flag is cleared or if the IMU is powered down, R02 illuminates the PROG alarm light; this alarm is verified by keying VERB 05 NOUN 09 ENTR. The DSKY displays alarm 00210 if the IMU is not on, or 00220 if the IMU is not aligned (no REFSMMAT). P52 is then terminated automatically.

If the IMU is powered up, P52 checks to determine if a preferred orientation has been stored (PREFERRED flag set). The first display the crew sees in P52 is a flashing VERB 04 NOUN 06, with 00001 in R1 (please specify IMU orientation option);

TABLE 7.2.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH CM IMU REALIGNMENT (P52) (SHEET 1 OF 6)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
1	V37 ENTR 52 ENTR	Astronaut	Initiate IMU Realign Program	---	---	---
2	FL V04 N06	P52	Request response to display of alignment option code	R1--"please specify IMU orientation" R2--option assumed by CMC; 00001 = preferred 00002 = nominal 00003 = REFSMMAT 00004 = landing site	R1 00001 checklist R2 oooox R3 Blank	Preferred-PRO to 5 Nominal-PRO to 3 REFSMMAT-PRO to 8 Landing Site-PRO to 3
3	FL V06 N34	P52	Request response to display of T_{align}	Nominal or landing site option R1, R2, R3--time of alignment in GET; all zeroes = present time	R1 xxxxx. hr R2 xxxxx. min R3 xxx.xx sec	Load desired GET. PRO to 5 for nominal, PRO to 4 for landing site option.
4	FL V06 N89	P52	Request response to display of landing site coordinates.	Landing site option R1-- latitude (+ North) R2-- longitude/2 (+ East) R3-- altitude above mean lunar radius	R1 xx.xxx deg R2 xx.xxx deg R3 xxx.xx n.mi.	Load desired coordinates. PRO to 5.
5	FL V06 N22	P52	Request response to display of gimbal angles after proposed coarse align at present CM attitude.	All options except REFSMMAT R1-- outer gimbal R2-- inner gimbal R3-- middle gimbal	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg	If middle gimbal angle >70 deg, maneuver and V32 ENTR to 5. PRO to 6.

TABLE 7.2.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH CM IMU REALIGNMENT (P52) (SHEET 2 OF 6)

No.	DSKY	Initiated By	Purpose	Condition	Register		Crew Action
6	FL V50 N25	P52	Request astronaut to perform normal or pulse torque coarse align	Proposed gimbal angles satisfactory R1-- "please perform coarse align"	R1 00013 R2 Blank R3 Blank	checklist	Normal coarse align–PRO, monitor NO ATT light on, then off, go to 8. Pulse torque–CMC Mode switch to FREE, ENTR to 7.
7	V16 N20	P52	Monitor gimbal angles	Pulse torque coarse align in progress R1-- outer gimbal R2-- inner gimbal R3-- middle gimbal	R1 xxx.xx R2 xxx.xx R3 xxx.xx	deg deg deg	Monitor for potential gimbal lock. Go to 18.
8	FL V50 N25	P52	Request celestial body acquisition	Normal coarse align accomplished. R1-- "please perform celestial body acquisition"	R1 00015 R2 Blank R3 Blank	checklist	Maneuver if necessary. CMC star acquisition–PRO to 9. Manual acquisition-ENTR to 9.
9	FL V01 N70	P52	Display celestial body identification code	R1-- 00000=any planet 00001 to 00045 =star 00046, 47, 50 =sun, earth, moon	R1 oooxx R2 Blank R3 Blank	celestial identification code	Load desired code. Optics Mode to CMC, Optics Zero to OFF, PRO to 11 (or to 10 if R1 = 00000).

TABLE 7.2.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH CM IMU REALIGNMENT (P52) (SHEET 3 OF 6)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
10	FL V06 N88	P52	Request response to display of planet position vector	Celestial body code =00000 R1-- X-component of planet unit position vector at T_{align} R2-- same as R1 for Y-component R3-- same as R1 for Z-component	R1 .xxxxx Xpl R2 .xxxxx Ypl R3 .xxxxx Zpl	Load vector and PRO to 11.
11	V06 N92	R52	Display desired optics angles	Will not appear if R53 has been called by setting Optics Mode switch to MAN R1-- shaft angle R2-- trunnion angle	R1 xxx.xx deg R2 xx.xxx deg R3 Blank	To call mark routine, set Optics Mode switch to MAN. Go to 12.
12	FL V51	R53	Request mark	Optics Mode switch in MAN	---	Use Mark pushbutton. Go to 13.
13	FL V50 N25	R53	Request terminate marking	One mark has been taken on the target R1-- "please terminate marking"	R1 00016 checklist R2 Blank R3 Blank	To terminate marking, PRO to 14.
14	FL V01 N71	R53	Request response to display of celestial body code	Mark sequence has been terminated	R1 oooxx celestial body code R2 Blank R3 Blank	Load code if needed. PRO to 9 after first mark (to 15 if code = 00). PRO to 16 after second mark (to 15 if code = 00).

TABLE 7.2.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH CM IMU REALIGNMENT (P52) (SHEET 4 OF 6)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
15	FL V06 N88	R53	Request response to display of celestial body vector	Celestial body code = 00000	R1 .xxxxx Xpl R2 .xxxxx Ypl R3 .xxxxx Zpl	Load vector if needed. PRO to 9 after first mark. PRO to 16 after second mark.
16	FL V06 N05	R54	Request response to display of difference between actual and measured celestial body angles	Two celestial bodies have been marked R1-- sighting angle difference	R1 xxx.xx deg R2 Blank R3 Blank	To reject—V32 ENTR to 18. To accept—PRO to 17.
17	FL V06 N93	R55	Request response to fine align torquing angles	Satisfactory sighting angle difference R1-- outer gimbal R2-- inner gimbal R3-- middle gimbal angles through which gyros must be torqued to complete fine alignment.	R1 xx.xxx deg R2 xx.xxx deg R3 xx.xxx deg	To torque-CMC Mode switch to FREE and PRO to 18. To bypass torquing-V32 ENTR to 18.
18	FL V50 N25	P52	Request third star check	R1-- "please perform third star alignment check"	R1 00014 checklist	Third star check—PRO to 8. Bypass star check and terminate P52—ENTR and set Optics Zero switch to ZERO.

TABLE 7.2.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH CM IMU REALIGNMENT (P52) (SHEET 5 OF 6)

DSKY	Initiated By	Purpose	Condition	Register
V05 N09 ENTR	Astronaut	Verify PROG alarm	00110--MARK REJECT depressed unnecessarily 00112--MARK REJECT depressed while CMC not flashing V51 00114--too many marks taken 00115--Optics Mode switch not in CMC for auto optics positioning 00116--optics not zeroed 00117--V41 N91 cannot be executed now 00120--optics not zeroed at time of optics torque request 00121--mark taken during CDU transient or CM rotating too fast 00122--mark made while CMC not in mark routine 00206--ICDU zero not allowed during gimbal lock 00207--ISS turn-on not present for 90 sec 00210--IMU not on 00211--coarse align error 00217--ISS mode switch failure 00220--no valid REFSMMAT 00401--desired angles yield gimbal lock	R1 xxxxx R2 xxxxx R3 xxxxx

TABLE 7.2.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH CM IMU REALIGNMENT (P52) (SHEET 6 OF 6)

DSKY	Initiated By	Purpose	Condition	Register
PROG FL V05 N09	P52	Display PROG alarm code	00405--two stars not available for auto optics positioning at present CM attitude	R1 xxxxx R2 xxxxx R3 xxxxx
PROG FL V05 N09	R52	Display PROG alarm code	00404--target not within hemisphere of optics visibility (trunnion angle > 90 deg)	R1 xxxxx R2 xxxxx R3 xxxxx

R2 contains the orientation option code assumed by the CMC. These codes are as follows:

00001 — Preferred Alignment
00002 — Nominal Alignment
00003 — REFSMMAT Alignment
00004 — Landing Site Alignment.

R2 contains 00001 if the preferred orientation flag has been set, and 00003 if it has not. If the crew chooses an option not displayed in R2, the option code is loaded by keying in VERB 22 ENTR and the desired option code.

If the REFSMMAT option is chosen, a PRO response to VERB 04 NOUN 06 takes P52 into the first display in paragraph 7.2.2.3.3 below; otherwise, a PRO response under the landing site or nominal options causes a flashing VERB 06 NOUN 34, with the proposed time of alignment displayed in R1, R2, and R3. (All zeroes in the registers indicates that the time of alignment is chosen to be the present time.) The crew can now reload the time by keying VERB 25 ENTR, followed by the time desired, or can accept the time indicated, by keying PRO. VERB 06 NOUN 34 does not appear if the preferred or REFSMMAT options were chosen, since these options do not integrate any vectors ahead in time.

If the landing site option is chosen, the crew sees, after VERB 06 NOUN 34, a flashing VERB 06 NOUN 89—a request to respond to the computer's display of the lunar landing site coordinates. R1 contains the landing site latitude in degrees, to 0.001 deg (+ signifies North); R2 contains the longitude divided by two (+ signifies East); R3 contains the landing site altitude to 0.01 n. mi. To load new coordinates, the crew keys in VERB 25 ENTR, followed by the correct coordinates. These are displayed to the crew and approved by a PRO response to flashing VERB 06 NOUN 89. At this time, any previously stored preferred orientation is lost. P52 then computes the landing site vector's orientation at the time specified, and proceeds to the gimbal angle computations discussed below in paragraph 7.2.2.3.2.

If the nominal option is chosen and the time of alignment specified, P52 calculates the CSM state vector at the time of alignment and uses it to calculate the desired stable member orientation. (VERB 06 NOUN 89 above will not appear in this program option.) Execution of the nominal option erases any previously stored preferred orientation.

7.2.2.3.2 Gimbal Angle Computation.—In the preferred, nominal, or landing site options, the CMC now has the desired stable member inertial orientation. Next, the CMC computes the gimbal angles required for the present CSM orientation and the proposed stable member orientation. These angles are displayed via a flashing VERB 06 NOUN 22; R1, R2, and R3 display, respectively, the outer, inner, and middle gimbal angles to the nearest 0.01 deg. If this display represents a potential gimbal lock (middle gimbal angle greater than 85 deg), the crew can reorient the spacecraft with the rotational hand controller and recycle P52 to recompute the proposed gimbal angles, by keying VERB 32 ENTR. (P52 may also be terminated at this time.) A PRO response to the gimbal angles displayed produces a flashing VERB 50 NOUN 25, with R1 containing Checklist code 00013 (please perform coarse align).

At this point, the crew can perform a normal coarse alignment to the new orientation, followed by a pair of celestial body sightings to accurately determine the new alignment. Alternatively, the crew can pulse torque the gyros to the new orientation, with the ISS remaining in the fine align mode. The pulse torquing operation bypasses SXT sightings. (See paragraph 7.2.2.2.5.)

Keying ENTR causes the CMC to compute the torquing angles required for the gyros to be pulse torqued to the new orientation. The CMC then resets the REFSMMAT flag and starts torquing. During this operation, the computer monitors the changing gimbal angles and displays them under VERB 16 NOUN 20. When torquing is completed the computer stores the desired stable member orientation in REFSMMAT and sets the REFSMMAT flag. P52 then proceeds to VERB 50 NOUN 25, 00014 (please perform fine align check) of paragraph 7.2.2.3.8.

A PRO response to VERB 50 NOUN 25, 00013 (please perform coarse align) above, causes P52 to call the Coarse Align Routine, R50 (Figure 7.2.2-3). This routine again calculates the desired gimbal angles (since the spacecraft's attitude might be changing), and reads the present gimbal angles. If none of the gimbals need to be driven more than one deg, coarse alignment is bypassed and control is returned to P52. If normal coarse alignment is required, the ISS is now switched by R50 to the coarse align mode and the NO ATT light is illuminated. The stable member is then repositioned.

After normal coarse alignment, P52 takes the matrix representing the desired orientation, stores it as the present REFSMMAT, and sets the REFSMMAT flag. But REFSMMAT does not represent precisely the actual new stable member orientation, since the normal coarse alignment process has only a limited degree of accuracy. A pair of celestial body sightings are now needed to eliminate any small errors in alignment.

7.2.2.3.3. Celestial Body Acquisition.—Unless the stable member has been pulse torqued and R50 was not used, all program options have arrived at a common point and now display a flashing VERB 50 NOUN 25, with R1 containing 00015 (please perform celestial body acquisitions). The astronaut must decide whether to have the CMC pick a pair of stars for sightings or to find two targets himself.*

A PRO response to VERB 50 NOUN 25 instructs the CMC to find two stars from its stored catalog that are available to the optics at the present CSM attitude, and to select these stars for use by the Auto Optics Positioning Routine, R52. If two catalog stars are not available for sightings, P52 displays program alarm 00405. To respond to this alarm, the crew can manually maneuver the CSM and recycle to VERB 50 NOUN 25, by keying VERB 32 ENTR, or acquire a celestial body manually and key PRO. If the celestial body is acquired manually, its identification code must be supplied by the astronaut after P52 flashes VERB 01 NOUN 70, as discussed below.

After flashing VERB 50 NOUN 25, P52 flashes VERB 01 NOUN 70, with a celestial body code displayed in R1. The crew can now correct the contents of R1 by keying VERB 21 ENTR followed by the desired code. If the planet code (00000) has been loaded, a PRO response to VERB 01 NOUN 70 is followed by a flashing VERB 06 NOUN 88, with R1, R2, and R3 containing, respectively, the x-, y-, and z-components of the planet unit position vector in Basic Reference coordinates. The crew can change these values by keying in VERB 25 ENTR followed by the desired vector components.

If the target is a star or planet, P52 now has its Basic Reference System coordinates in storage. Otherwise, if the celestial body code selected above indicates the sun, earth, or moon, the CMC must now calculate the Basic Reference System vector needed by the Auto Optics Positioning Routine, R52, to bring the target into the SXT star line-of-sight.

7.2.2.3.4 Auto Optics Routine.—P52 calls R52 (Figure 7.2.2-4). R52 resets the TERMINATE flag to recognize that the Sighting Mark Routine (R53) has not yet taken a mark. (R52 later tests this flag to see whether marks have been taken.) R52 then reads the CSM attitude from the present gimbal angles, obtains the

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* The CMC searches for stars only; the crew can use stars or planets.

REFSMMAT and celestial body Basic Reference coordinates from storage, and computes the Navigation Base coordinates of the celestial body. Using these computed coordinates, R52 calculates the optics shaft and trunnion angles required to point the SXT star line-of-sight toward the target.

If the required trunnion angle is greater than 90 deg, R52 illuminates the PROG light and flashes VERB 05 NOUN 09 to accompany alarm code 00404 (target not within hemisphere of optics visibility). The crew can respond to this display by terminating P52 via VERB 34 ENTR, or by maneuvering the CSM until the target can be acquired and then recycling the optics pointing by keying PRO.

If the required trunnion angle is less than 90 deg but greater than 50 deg, no alarm is displayed. Instead, the trunnion will be driven to 50 deg in the direction of the line of sight desired, and the crew must maneuver the CSM to acquire the target.

For trunnion angles less than 90 deg, R52 displays VERB 06 NOUN 92, with R1 containing the desired shaft angle and R2 containing the desired trunnion angle. (This is an information display only; no crew response is required.) The shaft and trunnion CDUs are now driven to the angles displayed, and, when the crew places the Optics Mode switch in MAN, R52 calls the Sighting Mark Routine, R53.*

7.2.2.3.5 Sighting Mark Routine (R53).—The Sighting Mark Routine (Figure 7.2.2-5) first flashes VERB 51 (please mark on celestial body). The crew now centers the target on the SXT or SCT reticle and depresses the MARK button, instructing the CMC to record the time of mark, the gimbal angles, and the optics angles. The MARK REJECT button is used to reject the sighting and to try again. When the mark is taken, R53 flashes VERB 50 NOUN 25, with R1 containing 00016 (please terminate mark sequence by keying PRO). A PRO response indicates to the CMC that marking is terminated on this target.

R53 now flashes VERB 01 NOUN 71, with the celestial body code stored by the CMC displayed in R1. If the astronaut marked on a different target than the one designated by P52, he has to load the correct target identification code now, by keying VERB 21 ENTR and the code. If this code is 00000 and the crew keys PRO, R53 displays flashing VERB 06 NOUN 88 with the planet vector Basic Reference components in R1, R2, and R3. These components can be corrected via VERB 25

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* In R53, if the astronaut switches from MAN to CMC, the program remains in R53, but the optics is automatically pointed at the target.

ENTR or approved via a PRO. R53 now sets the TERMINATE flag and calls a routine which calculates and stores a target line-of-sight vector in stable member coordinates using the optics and gimbal mark data. R53 then returns control to R52. Since the TERMINATE flag has been set by R53, R52 returns control, in turn, to P52. (The Optics Mode switch should now be returned to CMC, to enable the computer to position the optics for the second celestial body to be marked.)

P52 now selects the second star of the pair it obtained for auto optics positioning and recycles to the flashing VERB 01 NOUN 70 above. The procedures of crew celestial body selection, auto optics positioning (R52), sighting mark, and celestial body vector calculation (R53) are repeated for the second target.

7.2.2.3.6 Sighting Data Display Routine (R54).—After two celestial bodies have been marked, P52 calls the Sighting Data Display Routine, R54 (Figure 7.2.2-6). This routine first calculates the observed angle between the two celestial body vectors as measured in stable member coordinates. It then calculates this angle using the CMC stored Basic Reference vectors for the targets selected, and finds the difference between these two angles. This difference between the stored and measured star angles is displayed in R1 via flashing VERB 06 NOUN 05.

If this angle difference is unacceptably large, the crew can key in VERB 32 ENTR. This will return control to P52, which will flash VERB 50 NOUN 25 00014 (please perform fine align check). The stable member will not be pulse torqued into alignment (Figure 7.2.2-1, sheet 4).

If the sighting data of VERB 06 NOUN 05 is satisfactory, the crew will instruct the CMC to torque the gyros by keying PRO. CMC control is then transferred to the Gyro Torquing Routine.

7.2.2.3.7 Gyro Torquing Routine (R55).—During this routine (Figure 7.2.2-7), the CMC reads the desired stable member orientation (now stored as REFSMMAT) and the actual stable member orientation (calculated from celestial body sights), and calculates the difference between the two. The computer then calculates the gyro torquing angles required to reduce this stable member alignment error to zero. The crew now sees a flashing VERB 06 NOUN 93, which is a display of the angles through which the stable member must be pulse torqued to complete the fine alignment to the orientation specified in REFSMMAT. The outer, inner, and middle gimbal-torquing angles are displayed in registers R1, R2, and R3, respectively.

If these angles are too large (possibly from a faulty sighting) or represent a potential gimbal lock, the crew may bypass gyro-torquing. A VERB 32 ENTR here will return control to P52, which will generate flashing VERB 50 NOUN 25, 00014, (please perform fine align check). The astronaut responds by terminating P52 (ENTR) or recycling P52 to the beginning of celestial body acquisition (PRO).

If the displayed torquing angles are satisfactory, a PRO response to the VERB 06 NOUN 93 data will instruct the CMC to torque the stable member into the correct orientation.

7.2.2.3.8 Third Star Check.—When torquing is accomplished, the PREFERRED flag is reset. Any succeeding programs that test the PREFERRED flag (such as succeeding P52's) will now be informed that a preferred attitude is not stored. P52 next flashes VERB 50 NOUN 25, with R1 containing Checklist code 00014 (please perform fine align check). The astronaut can now, if desired, test the accuracy of the stable member realignment by having the computer point the optics at a star.

Keying PRO returns P52 to flashing VERB 50 NOUN 25, Checklist code 00015 (please perform celestial body acquisition). Another PRO will command the CMC to search its catalog for a usable pair of stars, as before (paragraph 7.2.2.3.3) and to flash VERB 01 NOUN 70. A third PRO will cause a star to appear in the SXT. The astronaut might want to take marks now, if he has executed pulse torque coarse alignment. He should follow the marking and fine align pulse torquing procedures detailed above (starting with paragraph 7.2.2.3.4).

An ENTR response to "please perform fine align check" terminates P52. The IMU realignment is accomplished.

7.2.2.4 Program Alarms

Viewing a PROG alarm light on the DSKY, the crew keys VERB 05 NOUN 09 ENTR to produce a display of the alarm code—if the code has not already been displayed by the CMC. After the astronaut has taken corrective action, he should depress RSET to extinguish the PROG light and alarm and continue with the program selected. The alarm codes that the crew is likely to encounter in P52 are listed below and in Table 7.2.2.-I.

a. Alarm 00110 indicates that the crew depressed the MARK REJECT button unnecessarily; no marks were taken yet. The astronaut should key RSET to extinguish the OP ERR light and continue normal operation.

b. Alarm 00112 indicates MARK REJECT was pressed while the CMC was not requesting marks (not flashing VERB 51). Key RSET and continue normal operation.

c. Alarm 00114 indicates that more marks were made than desired. Key RSET and continue normal operation.

d. Alarm 00115 indicates VERB 41 NOUN 91 attempted to drive the optics while the Optics Mode switch was not in CMC. Set the Optics Mode switch to CMC, the Optics Zero switch to ZERO, and key RSET.

e. Alarm 00116 indicates the optics were switched to OFF from ZERO before the 15 sec optics zeroing time had elapsed. Set the Optics Zero switch to ZERO, key RSET, wait 15 sec and continue normal operation.

f. Alarm 00117 indicates Coarse Align OSS extended verb (VERB 41 NOUN 91) cannot be performed at this time. The CMC has reserved the OCDUs for other use. Key RSET and do not execute VERB 41 NOUN 91.

g. Alarm 00120 indicates optics not zeroed at the time of an optics torque request. Set Optics Zero switch to OFF, then to ZERO. Key RSET and wait 15 sec before continuing normal operation.

h. Alarm 00121 indicates a mark was made at the time of a CDU switching transient or vehicle rotation rate too high. Key RSET and repeat mark.

i. Alarm 00122 indicates a mark was made while the CMC was not in a mark routine (R53). Key RSET and continue normal operation.

j. Alarm 00206 indicates that zeroing the ICDUs by VERB 40 NOUN 20 was attempted by the astronaut but not allowed during gimbal lock. When the IMU is in coarse align mode with gimbal lock, zero CDU encoding can only be done by first commanding coarse alignment to zero as follows: key RSET; key VERB 41 NOUN 20 ENTR and load 00000 ENTR, 00000 ENTR, 00000 ENTR; then key VERB 40 NOUN 20 ENTR.

k. Alarm 00207 indicates ISS turn-on not present for 90 sec. Key RSET and reinitiate ISS turn-on sequence.

l. Alarm 00210 indicates IMU not operating. It should be turned on and the stable member orientation determined before entering P52.

m. Alarm 00211 indicates gimbal angles are not within two degrees of commanded position at time of coarse alignment. To determine magnitude of error, key VERB 06 NOUN 20 ENTR for display of gimbal angles. Continue the alignment and record the gyro torquing angles. Then do the fine align check (paragraph 7.2.2.3.8). If performing VERB 41 NOUN 20, terminate VERB 41 and align with an alignment program.

n. Alarm 00217 indicates ISS mode switching failure, possibly due to power failure during coarse or fine alignment. Key RSET and reinitiate current program. If alarm occurs, terminate use of ISS. This alarm usually accompanies alarm 00211 in R50.

o. Alarm 00220 indicates IMU not aligned. No REFSMMAT is stored. Key RSET and execute P51.

p. Alarm 00401 indicates desired angles yield gimbal lock. Key RSET and either select new gimbal angles or maneuver spacecraft to avoid gimbal lock.

q. Alarm 00404, displayed automatically by R52, indicates optics cannot acquire the target selected (required trunnion angle greater than 90 deg). Perform one of the following and key RSET: (a) manually maneuver spacecraft until optics can acquire target and key PRO; or (b) key VERB 34 ENTR to terminate auto optics positioning routine.

r. Alarm 00405, displayed automatically by P52, indicates the computer was not able to find two target stars at the present spacecraft attitude. Perform one of the following: (a) maneuver spacecraft until two targets can be manually acquired, then key PRO; or (b) maneuver spacecraft until two useable stars can be automatically acquired, then key VERB 32 ENTR. Alarm 00405 is displayed when the computer has tested all possible pairs of stars in its catalog and is not able to find a pair that meets the following criteria: (a) the stars are not occulted by the sun, earth, or moon; (b) they are separated by between 76 and 30 deg; and (c) the pair is within 38 deg of the SXT shaft axis at the present spacecraft orientation.

7.2.2.5 Program Coordination and Procedures

P52 can be completed in approximately five minutes, if the operator is experienced. Additional time (about 15 min) will almost certainly be needed for the astronaut to dark-adapt sufficiently to see stars through the optics. The following activities should be carried out before P52 is initiated:

a. The IMU must be on for about 15 min to allow the IRIGs to reach stable operating conditions.

b. The OSS should be turned on for about 30 min to allow the optics to thermally stabilize.

c. The stable member orientation must be determined by P51 or P53.

d. The DAP Data Load Routine (R03, paragraph 9.2.1) should be performed.

An important application of P52 is its relation to SPS burn guidance. To align the stable member for a burn, the Preferred option of P52 is called during the execution of P40. A typical program sequence would be as follows:

a. The astronaut keys in a prethrust program (one of the P30's). This determines the time of ignition and velocity change. Refer to paragraph 5.2.6.7.

b. The astronaut keys in P40, and sees a flashing VERB 50 NOUN 18 (please perform a maneuver to the displayed gimbal angles). This is P40's calculation of the preferred spacecraft attitude based on the prethrust program's calculation of the desired velocity change. P40 is terminated at this point. Refer to Figure 6.2.1-2.

c. The astronaut keys in P52, and sees the Preferred option displayed as the CMC's assumed option. P52 now treats the preferred spacecraft attitude as a desired stable member attitude, and realigns the stable member axes to be parallel to the desired orientation of the vehicle axes. If the stable member was already at the proper orientation for thrusting, the REFSMMAT option could be used to eliminate any uncompensated platform drift that may have occurred since the last alignment.

   During the gyro pulse torquing process, the DAP will manuever the spacecraft to follow the platform as its inertial orientation changes, when the CMC Mode Switch is in HOLD. However, this procedure will bring the spacecraft into the preferred attitude only if the gimbal angles are at (0,0,0). (P40 can also carry out an auto maneuver; see paragraph 6.2.1.3.)

d. The astronaut returns to the beginning of P40 and executes the entire program.

P52 is also used to realign the stable member into an orientation favorable for out-of-plane SPS or RCS burns. This can be accomplished by using the Preferred option to realign to an uplinked orientation (or one calculated by P40) or by changing the CMC stored landing site coordinates and realigning via the Landing Site option. The landing site coordinate change provides the advantages of speed and independence of communication with the ground, although it is less often used than the Preferred option plane change. The landing site technique is as follows:

a. Initiate P52 and load the Landing Site option (00004). Specify the present time as the time of alignment and load a new landing site latitude of +35.000 deg if ΔVy is positive or -35.000 if ΔVy is negative. The half-longitude and altitude can remain unchanged.

b. If the desired ICDU angles displayed by P52 appear satisfactory, set the CMC Mode switch to FREE and key ENTR to start gyro torquing. When torquing is completed, key ENTR to terminate P52.

c. Execute P30.

d. Execute P40.

e. After the burn, yaw back manually to zero degree on the FDAI.

f. Initiate the Landing Site option of P52. Verify that the proposed time of alignment and landing site coordinates are equal to the values prescribed for the actual landing site.

g. If the desired ICDU angles displayed by P52 appear satisfactory, set the CMC Mode switch to FREE and key ENTR to torque the stable member back into plane. When torquing is completed, key PRO to acquire stars for alignment check or key ENTR to terminate P52.

Some noteworthy procedures within P52 are discussed below.

In the event that the computer is unable to find a pair of stars for sightings (program alarm 00405), the astronaut can attempt to locate and identify a pair of targets by himself. (The CMC searches for stars only; the astronaut can use stars or planets.) The Optics Hand Controller, Minimum Impulse Controller, or Rotational Hand Controller can be used to hunt for new targets. If no targets can be found, the spacecraft is generally rolled to a new attitude. When a useful target has been found, the astronaut should key PRO; the computer will then request the target's identification code (flashing VERB 01 NOUN 70).

Alternatively, after alarm code 00405, the spacecraft can be rolled into a new attitude; a VERB 32 ENTR will then instruct the computer to again search for a pair of stars.

Figure 7.2.2-8 shows the size of the accessible star field for a given vehicle attitude, for the undocked CSM. When the LM and CSM are docked, there is a small chance that the computer will position the optics to a star which is occulted by the LM. The effect of the docked LM on the size of the SXT and SCT fields of coverage is shown in Figure 4.2.3-3. If LM occultation occurs, the astronaut can search for other targets, using the optics hand controller (unless the RCS fuel supply permits maneuvering the vehicle to uncover the target). He would then mark on the target

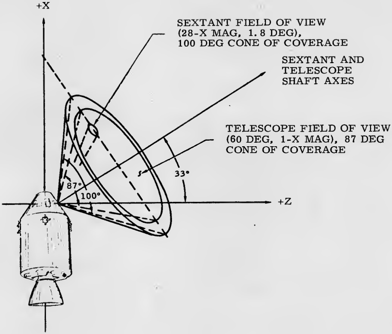


Figure 7.2.2-8. CM Optics Field of Coverage

of opportunity, and then reload the target identification code after the computer flashes VERB 01 NOUN 71.

As an example of the celestial bodies available for sightings at a particular time during the mission of APOLLO 12, Figure 7.2.2-9 illustrates the view through the SCT during revolution 10 of the CSM lunar parking orbit. The circle represents the SCT field of view at zero trunnion angle—here containing three stars useful for alignment measurements. The SCT cone of coverage is large enough to allow the astronaut to also view Dnoces, Regulus, and Alphecca, without changing the CSM attitude from that described in the figure.

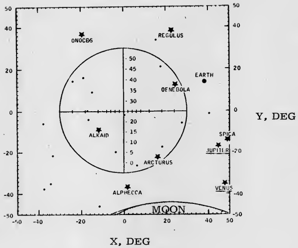
When the astronaut is sighting through the optics, stray light scattered from the SCT or SXT optical elements can interfere with the target. The SCT, because it has a wide field of view, is especially susceptible. The sun is the major source of unwanted light that eventually finds its way into the eyepiece; a general guideline is to keep the sun at least 60 deg from the SCT shaft axis, and at least 15 deg from the SXT lines-of-sight. The ablative cover which surrounds the optics can also be an occasional source of reflected sunlight that could obscure potential targets. With LM attached, accuracy is greatest when the shaft angle is between 100 deg and 270 deg, and the trunnion angle is less than 45 deg.

The optics CDU has an inherent limit on the SXT positioning accuracy (CDU bit size) of 40 arc-sec about the shaft axis and 10 arc-sec about the trunnion axis. The astronaut can position the SXT to greater accuracy than 40 arc-sec, however. The SCT has a star sighting accuracy of about 0.05 deg.

As discussed earlier, the Sighting Data Display Routine (R54) displays the difference between the actual and measured angles between the celestial bodies used in marking (Section 7.2.2.3.6). The crew must decide whether to accept (PRO) or reject (VERB 32 ENTR) the data. A star angle difference greater than 0.05 deg is considered unacceptable. In this case, the celestial body marking process should be repeated.

As an example of the expected size of the star angle differences, the APOLLO 12 R54 sighting data is as follows: three displays of 0.00 deg; eight displays of 0.01 deg; three displays of 0.02 deg; and one display of 0.03 deg.

During the pulse-torquing operations in R55, VERB 16 NOUN 93 (monitor all components of delta-gyro angles) has been used to monitor the remaining angle through which the stable member is to be torqued. In this display, the amount of gyro-torquing to be completed is displayed in a separate register for each gimbal



G. E. T. = 102:50:00

Landing Site REFSMMAT

IMU Gimbal Angles:

Inner = 330. 4 deg
Middle = 0. 0 deg
Outer = 239. 9 deg

Figure 7. 2. 2-9. View through Scanning Telescope during Revolution 10 of APOLLO 12 Lunar Parking Orbit

axis, with the registers initially scaled to read xx.xxx degrees. This scaling does not remain constant throughout torquing, however. As each gyro axis is torqued, the scaling of the delta-gyro angle is changed to be of use to the torquing program.

But NOUN 93 is displayed as if the scaling were unchanged. Approximately each 2.5 sec, the angle in the axis being torqued appears to have been decremented by 0.022 deg; actually, it has been decremented approximately 1.4 deg (approximately 0.55 deg/sec). Consequently, during pulse-torquing, NOUN 93 will initially display correct numbers in R1, R2, and R3. But after they start to decrease, they become more and more in error from the actual angles remaining to be torqued. The gyros are torqued in Y,Z,X order; the R2 number will diminish to a fractional degree number and then decrement to zero, while R1 and R3 remain unchanged. Then R3 undergoes the same change, and finally R1.

NOUN 20, which monitors the present gimbal angles, is suggested as a less misleading display during pulse torquing.

P52 can be used to carry out a gyro drift test. Drift can be determined from the gyro torquing angles. The test is most precise if the stable member is allowed to drift for several hours; attitude changes during the test do not affect the results. The procedure is as follows:

a. Perform P52.
b. During Gyro Torquing Routine R55, record the gyro-torquing angles (flashing VERB 06 NOUN 93) and the time, and command gyro-torquing (PRO).
c. After two hours, repeat steps a and b.
d. The second set of recorded torquing angles represents the torquing angles about the stable member axes required to correct the misalignment. The following equations relate drift to torquing angles: for the X and Y gyros,

   NOUN 93 = (-GD+LC) (0.015t); for the Z gyro,
   NOUN 93 = (+GD-LC) (0.015t).

NOUN 93 is the gyro torquing angle in deg, GD is the existing gyro drift about the gyro input axis before compensation in meru, LC is the loaded compensation in meru, t is the time in hours since the last realignment and 0.015 is the conversion factor between meru and deg/hour.

To set or clear (reset) the REFSMMAT flag, the following procedure is executed:

a. Key VERB 25 NOUN 07 ENTR. This prepares the computer to accept the REFSMMAT flag word address.

b. The CMC flashes VERB 21 NOUN 07 (please load flag word address into R1). The astronaut now keys 77 ENTR.

c. The CMC flashes VERB 22 NOUN 07 (please load code for flag bit to be changed). The astronaut keys 10 000 ENTR corresponding to bit 13 of flagword 3.

d. The CMC flashes VERB 23 NOUN 07 [please set or reset (clear) the flag bit to be changed]. To set the bit, the astronaut keys 1 ENTR; to clear the bit, he keys 0 ENTR.

To verify that the REFSMMAT flag is set or reset the astronaut should key VERB 01 NOUN 01 ENTR 77 ENTR. The CMC will then display VERB 01 NOUN 01, with R1 containing the flag word (ABCDE) and R3 containing the flag word address (77). Digit A in R1 will be odd if the REFSMMAT flag is set; if the REFSMMAT flag is reset, A will be even.

The automatic optics positioning capability of P52 is used to calibrate the Crew Optical Alignment Sight (COAS) by the following procedure:

a. Set the SC Cont switch to SCS, the Optics Mode Switch to CMC, and the Optics Zero switch to ZERO.

b. Key VERB 37 ENTR 52 ENTR, and when the CMC flashes VERB 04 NOUN 06 ("please select alignment option"), select the REFSMMAT alignment option.

c. When the CMC flashes VERB 50 NOUN 25 checklist code 00015 ("please perform celestial body acquisition"), key ENTR. This indicates to the computer that the astronaut will acquire a star himself.

d. The CMC will now flash VERB 01 NOUN 70. The astronaut must now load into DSKY register R1 the identification code for the star which he has chosen to center in the COAS reticle. The Optics Zero switch should now be turned off.

e. Key PRO. This instructs the computer to point the optics at the chosen star.

f. Key VERB 16 NOUN 92 (display new OCDU angles) and center the star in the COAS by maneuvering the spacecraft. When the star is centered, hit the VERB key to freeze the displayed OCDU angles. To again monitor the new OCDU angles for another mark, hit KEY RLSE. When marking is completed and shaft and trunnion angles recorded, set the Optics Zero switch to ZERO and select another program.

This procedure determines the shaft and trunnion angles which would be required to orient the SXT line of sight parallel to the COAS line of sight. When the backup alignment programs (P53 and P54) are used, the astronaut must supply these angles to the computer.

7.2.2.6 Restarts

P52 is restart protected. Should a hardware restart occur, the program will, in general, return to the flashing display preceding the point of restart. If a restart occurs during pulse torquing, the stable member will be left at an unknown orientation, and the REFSMMAT flag will be left reset. It will then be necessary to execute P51 to redetermine the stable member inertial orientation.

7.2.2.7 Extended Verbs

The extended verbs discussed here are not automatically called by P52, nor are they initiated by the CSM crew as a part of the IMU Realign Program. They are separate, individual routines, designed to accomplish relatively simple tasks, i.e., to control the alignment of the stable member and optics. Table 7.2.2-II lists the extended verbs' DSKY activity.

The coarse align ISS extended verb (VERB 41 NOUN 20) is used to coarse align the gimbal angles to values specified by the astronaut (Figure 7.2.2-10). This verb is not called by P52 but can be used to align the gimbals to zero (or any other value) when the ISS is in the coarse align mode with a gimbal lock. The astronaut calls VERB 41 NOUN 20, loads the angles desired, and the computer coarse aligns the stable member. The specified gimbal angles may be displayed by keying VERB 16 NOUN 22 ENTR; the current gimbal angles may be monitored by keying VERB 16 NOUN 20 ENTR. The NO ATT light remains illuminated after VERB 41 NOUN 20 is completed. This extended verb should never be used during a process which requires the stable member to be at a constant inertial orientation, because inertial reference is not maintained during coarse alignment or after VERB 41 NOUN 20 is completed.

The coarse align OSS extended verb (VERB 41 NOUN 91) is used to drive the optics to a position selected by the operator (Figure 7.2.2-11). The OSS must be on and in the CMC mode. The astronaut loads the desired shaft and trunnion angles, and the optics are driven to the position specified by the values loaded.

The fine align extended verb (VERB 42) (Figure 7.2.2-12) is used to fine-align the stable member and to switch from coarse align to fine align mode after the coarse align extended verb is used. The operator, after observing a flashing VERB 21 NOUN 93, loads the angles through which the gyros are to be torqued. In flight, all angles must be less than 100 deg.

Note that the coarse and fine align ISS extended verbs provide neither a means of determining the stable member's inertial orientation, nor a means of alignment to one of P52's options.

TABLE 7.2.2-II

EXTENDED VERBS ASSOCIATED WITH CSM IMU AND OPTICS REALIGNMENT

VERB	Identification	Purpose	Remarks
V41 N20	Coarse align ISS extended verb	Coarse align stable member to gimbal angles specified by astronaut	Astronaut keys in V41 N20 ENTR to initiate coarse alignment. CMC then flashes V21 N22 requesting astronaut to load gimbal angles desired. Astronaut loads outer, inner, and middle gimbal angles in DSKY registers R1, R2, and R3, respectively. CMC then displays V41 while stable member is reoriented. The NO ATT light remains illuminated during coarse alignment and after the coarse align ISS extended verb has terminated.
V42	Fine align ISS extended verb	Pulse torque stable member through angles indicated by astronaut	Astronaut keys in V42 ENTR. CMC then flashes V21 N93 requesting astronaut to load delta gyro angles. Astronaut then loads outer, inner, and middle gimbal delta gyro angles into registers R1, R2, and R3, respectively. CMC then displays V42 while pulse torquing is in progress, and the NO ATT light is extinguished.
V41 N91	Coarse align OSS extended verb	Align optics shaft and trunnion to angles specified by astronaut.	Astronaut keys in V41 N91 ENTR. CMC then flashes V21 N92 requesting astronaut to load the desired shaft and trunnion angles into registers R1 and R2, respectively. Astronaut then loads shaft and trunnion angles or keys VERB 33 ENTR to bypass loading. While the optics are being driven, the CMC displays V41.

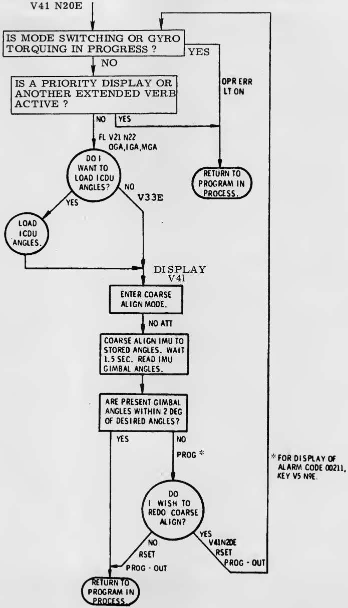


Figure 7. 2. 2-10. Coarse Align ISS (Extended Verb V41 N20)

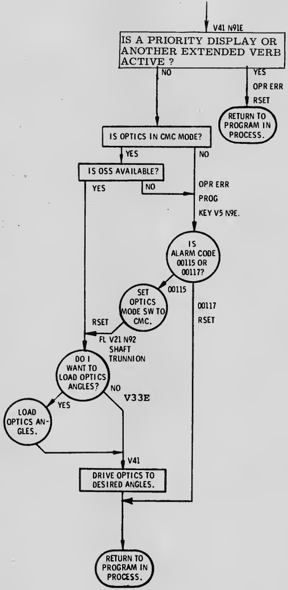


Figure 7. 2. 2-11. Coarse Align OSS (Extended Verb V41 N91)

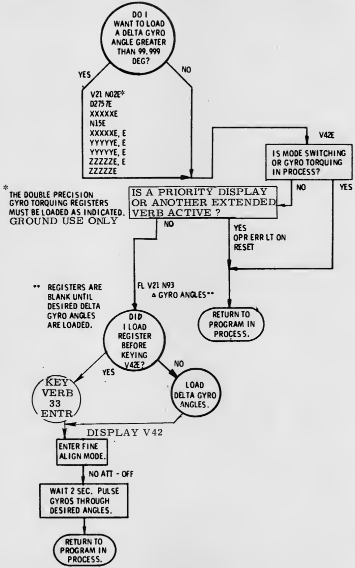


Figure 7. 2. 2-12. Fine Align ISS (Extended Verb V42)

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7.2.3 P53, Backup IMU Orientation Determination—CMC

(TBF)

BLANK

7.2.4 P54, Backup IMU Realign—CMC

(TBF)

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SUBSECTION 7.3

LGC ALIGNMENT PROGRAMS

B L A N K

7.3.1 P51, IMU Orientation Determination Program—LGC

The IMU Orientation Determination Program (P51) is used during free fall to determine the present IMU stable member orientation with respect to the Basic Reference Coordinate System and the associated REFSMMAT. This is accomplished by sighting on two navigation stars, or known celestial bodies, with the Alignment Optical Telescope (AOT) or the Crew Optical Alignment Sight (COAS). Determining the stable member orientation with respect to the Basic Reference Coordinate System requires the transformation matrix REFSMMAT.

$$\text{REFSMMAT} = \begin{bmatrix} \underline{u}_{XSM}^{T} \\ \underline{u}_{YSM}^{T} \\ \underline{u}_{ZSM}^{T} \end{bmatrix}$$

where $\underline{u}_{XSM}$, $\underline{u}_{YSM}$, and $\underline{u}_{ZSM}$ define the orientations of the stable member axes with respect to the Basic Reference Coordinate System.

The crew acquire the desired celestial bodies by maneuvering the LM until the bodies are visible in the optical sighting devices. The crew identify the two celestial bodies and takes up to five pair (X and Y) of marks on each. After the optical sightings have been made on both celestial bodies, the LM Guidance Computer (LGC) has the unit line of sight (LOS) vectors for the two bodies, in IMU stable member coordinates. These vectors are compared with the stored vectors in the Basic Reference Coordinate System, and the angle difference is displayed to the crew to either accept or reject and repeat the sightings.

In addition to IMU orientation determination information, the outputs of P51 also include the following:

a. Optical azimuth and elevation angles
b. Difference angle between the actual and measured lines of sight.

The displays during the IMU orientation determination program are listed in Table 7.3.1-I.

7.3.1.1 Related Routines

P51 has the following four related routines:

TABLE 7.3.1-I

PROGRAM DISPLAYS (P51)(SHEET 1 of 2)

DSKY	Initiated by	Purpose	Condition	Register(s)
FL V01 N71	R53	Display AOT detent code/star code	AOT detent and star code A, B = 0 C = Detent 1 = Left 2 = Center 3 = Right 4 = Right rear 5 = Center rear 6 = Left rear 7 = Back-up optical D, E, star code 00 planet, 01/45 star, 46, 47, 50, sun, earth, moon respectively	R1 ABCDE R2 Blank R3 Blank
FL V06 N87	R53	Display back-up optical system LOS definition	OPT AZ OPT EL	R1 xxx.xx deg R2 xxx.xx deg R3 Blank
FL V54 N71 FL Vxx N71	R53	Request Mark X or Y recticle line/star intersection	MARK X and/or Y recticle/star intersection (Same as N71 above)	R1 ABCDE R2 Blank R3 Blank

TABLE 7.3.1-I

PROGRAM DISPLAYS (P51) (SHEET 2 of 2)

DSKY	Initiated by	Purpose	Condition	Register(s)
FL V06 N88	R58	Display assumed planet position	XPL (1/2 unit YPL (Position Vector) ZPL (Components)	R1 .xxxxx R2 .xxxxx R3 .xxxxx
FL V06 N05	R54	Display sighting angle difference	Difference between the measured and actual sighting angle	R1 xxx.xx deg R2 Blank R3 Blank
V41 N22	P51	Coarse align verb and ICDU gimbal angles noun	OG IG MG	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
FL V50 N25	P51	Request please perform celestial body acquisition	OPT code 00015 = celestial body acquisition	R1 00015 R2 Blank R3 Blank

a. AOT Mark Routine (R53)
b. Sighting Data Display Routine (R54)
c. Markrupt Routine (R57)
d. Celestial Body Definition Routine (R58).

The AOT Mark Routine (R53) is called automatically by P51 and is used to request and process sighting marks (using the AOT or COAS) on the celestial bodies determined by the crew. R53, by requesting the mark (i.e., the depressing of the MARK X, MARK Y, or MARK REJECT pushbutton), calls the Markrupt Routine (R57) to accept and process the crew inputs associated with the orientation determination process. This routine is automatically called when either of the three above-mentioned pushbuttons is depressed. With the processed information from R53 and R57, the Celestial Body Definition Routine (R58) establishes the planet position vectors to be used for the IMU orientation. The Sighting Data Display Routine (R54) then calculates the difference between the actual and measured sighting angles and displays this information to the crew. The crew then decide whether or not to continue with the orientation determination or to take new sightings and start the process again.

7.3.1.2 Options

To complete P51 the crew have the option of using either the AOT or the COAS in determining the IMU orientation. The operation of the COAS within the program is described in paragraph 7.3.1.3.

7.3.1.3 Logical Flow Description

The crew enter the IMU Orientation Determination Program by keying VERB 37 ENTR 51 ENTR into the DSKY. (See Figure 7.3.1-1.) They should immediately ensure that the AOT lamp circuit breaker is closed so that the reticle is properly illuminated. The program immediately checks to determine whether the inertial subsystem (ISS) is on. If the ISS is not on, the PROG alarm light comes on and the LGC exits P51. (See paragraph 7.3.1.4, alarm code 00210.) In order to reenter P51, the program has to be reinitiated as described above. If the ISS is on, the DSKY displays a flashing VERB 50 NOUN 25, requesting a "please perform celestial body acquisition"– indicated by 00015 in R1. (See Table 7.3.1-I.)

At this point, the crew must decide whether they will maneuver the LM such that the inner-gimbal axis is in the preferred direction (X_{SM} axis in the thrust direction) or such that there are two celestial bodies visible in the optical system (AOT or

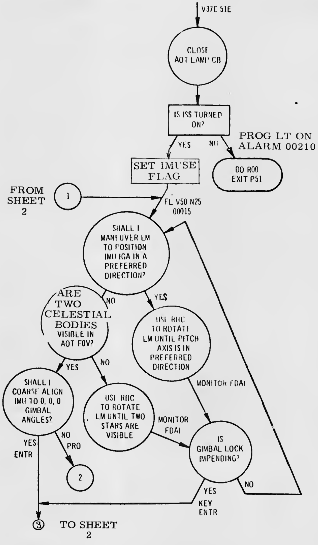


Figure 7.3.1-1. IMU Orientation Determination Program (P51) (LGC) (Sheet 1 of 2)

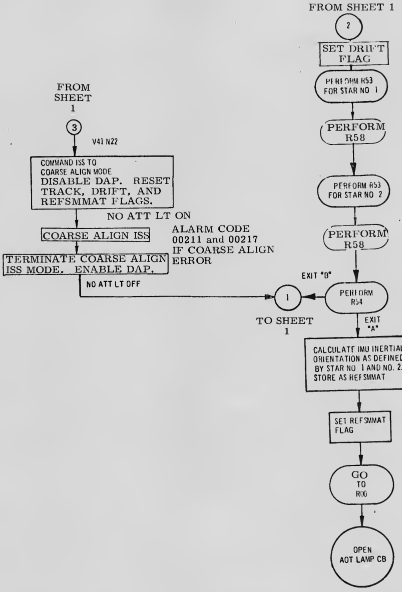


Figure 7. 3. 1-1. IMU Orientation Determination Program (P51) (LGC) (Sheet 2 of 2)

COAS) field of view. In either case, they must be sure to monitor the FDAI ball as they maneuver the LM to ensure that gimbal lock is not impending. Gimbal lock occurs when the middle gimbal angle exceeds ±85 degrees from its zero position. The gimbal lock warning light, however, is illuminated when the angle exceeds 70 degrees from zero. If 85 degrees is exceeded, the LGC automatically commands a coarse align to prevent gimbal oscillation. If gimbal lock is impending, or if the crew desire, they can coarse-align the IMU to 0, 0, 0, gimbal angles. If gimbal lock is not impending or the crew do not desire to coarse align the IMU, they can key in PRO and the program will go directly to the AOT Mark Routine (R53). If the crew desire to coarse-align, the astronaut can key in ENTR and immediately obtain VERB 41 NOUN 22 display. (See Table 7.3.1-I.) This display shows the ICDU/gimbal angles to which the IMU should be aligned. The angles should be all zeros. The crew will also see the NO ATT light come on, indicating that the IMU is in the Coarse Align Mode. If, upon completion of coarse-align, the gimbals are not within ±2 degrees of the desired 0 degree, the PROG alarm light will come on (see paragraph 7.3.1.4, alarm codes 00211 and 00217) and the NO ATT light will go off. Should either of these alarms come up, the IMU would have to be coarse-aligned again. When the IMU is within ±2 degrees of the desired 0 degree, the crew should key in PRO on the flashing VERB 50 NOUN 25 display. This will allow the program to go to the AOT Mark Routine (R53). (See Figure 7.3.1-2.)

The AOT Mark Routine (R53) processes the sighting marks on the celestial bodies. Upon initial entry into R53, several checks are made by the LGC to determine if it is possible to use the routine at this time. (See paragraph 7.3.1.4, alarm codes 20105, 31211, and 31207.) The first display the crew see in this routine is a flashing VERB 01 NOUN 71, indicating the AOT detent and star code. (See Table 7.3.1-I.) If these codes are correct for the present sightings, the crew should key in PRO. If these codes are not correct for the present sightings, the crew should key in VERB 21 ENTR, load the correct codes, and then key in PRO. For the present, assume that the detent code is other than a zero or seven. A zero code is invalid in R53, and a seven code indicates that the crew should use the backup (COAS) system. The use of the COAS is described later.

On the PRO, the next display the crew see is a flashing VERB 54 NOUN 71, requesting a "please perform a mark X or mark Y reticle line/star intersection." Before putting up this display, the computer picks up azimuth and elevation calibrations and apparent rotation compensation for the specified detent position, and computes the X and Y mark-plane vectors and the optical-axis vector. LGC also zeros the mark identifier and mark counter. The mark identifier is a special internal register that identifies whether the mark is X or Y. The counter is a special register to

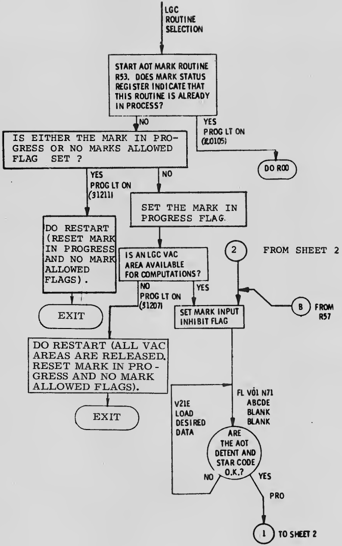


Figure 7. 3. 1-2. AOT Mark Routine (R53) (Sheet 1 of 3)

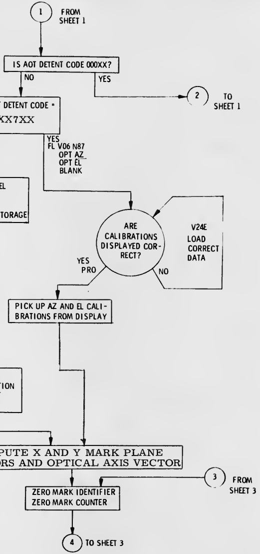


Figure 7.3.1-2. AOT Mark Routine (R53) (Sheet 2 of 3)

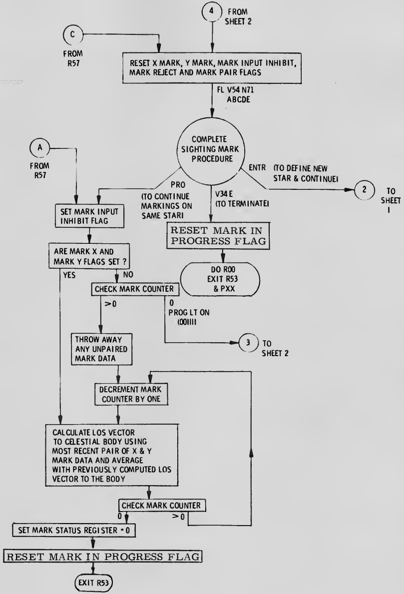


Figure 7. 3. 1-2. AOT Mark Routine (R53) (Sheet 3 of 3)

count the mark pairs. While in free fall, marks are taken in pairs by depressing the MARK X, then the MARK Y (or vice-versa) pushbuttons. Before taking any marks, the crew must adjust the AOT reticle to zero. A mark is then made by (1) maneuvering the LM such that the target body crosses the X or Y reticle line, and (2) depressing the appropriate mark pushbutton. The sequence of these marks, as stated before, can be X then Y, or Y then X. By depressing the MARX X, MARX Y, or MARK REJECT pushbutton, the crew call the Markrupt Routine (R57) and a flashing VERB xx NOUN 71 display comes up. (See Figure 7.3.1-3.) The xx could be 54, 53, or 52, depending on whether a pair of marks is required, a Y mark is required, or an X mark is required, respectively, before the program returns to R53. For instance, if the method of entering R57 was by depressing the MARK X pushbutton, then most likely the display that comes up will be VERB 53 NOUN 71, indicating that a mark on the Y reticle line is required. If entry was by depressing the MARK REJECT button following either an X or Y mark, the chances are that the display would be VERB 54 NOUN 71, indicating that both an X and Y mark are required. If entry was via the MARK REJECT pushbutton and no marks are there to reject, then the PROG alarm light will come on. (See paragraph 7.3.1.4, alarm code 00115.) If the crew wish to erase all the marks taken and start over, they key ENTR on the VERB xx NOUN 71 display. Keying in PRO on this display allows the LGC to calculate the LOS vector to the celestial body, starting with the most recent pair of X and Y mark data and averaging them with the previously computed LOS vector to the body.

After each pair of marks, the crew have the following options: (1) to terminate the marking by keying in PRO; (2) to continue marking on the same celestial body (if less than five pairs are already stored in the LGC) by using the appropriate mark buttons; (3) to discard all data on the present celestial body by keying in ENTR, select a new celestial body and continue marking on the new body; or (4) to terminate the whole alignment by keying in VERB 34 ENTR (terminate).

This marking procedure must be accomplished on two celestial bodies. Their LOS vectors are then computed in stable member coordinates. The measured angle between these vectors is compared, using the Sighting Data Display Routine (R54) (Figure 7.3.1-4), with the actual vector angle obtained either from the LGC star catalog, loaded by the crew, or computed from ephemeris data. Ephemeris data are computed using the Celestial Body Definition Routine (R58) (Figure 7.3.1-5). The comparison is between the actual or stored ephemeris data and the vectors derived from the mark data. Note that R58 is called after taking up to five pair of marks on each celestial body. R54 is called following R58 for the second celestial body.

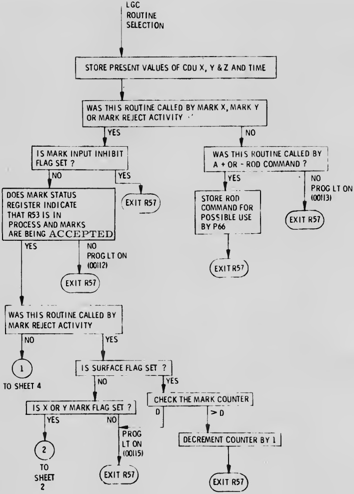


Figure 7.3.1-3. Markrupt Routine (R57) (Sheet 1 of 4)

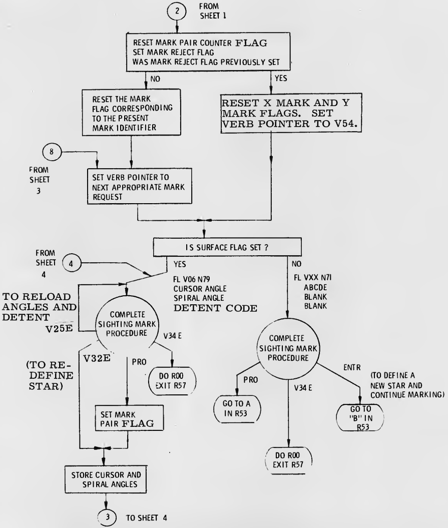


Figure 7.3.1-3. Markrupt Routine (R57) (Sheet 2 of 4)

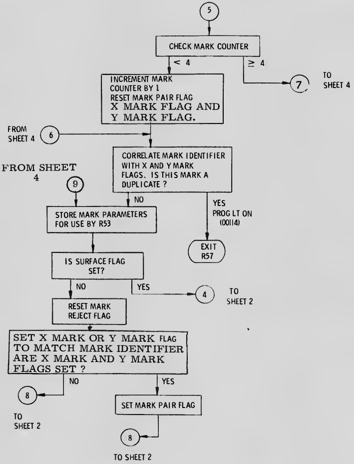


Figure 7.3.1-3. Markrupt Routine (R57) (Sheet 3 of 4)

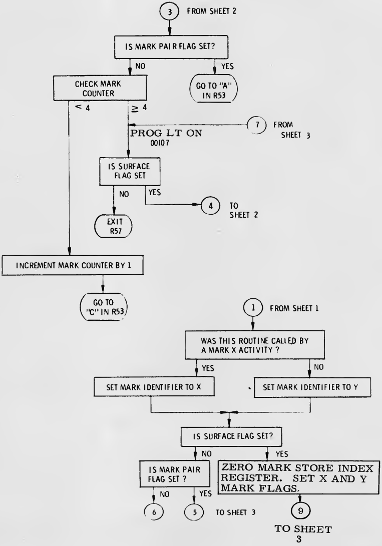


Figure 7.3.1-3. Markrupt Routine (R57) (Sheet 4 of 4)

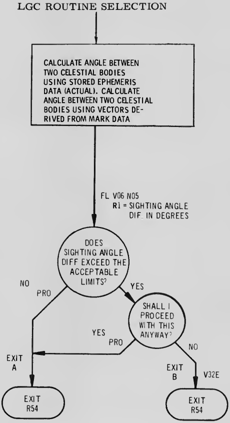


Figure 7. 3. 1-4. Sighting Data Display Routine (R54)

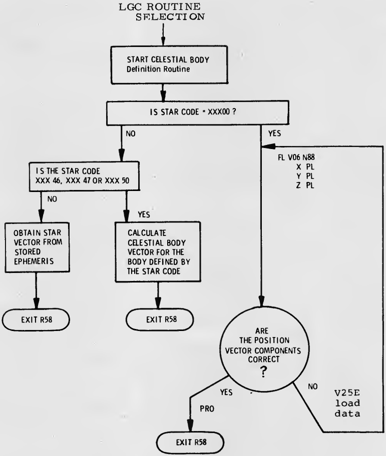


Figure 7.3.1-5. Celestial Body Definition Routine (R58)

The difference angle obtained in R54 is displayed to the crew by a flashing VERB 06 NOUN 05. If the angle is within acceptable limits (less than 0.05 degree), the crew key in PRO and the computer calculates the IMU inertial orientation with respect to the celestial body coordinates, as defined by the two celestial bodies, and stores these data as the present platform orientation (REFSMMAT) for use in future alignments. If the angle is not within the above specified limit, the crew can key in VERB 32 ENTR (recycle), and return to the flashing VERB 50 NOUN 25 display at the start of P51 (see Table 7.3.1-I), select a celestial body, and start the orientation determination procedure over again.

Recall that, when the program entered R53, the first display (VERB 01 NOUN 71) specified the AOT detent position code and the star code. If the detent position code was 007xx, it would indicate that the COAS would be used for the IMU orientation determination and a flashing VERB 06 NOUN 87 (see Table 7.3.1-I) calling for the optics azimuth and elevation would come up. If the OPT AZ and OPT EL displays that come up in R1 and R2, respectively, are not correct for the optical device being used, the crew can key in VERB 24 ENTR and load the correct azimuth and elevation data.

The computer then computes the X and Y mark plane vectors and the optical axis vector and continues with the orientation determination as with the AOT.

7.3.1.4 Program Alarms

In addition to the anticipated outputs, the program displays a PROG alarm light and stores an alarm code for display at crew discretion. Keying in VERB 05 NOUN 09 allows the program to display an alarm in R1, R2, and R3 (R1 displays the first alarm to occur after the last RSET, R2 the second, and R3 the last). Keying in RSET turns off the alarm light on the DSKY as long as the alarm condition itself has been corrected. Upon correcting the alarm conditions and keying in RSET, keying in KEY REL allows the program to pick up from where it was interrupted. The alarm codes are as follows:

a. Alarm code 00210 is displayed if the IMU is not operating when P51 is entered.

b. Alarm codes 00211 and 00217 are displayed if, at the end of a coarse alignment, the gimbals are not within 2 degrees of the desired value.

c. Alarm code 20105 is displayed if, when the crew desires to start processing marks, the mark register indicates that the AOT mark system is in use.

d. Alarm code 31211 is displayed when there is an illegal interrupt of an extended verb.

e. Alarm code 31207 is displayed if no vector accumulator (VAC) areas are available for the computation and processing of marks.

f. Alarm code 00111 is displayed if, on a PRO from a NOUN 71 display, a complete pair of marks is not stored in the LGC.

g. Alarm code 00107 is displayed if more than five mark pairs have been taken on a single celestial body.

h. Alarm code 00112 is displayed if a mark or a mark reject is not being accepted.

i. Alarm code 00113 is displayed if no in bits are available in channel 16 due to either a hardware or a software failure.

j. Alarm code 00114 is displayed if a duplicate mark has been made within a mark pair (X after an X, or Y after a Y).

k. Alarm code 00115 is displayed if a mark reject has been attempted with no marks to reject.

The inertial subsystem (ISS) must be on, and may be either at a known or unknown orientation in order to perform the IMU Orientation Determination Program (P51). If the ISS is not on, alarm 00210 alerts the crew to turn on the IMU and, following a 15-minute warmup of the ISS, reselect P51 by keying in VERB 37 ENTR 51 ENTR.

Upon completion of a coarse-align, if the gimbals are not within 2 degrees of the desired values, alarms 00211 and 00217 alert the crew that a realignment should be made.

Although unlikely to occur in practice, if the alignment optical telescope marking system is in use and the crew desire to start processing additional marks, there is a good possibility that the PROG alarm light will go on, indicating that it is impossible at this time to process additional marks. Alarm code 20105 is displayed by keying in VERB 05 NOUN 09. If this alarm does occur, the program automatically goes to R00 and the whole marking process has to be reinitiated via the calling program. The alarm code displayed could also be 31207, indicating that no VAC areas were available for storing parameters for computations of mark information because the areas were used by previous computations. If this alarm occurs, the computer does an automatic restart, releasing all the VAC areas, and recycles to the beginning of the AOT Mark Routine (R53).

Register 1 of the NOUN 71 display indicates the AOT detent and star codes. Marks on the indicated star are made in pairs by depressing the MARK X and the MARK

Y pushbuttons. If, for any reason, there is not a complete pair of marks (X and Y) when PRO is keyed in on NOUN 71, the PROG alarm light will come on. Keying in VERB 05 NOUN 09 allows alarm code 00111 to come up.

The above situation may be remedied by taking another pair of marks (X and Y) or by depressing the MARK REJECT pushbutton and taking additional marks, and then keying in PRO. After each mark, the crew can terminate marking by keying in PRO; continue marking on the same celestial body (if less than five pairs of marks are already stored in the LGC); discard all data, select a new celestial body and continue marking by keying ENTR; or terminate the whole alignment by keying in VERB 34 ENTR (terminate).

The mark counter in the LGC keeps track of the number of mark pairs taken on a particular celestial body. If the number of mark pairs registered by the counter exceeds five, the PROG alarm light comes on. The crew, by keying in VERB 05 NOUN 09, may determine that the alarm code is 00107, indicating that more than five marks have been taken on that particular celestial body.

When either the MARK X, MARK Y, or REJECT pushbuttons on the alignment optical telescope has been depressed and R53 has selected the Markrupt Routine (R57), four alarms could occur. The first, alarm code 00113, occurs when there are no in bits in channel 16, although R57 was called. This could be either a hardware or software failure, and backup procedures are required to remedy the situation. The next alarm the crew might encounter is alarm code 00112. This alarm may occur when no more marks are being accepted. (The mark status register in the LGC indicates that R53 is not accepting any marks at this time due to processing previous mark data.) The third alarm, alarm code 00114, may occur if the crew make either two consecutive X marks or two consecutive Y marks within the same required mark pair. Should this alarm occur, the crew should monitor the DSKY mark request and make the proper mark. The fourth alarm, alarm code 00115, is a mark reject when there are no marks to reject. In this case also, the DSKY should be monitored and the proper action taken. All four of these alarms return the program to the point where R53 called R57.

7.3.1.5 Restrictions and Limitations

The only real restriction in P51 is in the area of proper selection of celestial bodies. For more accurate results in determining the IMU orientation, celestial bodies should be chosen that are at an angle greater than 50 degrees from each other.

7.3.1.6 Program Coordination and Procedures

There is really no best time to perform P51. It is strictly an orientation determination program and is used in cases where it is necessary to calculate a new REFSMMAT. The time to be allowed for the performance of P51, however, depends on two conditions: (1) if the ISS is off and (2) how adept the crew is in sighting and marking on celestial bodies. The first condition requires a warmup period of 15 minutes; the second is variable, depending on the crew. All programs that require REFSMMAT in their computational sequence might first require the performance of P51.

7.3.1.7 Restarts

P51 is restart-protected. Should a restart occur, the program returns to one of several predetermined points depending on where in the program the restart occurs. The program then continues to completion.

BLANK

7.3.2 P52, IMU Realignment—LGC

The LGC IMU Realignment Program performs the same functions of stable member realignment and celestial body sighting calculation as the CMC IMU Realignment Program. (Refer to paragraph 7.2.2 for a description of CMC P52.) Any reference to the CSM and CMC can be applied to the LM and LGC. Where they exist, differences between the CSM and the LM IMU Realignment Programs arise chiefly from the different optical systems used for star sightings.

The LM crew takes sightings through either the Alignment Optical Telescope (AOT) (a unity-power, 60-deg field-of-view instrument) or the Crew Optical Alignment Sight (COAS) (a backup sighting device). The AOT can be rotated to any one of six fixed viewing positions (detents). Refer to Figure 7.3.2-1. The orientation of each detent relative to the LM body axes is stored in the LGC. Since there are only six discrete AOT viewing positions, a LM attitude maneuver will be necessary if a celestial body is to be centered for marking in one of the optics fields-of-view. For this reason, the LM IMU Realignment Program includes an attitude maneuver subroutine that is automatically entered during the execution of P52 (paragraph 7.3.2.3.6). When the LM is on the lunar surface, IMU orientation determination and realignment are performed by P57, the Lunar Surface Alignment Program.

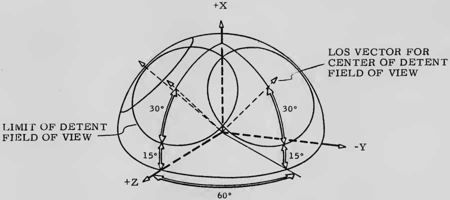
7.3.2.1 IMU Realignment Program Options

The alignment options for the LM P52 are the same as for the CSM P52, paragraph 7.2.2.2. References to the CSM and CMC should, of course, be applied to the LM and LGC. The thrust programs that calculate a preferred orientation relevant to LM alignment are P40, P41, and P42 (the DPS, RCS, and APS thrust programs, paragraphs 6.3.1, 6.3.2, and 6.3.3). (Refer to paragraph 7.2.2.2.1, Preferred Alignment.) In the LM, AOT sightings replace the SXT sightings discussed in paragraph 7.2.2.2.5. The technique of docked LM alignment is discussed in paragraph 7.3.2.5, Program Coordination and Procedures.

7.3.2.2 Related Routines

The ten routines listed below are related to the LM IMU Realignment Program. Three of these are called directly by P52; the rest are called by other routines.

a. IMU Status Check Routine (R02)
b. Coarse Align Routine (R50)
c. Inflight Fine Align Routine (R51)



RIGHT, FORWARD, AND LEFT DETENT GEOMETRY

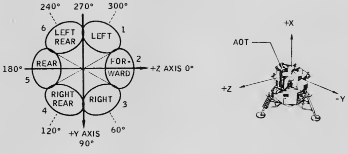


Figure 7.3.2-1. AOT Detent Geometry

d. Auto Optics Positioning Routine (R52)
e. AOT Mark Routine (R53)
f. Sighting Data Display Routine (R54)
g. Gyro Torquing Routine (R55)
h. Markrupt Routine (R57)
i. Celestial Body Definition Routine (R58)
j. Attitude Maneuver Routine (R60)

The first routine called by P52 is the IMU Status Check Routine (R02) which informs the crew if the IMU power is off or if there is no valid REFSMMAT in the LGC. The Coarse Align Routine (R50), also called by P52, calculates the present LM inertial orientation and the gimbal angle changes required to move the stable member into its desired inertial orientation. R50 then positions the stable member to within about 1 deg of the desired orientation.

Next, P52 calls the Inflight Fine Align Routine (R51), which assists the astronaut in selecting two stars suitable for AOT sightings and, in turn, calls several other routines that perform the following:

a. Auto optics positioning (R52)
b. Calculation of observed line-of-sight vectors to a celestial body using AOT mark data (R53 and R57)
c. Retrieval of the corresponding celestial body vector from storage (R58)
d. Display of the difference between stored and measured celestial body angles (R54)
e. Torquing of the gyros into fine alignment with the desired inertial orientation (R55).

Once the stable member has been realigned, R51 offers the astronaut the opportunity to select two more stars and try the marking sequence again. P52 is completed when R51 is completed.

7.3.2.3 LM P52 Flow Description

The following paragraphs discuss the calculation and DSKY activities that occur during P52 (Figure 7.3.2-2); Table 7.3.2-I lists the displays.

7.3.2.3.1 Program Initiation.—The LM crew initiates P52 by keying VERB 37 ENTR 52 ENTR on the DSKY. P52 then calls the IMU Status Check Routine (R02) (Figure 7.3.2-3). R02 tests the REFSMMAT flag; if the flag is set, there is a valid REFSMMAT in storage and R02 returns control to P52. If the REFSMMAT flag is reset (cleared),

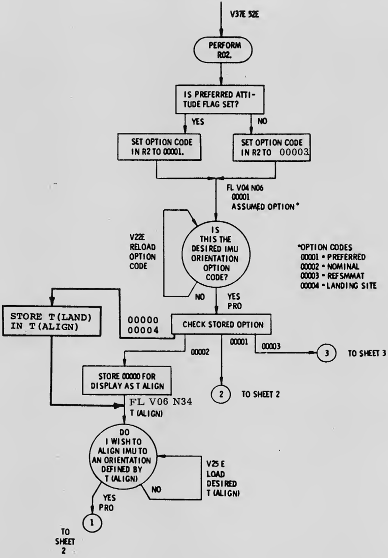


Figure 7.3.2-2. IMU Realignment Program (P52) (Sheet 1 of 3)

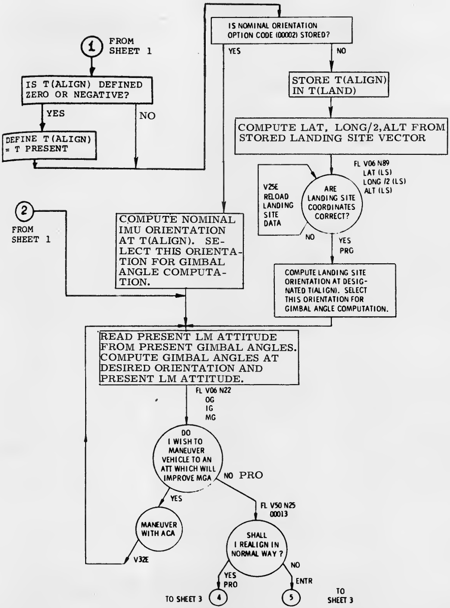


Figure 7.3.2-2. IMU Realignment Program (P52) (Sheet 2 of 3)

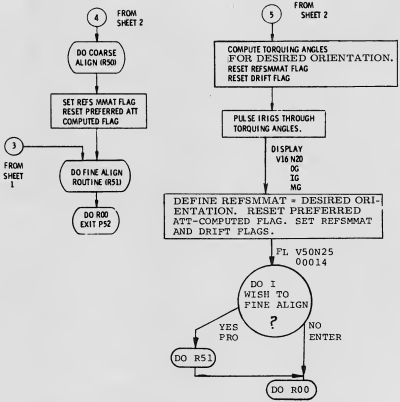


Figure 7.3.2-2. IMU Realignment Program (P52) (Sheet 3 of 3)

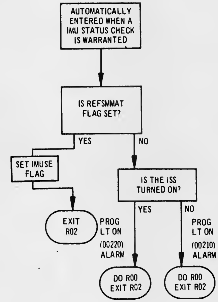


Figure 7.3.2-3. IMU Status Check Routine (R02)

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (P52) (SHEET 1 OF 8)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
1	V37 ENTR 52 ENTR	Astronaut	Initiate P52	---	---	---
2	FL V04 N06	P52	Request response to display of alignment option code.	IMU--orientation known R1-- please specify IMU orientation option R2-- option assumed by LGC 00001 = Preferred 00002 = Nominal 00003 = REFSMMAT 00004 = Landing site	R1 00001 check-list R2 oooox R3 Blank	Load desired option. Preferred-PRO to 5 Nominal-PRO to 3 REFSMMAT-PRO to 8 Landing site-PRO to 3
3	FL V06 N34	P52	Request response to display of time of alignment	Nominal or landing site options R1, R2, R3--time of alignment in GET; all zeros indicates present time	R1 xxxxx. hr R2 xxxxx. min R3 xxx.xx sec	Load desired time. Nominal-PRO to 5 Landing site-PRO to 4
4	FL V06 N89	P52	Request response to display of landing site coordinates	Landing site option R1--latitude (+ North) R2--longitude/2 (+ East) R3--landing site altitude	R1 xx.xxx deg R2 xx.xxx deg R3 xxx.xx n.mi.	Load desired coordinates. PRO to 5.

TABLE 7. 3. 2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (P52) (SHEET 2 OF 8)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
5	FL V06 N22	P52	Request response to display gimbal angles after proposed coarse alignment at present spacecraft attitude	All options except REFSMMAT R1-- outer gimbal R2-- inner gimbal R3-- middle gimbal	R1 xxx. xx deg R2 xxx. xx deg R3 xxx. xx deg	If near gimbal lock, maneuver, then V32 ENTR to 5. PRO to 6.
6	FL V50 N25	P52	Request crew to perform coarse or fine alignment	Proposed gimbal angles satisfactory	R1 00013 checklist perform coarse align R2 Blank R3 Blank	Normal-PRO to 8, monitor NO ATT light. Torque-Mode Cont = ATT HOLD, V76 ENTR, ENTR to 7
7	V16 N20	P52	Monitor current gimbal angles	Astronaut has chosen pulse torque R1-- outer gimbal R2-- inner gimbal R3-- middle gimbal	R1 xxx. xx deg R2 xxx. xx deg R3 xxx. xx deg	When torquing complete, go to 20.
8	FL V50 N25	R51	Request celestial body acquisition	Coarse align to new gimbal angles accomplished. Perform celestial body acquisition. Key ENTR for acquisition by crew or key PRO to have computer acquire stars.	R1 00015 checklist request celestial body acquisition R2 Blank R3 Blank	Maneuver if necessary. LGC star acquisition-PRO to 9. Manual acquisition-ENTR to 9.

TABLE 7. 3. 2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (P52) (SHEET 3 OF 8)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
9	FL V01 N70	R52	Request response to display of AOT detent and star code	LGC has selected two stars for sightings R1-- AOT detent code and star code A and B = Zero C = AOT detent D and E = Star Code Key V21 ENTR to reload all codes	R1 ABCDE R2 Blank R3 Blank C = 0-COAS/LPD calibration = 1-front left detent = 2-front center detent = 3-front right detent = 4-rear right detent = 5-rear center detent = 6-rear left detent = 7-backup optical system DE= 00-planet = 01 to 45-star = 46, 47, 50-sun earth, moon	PRO to 12 (to 10 if C = 0 or 7, to 11 if DE = 00). To terminate P52, key V34 ENTR.
10	FL V06 N87	R52	Display and request response to optical system LOS definition.	AOT detent code = zero or 7 R1--the azimuth of the optical system in use. (the angle in the LM Y-Z plane measured	R1 xxx.xx deg R2 xxx.xx deg R3 Blank	Load desired values. PRO to 12 (to 11 if target is planet).

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (P52) (SHEET 4 OF 8)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
				from the LM +Z-axis to the projection of the LOS on the Y-Z plane.) Polarity is positive for negative rotation about the LM +X-axis. R2-- The corresponding LOS elevation. (the angle from the LOS to the LM Y-Z plane.) Polarity is positive for a LOS in the same hemisphere as the LM +X-axis.		
11	FL V06 N88	R58	Display and request response to assumed planet position vector	Celestial body code indicated planet R1-- Xpl = X component of LGC assumed planet half-unit position vector in Basic Reference coordinates at alignment time specified. R2-- same as R1 for Y component R3-- same as R1 for Z component	R1 .xxxxx Xpl R2 .xxxxx Ypl R3 .xxxxx Zpl	Load desired values. PRO to 12.

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (P52) (SHEET 5 OF 8)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
12	FL V50 N18	R60	Request auto maneuver be performed and display final FDAI ball angles which will result from desired auto maneuver.	If final FDAI angles indicate + or -90 deg yaw, the transformation from IMU to FDAI in roll and pitch is indeterminate and R1 and R2 will indicate zero. For yaw angles near + or -90 deg, the values of R1 and R2 may not be reliable.	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg R1 roll R2 pitch R3 yaw	Auto maneuver-Guid Cont switch to PGNS, Mode Cont switch to PGNS AUTO, PRO to 13. Manual maneuver—Mode Cont to PGNS ATT HOLD, maneuver, PRO to 12. Bypass—ENTR to 14 (to 9 if COAS/LPD calibration).
13	V06 N18	R60	Display final FDAI ball angles	Auto maneuver in progress to FDAI angles displayed R1-- roll R2-- pitch R3-- yaw	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg	Monitor auto maneuver and go to 12.
14	FL V01 N71	R53	Request response to display of AOT detent and star code	R1--A, B = 0; C= AOT detent; DE = star code. AOT detent code used for sighting: 1 = front left detent 2 = front center detent	R1 ABCDE AOT detent code and star code R2 Blank R3 Blank	Load desired values. PRO to 16 (to 15 if C = 7).

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (P52) (SHEET 6 OF 8)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
				3 = front right detent 4 = rear right detent 5 = rear center detent 6 = rear left detent 7 = backup optical system Star code: 00--planet 01 to 45--star 46--sun 47--earth 50--moon		
15	FL V06 N87	R53	Display and request response to present optical system LOS definition	R1--optics azimuth R2--optics elevation (see FL V06 N87 of R52 above)	R1 xxx.xx deg R2 xxx.xx deg R3 Blank	Load desired values. PRO to 16.
16	FL V54 N71	R53	Request astronaut to mark on celestial body	(See FL V01 N71 of R53 above.)	R1 ABCDE AOT detent and star code R2 Blank R3 Blank	Execute five or less mark pairs on each celestial body. After 1st target PRO to 9. After 2nd target PRO to 18. To redefine star, ENTR to 14. If target is planet, PRO after marks will go to 17.

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (P52) (SHEET 7 OF 8)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
16a	FL Vxx N71	R57	Request astronaut to mark one of the following: (1) X reticle--V52 (2) Y reticle--V53 (3) X or Y reticle--V54	MARK X or MARK Y depressed (see FL V01 N71 or R53 above)	R1 ABCDE AOT detent and star code R2 Blank R3 Blank	See No. 16
17	FL V06 N88	R58	Display and request response to assumed planet position vector	See No. 11	R1 .xxxxx Xpl R2 .xxxxx Ypl R3 .xxxxx Zpl	PRO to 9 after 1st target. PRO to 18 after 2nd target.
18	FL V06 N05	R54	Request response to display of sighting angle difference	R1--difference between actual and measured angle between celestial bodies marked.	R1 xxx.xx deg R2 Blank R3 Blank	Reject—V32 ENTR to 20. Accept—PRO to 19.
19	FL V06 N93	R55	Display and request response to angles through which each gyro must be torqued to complete fine alignment	R1 -- X gyro R2 -- Y gyro R3 -- Z gyro	R1 xx.xxx deg R2 xx.xxx deg R3 xx.xxx deg	Torque-V76 ENTR, PRO to 20. Bypass torque-V32 ENTR to 20.
20	FL V50 N25	P52, R51	Request please perform fine align	R1--please perform fine align	R1 00014 checklist R2 Blank R3 Blank	Third star check—PRO to 8. Exit P52-ENTR.

TABLE 7. 3. 2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (P52) (SHEET 8 OF 8)

DSKY	Initiated By	Purpose	Condition	Register
V05 N09 ENTR	Astronaut	Display alarm codes stored by LGC	Alarm codes displayed as follows:	R1 xxxxx R2 xxxxx R3 xxxxx
			00107--too many mark pairs taken	
			00111--mark missing	
			00112--mark made but not needed	
			00113--routine called unnecessarily by hardware failure	
			00114--wrong MARK button depressed	
			00115--mark reject attempted with no marks to reject	
			00206--zero encode not allowed with coarse align and gimbal lock	
			00207--ISS turn-on request not present for 90 sec	
			00210--IMU not on	
			00211--coarse align error	
			00217--bad return from ISS mode switch	
			00220--IMU on, but no REFSMMAT	
FL V05 N09	R51	Display alarm code	00405--two stars not available	
V05 N09 ENTR	Astronaut	Display alarm code stored by LGC	20105--AOT mark system in use	
			31107--no VAC available	
			31211--illegal interrupt of extended verb	

R02 illuminates the PROG light. The alarm is verified by keying VERB 05 NOUN 09; alarm code 00210 indicates the ISS is not on. Alarm 00220 indicates the ISS is on, but there is no valid REFSMMAT. (If alarms occur here, P52 is automatically terminated. The IMU should be powered up and P51 executed.)

If all is well with the ISS and REFSMMAT, P52 tests the PREFERRED ATTITUDE-COMPUTED flag. If the flag is set, the Preferred alignment option code (00001) is displayed in register R2 as discussed below; if the flag is cleared, the REFSMMAT option code (00003) is displayed.

The first display the astronaut sees in P52 is a flashing VERB 04 NOUN 06, with R1 containing 00001 ("Please specify IMU orientation option") and R2 containing the alignment option code assumed by the LGC. The astronaut can key VERB 22 ENTR to reload the desired code in R2, or can approve the option displayed by keying PRO. (The four option codes are: 00001—preferred; 00002—nominal; 00003—REFSMMAT; 00004—landing site.)

P52 now proceeds to one of three activities, depending on the alignment option chosen: (a) if the REFSMMAT option was chosen, coarse alignment is bypassed and P52 calls the Fine Align Routine, R51 (see paragraph 7.3.2.3.4); (b) if the preferred option was chosen, P52 now carries out the coarse align gimbal angle computations of paragraph 7.3.2.3.2; (c) if the nominal or landing site option was chosen, P52 needs more information before it can coarse align the gimbals and requests it by the displays described below.

In the nominal or landing site option, the astronaut sees a flashing VERB 06 NOUN 34, with the time of alignment displayed in hours, minutes, and seconds (GET). If the nominal option was chosen, the display is all zeros, indicating the computer chose the present time as the time of alignment. If the landing site option was chosen, the DSKY registers show the time of lunar landing as the selected time of alignment. The astronaut can correct the time by keying VERB 25 ENTR and loading the desired time or can proceed with the time displayed by keying PRO.*

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*The stored landing site coordinates can be modified only by prelaunch erasable load, P27, P57, or P68. If the crew corrects VERB 06 NOUN 89 in P52, the newly defined landing site will be effective only to define an orientation for the stable member.

If the nominal option was chosen, P52 calculates the desired stable member inertial orientation based on the LM state vector at the time of alignment and executes the gimbal angle computations given in paragraph 7.3.2.3.2. The landing site option of P52 must know the lunar landing site coordinates before it can realign the stable member. Accordingly, P52 displays the landing site coordinates, which the computer has in storage, by flashing VERB 06 NOUN 89. R1, R2, and R3 contain the landing site latitude, half-longitude, and altitude, respectively. The astronaut can load new numbers and, when satisfied with the data, continue into the gimbal angle computations below by keying PRO.

7.3.2.3.2 Gimbal Angle Computation.—For the preferred, nominal, or landing site option, the program now reads the current LM attitude from the gimbal angles and uses this information to determine the gimbal angles for the desired stable member alignment at the present LM attitude. P52 flashes VERB 06 NOUN 22 and displays the calculated outer, inner, and middle gimbal angles. If there is a risk that the stable member will be positioned into gimbal lock (middle gimbal angle of 85 deg or more), the astronaut can maneuver the LM with the attitude control assembly (ACA) and recycle to update the displayed gimbal angles by keying VERB 32 ENTR. When the displayed angles appear satisfactory, the astronaut keys PRO.

P52 next flashes VERB 50 NOUN 25. R1 contains checklist code 00013 ("Please perform normal or gyro torque coarse align"). The astronaut must now choose one of two responses: (1) pulse torque coarse alignment (ISS in fine align mode), or (2) normal coarse alignment (ISS in coarse align mode).

If the astronaut intends to have the stable member pulse torqued to the desired orientation and if he does not want the DAP to maneuver the LM to follow the stable member during pulse torquing, he must command the minimum impulse mode. He keys VERB 76 ENTR with the Mode Control switch set to ATT HOLD. This sets the PULSES flag. The DAP now responds only to ACA inputs.* Another ENTR commands P52 to compute the torquing angles required to achieve the new IMU orientation and to pulse the gyros through the torquing angles. Before torquing starts, P52 resets the REFSMMAT flag. While torquing is in progress, P52 displays VERB 16 NOUN 20 and the current outer, inner, and middle gimbal angles. When torquing is accomplished, P52 puts the desired IMU orientation into REFSMMAT and sets the REFSMMAT flag. The DSKY next flashes VERB 50 NOUN 25, with R1

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*To return to Rate Command and ATT HOLD modes, the astronaut must key VERB 77 ENTR.

containing checklist code 00014 ("Please perform fine align"). If the astronaut wants to carry out AOT sightings, he keys PRO. P52 then calls R51, the Inflight Fine Align Routine (paragraph 7.3.2.3.4). If no AOT sightings are desired and the astronaut keys ENTR, P52 is terminated.

The alternate crew response to "Please perform normal or gyro torque coarse align" is to key PRO. P52 will then call the Coarse Align Routine (R50) (paragraph 7.3.2.3.3). After calling R50, P52 calls R51, the Inflight Fine Align Routine.

7.3.2.3.3 Coarse Align Routine.—When the Coarse Align Routine (R50) (Figure 7.3.2-4) is called, it computes the gimbal angles at the desired stable member orientation and present LM attitude. If no required gimbal angle change is greater than one deg, the desired stable member orientation is put into REFSMMAT, and R50 returns control to P52. For larger required gimbal angle changes, the LGC commands the ISS to the coarse align mode, turns on the NO ATT light, disables the DAP, and repositions the stable member. (Alarm codes 00211 and 00217 will be stored at this time if there is a 2-deg error between the actual and commanded gimbal angles.) The LGC then terminates the coarse align ISS mode and enables the DAP to resume LM attitude hold. The NO ATT light is then turned off by the LGC. R50 then defines REFSMMAT to be the desired stable member orientation.

When R50 is completed, it returns control to P52, which sets the REFSMMAT flag and resets the PREFERRED ATTITUDE-COMPUTED flag, informing other programs that there is a valid REFSMMAT but no preferred attitude in storage. P52 then calls R51, the Inflight Fine Align Routine (Figure 7.3.2-5), to manage celestial body acquisition, AOT marktaking, and pulse torque fine alignment.

7.3.2.3.4 Inflight Fine Align Routine.—R51 flashes VERB 50 NOUN 25, with checklist code 00015 in R1 ("Please perform celestial body acquisition"). If the astronaut wants the computer to pick a pair of stars, he keys PRO. The computer then searches its star catalog to find a usable pair of stars. The LGC considers only the forward center detent and tests for two stars that meet the following criteria:

a. Both stars are within 50 deg of the center of the field of view.
b. The angle of separation of the pair is at least 50 deg.
c. The stars are not obscured by the sun, earth, or moon.

If there is more than one pair that is satisfactory, the pair with the largest separation is automatically chosen for sightings. If a pair is not available at the present LM attitude, the LGC displays alarm code 00405. The astronaut can either (1) reorient

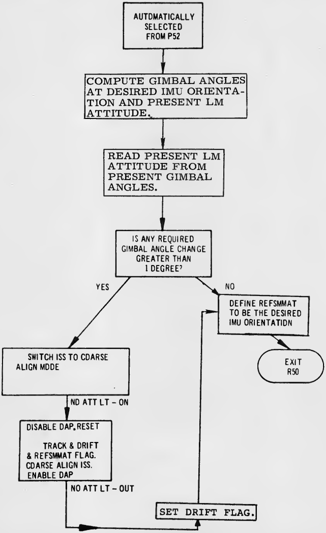

Figure 7.3.2-4. Coarse Align Routine (R50)

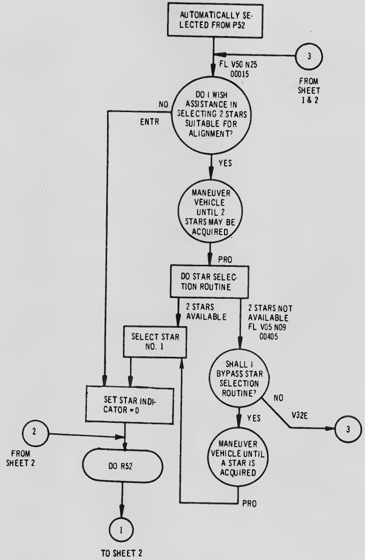

Figure 7.3.2-5. Inflight Fine Align Routine (R51) (Sheet 1 of 2)

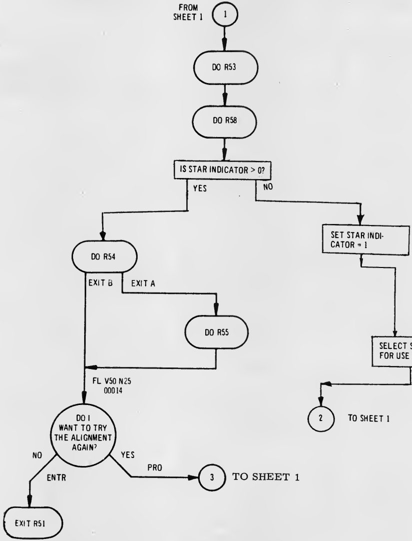

Figure 7. 3. 2-5. Inflight Fine Align Routine (R51) (Sheet 2 of 2)

the LM and recycle (by VERB 32 ENTR) to the beginning of R51, or (2) maneuver until he acquires a suitable celestial body himself and then key PRO, calling the Auto Optics Positioning Routine, R52 (paragraph 7.3.2.3.5). If the computer was successful in finding a pair of stars for sightings, it selects one star from the pair as a target for the Auto Optics Positioning Routine.

If the astronaut wants to find a pair of celestial bodies without the aid of the computer, he keys ENTR when the computer requests "Please perform celestial body acquisition." R51 then immediately calls the Auto Optics Positioning Routine, R52 (Figure 7.3.2-6).

7.3.2.3.5 Auto Optics Positioning Routine.—The purpose of R52 is to point the line of sight (LOS) of any AOT detent at a specified celestial body by maneuvering the LM. R52 flashes VERB 01 NOUN 70 and displays the AOT detent and target celestial body codes in R1. (See Table 7.3.2-I.) If the astronaut wants to change these numbers, he can do so now by keying VERB 21 ENTR and loading the desired codes. When the codes are correct and the astronaut wants to go ahead with auto optics positioning, he keys PRO. (A VERB 34 ENTR terminates P52.) R52 then resets the 3-AXIS flag, which is tested later by the Attitude Maneuver Routine, R60. If the astronaut has approved an AOT detent code of 0 or 7 (COAS/LPD calibration or COAS sighting, respectively), he sees flashing VERB 06 NOUN 87 with the azimuth and elevation of the present optics LOS displayed in R1 and R2. VERB 24 ENTR is used to correct these numbers, if desired; PRO is used to approve the displayed values.

For any AOT detent code, the LGC now computes the LOS vector as specified by the preceding displays and calls the Celestial Body Definition Routine (R58) for the intended target. If the target is a star, R58 obtains its Basic Reference vector from the computer's stored ephemeris; if the target is the sun, earth, or moon, R58 calculates the celestial body vector. If the celestial body code of VERB 01 NOUN 70 above was zero (planet or other target), R58 flashes VERB 06 NOUN 88, with the X, Y, and Z components of the planet half-unit position vector. If these numbers are correct, the astronaut keys PRO; he can change them by keying VERB 25 ENTR followed by the correct components. R58 then returns control to R52.

At this time, R52 defines the LOS to the target celestial body as the direction in which the Attitude Maneuver Routine, R60 (Figure 7.3.2-7), will point the previously selected optics LOS. R52 then calls R60.

7.3.2.3.6 Attitude Maneuver Routine.—The purpose of R60 is to maneuver the LM to point a specific body-fixed vector, such as the center of the AOT field of view

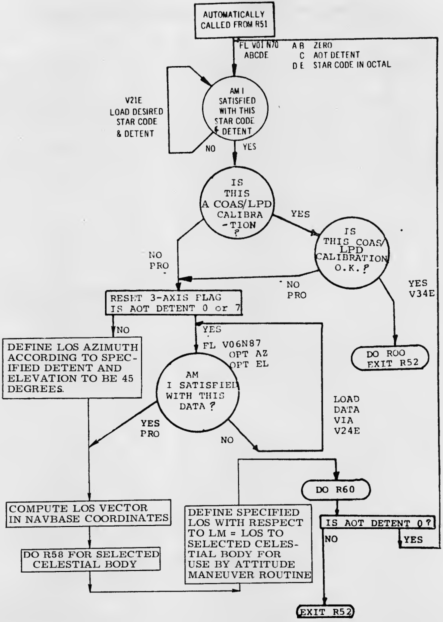

Figure 7.3.2-6 Auto Optics Positioning Routine (R52)

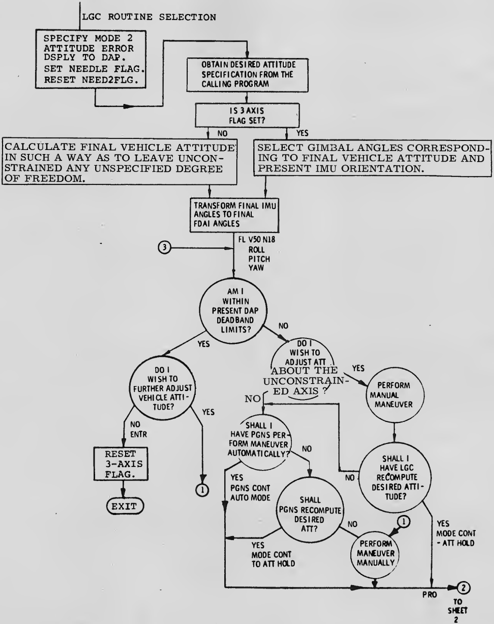

Figure 7.3.2-7. Attitude Maneuver Routine (R60) (Sheet 1 of 2)

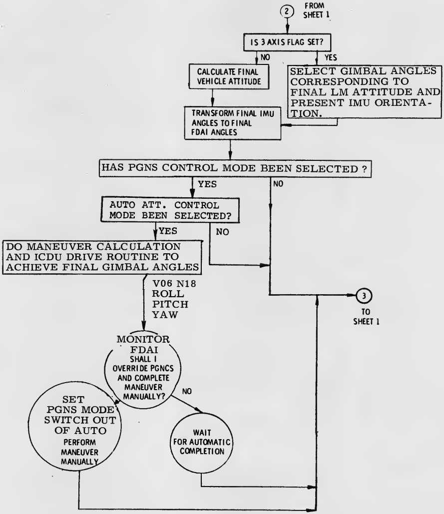

Figure 7.3.2-7. Attitude Maneuver Routine (R60) (Sheet 2 of 2)

for a specified detent, along a specified direction in space. This direction is calculated and stored by the calling program. R60 tests the 3-AXIS flag at this time. Since it has been reset by R52, R60 calculates the final LM attitude and gimbal angles required to meet the LOS specifications in such a way as to conserve RCS fuel and not constrain any unspecified degree of freedom. (The alternative for R60, if the 3-AXIS flag is set, is to orient all three LM body axes in specified directions.)

The Attitude Maneuver Routine then flashes VERB 50 NOUN 18 ("Please perform auto maneuver") with the FDAI angles resulting from the proposed maneuver displayed in R1, R2, and R3 as roll, pitch, and yaw, respectively. There are three responses to this display:

a. Auto maneuver—the astronaut sets the PGNS Mode Control switch to AUTO and keys PRO. The LGC then calculates the required final vehicle attitude (using the routine VECPOINT) and displays VERB 06 NOUN 18 with the final FDAI angles. During this display, the RCS jets are fired to attain the required attitude. If the PGNS Mode switch is set out of AUTO, the maneuver will be terminated immediately. Following astronaut or LGC termination of the maneuver, the computer again flashes VERB 50 NOUN 18 and the desired FDAI angles. The astronaut can now perform another auto maneuver, manual maneuver, or bypass the maneuver.

b. Manual maneuver—the astronaut sets the PGNS Mode Control switch to ATT HOLD and acquires the target using the ACA and FDAI. When the target is acquired, he keys PRO and again sees flashing VERB 50 NOUN 18 and the desired FDAI angles.

c. Bypass the requested maneuver—the astronaut keys ENTR when the DSKY flashes VERB 50 NOUN 18 and the desired ball angles after a successful auto or manual star acquisition maneuver.

At this point, R52 tests the AOT detent code selected earlier. If it is zero (COAS/LPD calibration), R52 again flashes VERB 01 NOUN 70 and displays the AOT detent and celestial body codes. (Refer to paragraph 7.3.2.3.5.) A VERB 34 ENTR response to VERB 01 NOUN 70 terminates R52 and P52. If the AOT detent code is not zero, R52 is terminated and control returns to R51. (By now, the astronaut should have acquired the celestial body in the AOT, and the next step is to take marks.)

7.3.2.3.7 AOT Mark Routine.—R51 now calls the AOT Mark Routine, R53 (Figure 7.3.2-8). R53 requests and processes sighting marks on the two targets. When R53 is initiated, the possible program alarms that may occur are 20105 (R53 already in progress); 31211 (no marks allowed); or 31207 (no LGC VAC area available for computations) (Table 7.3.2-I). If no alarms occur, R53 sets the MARK INPUT INHIBIT flag and flashes VERB 01 NOUN 71, with the AOT detent and star codes displayed in R1. VERB 21 ENTR followed by the desired code corrects the values displayed; PRO indicates the astronaut accepts the code values displayed. If the detent code

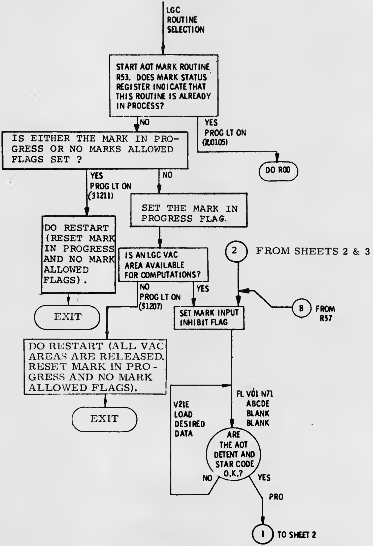

Figure 7.3.2-8. AOT Mark Routine (R53) (Sheet 1 of 3)

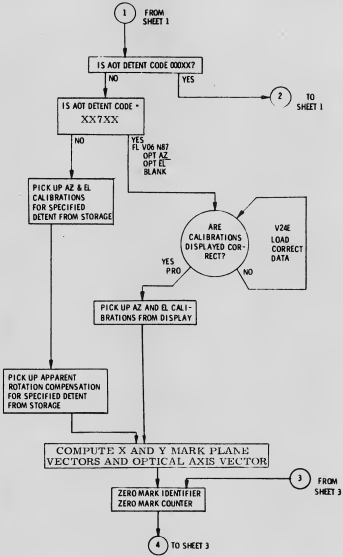

Figure 7.3.2-8. AOT Mark Routine (R53) (Sheet 2 of 3)

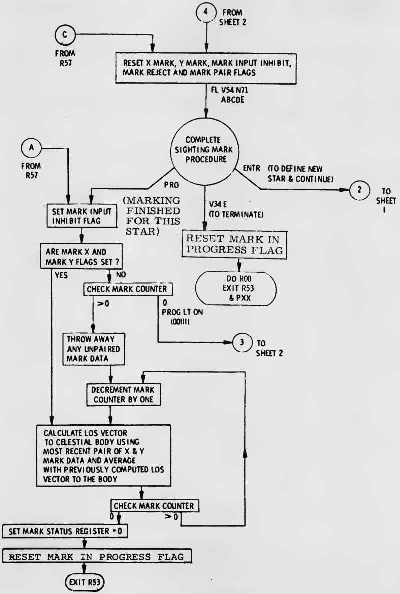

Figure 7.3.2-8. AOT Mark Routine (R53) (Sheet 3 of 3)

is seven (COAS sighting), R53 flashes VERB 06 NOUN 87, with the stored values for the azimuth and elevation of the backup optics LOS displayed in R1 and R2. These values can be approved by keying PRO or reloaded after keying VERB 24 ENTR. The LGC is then able to calculate the backup optics LOS vector in Navigation Base coordinates. For either AOT or backup optics sightings, R53 computes the orientation of the planes defined by the X- and Y-reticle lines and the optic axis vector. The Sighting Mark Routine then flashes VERB 54 NOUN 71 ("Please mark X- or Y-reticle line-star intersection"). R1 again contains the AOT detent and star codes.

When the astronaut prepares to take a sighting, he should be sure that the AOT reticle rotation angle is set to zero to ensure that the X- and Y-reticle lines define the proper planes for the LGC LOS vector computations. (The greatest accuracy will result if the marks are taken with the star as close as possible to the field-of-view center.)

When the target body crosses the X- or Y-reticle mark line, the astronaut takes a mark by depressing the MARK X or MARK Y pushbutton. Either mark of the pair can be taken first. The computer accepts five mark pairs or less; when the astronaut is finished marking, he keys PRO. The MARK REJECT pushbutton is used to throw away one or both members of the most recent pair of marks taken. When one of the MARK pushbuttons is depressed, R53 calls the Markrupt Routine, R57 (Figure 7.3.2-9).

7.3.2.3.8 Markrupt Routine.—When the Markrupt Routine is called, it stores the current X, Y, and Z gimbal angle values and the time for use by the Sighting Mark Routine. R57 then determines which one of the MARK X, MARK Y, and MARK REJECT pushbuttons was depressed. The DSKY then flashes VERB xx NOUN 71, where xx can have the following values: 52—"Please mark X-reticle line/star crossing"; 53—"Please mark Y-reticle line/star crossing"; 54—"Please mark X- or Y-reticle line/star crossing." R1 contains the AOT detent and celestial body codes. The astronaut must then depress the other mark pushbutton to complete the X-Y mark pair. He can then continue to take mark pairs by additional X or Y marks (as many as five mark pairs can be taken). If he wants to throw away all the marks he has taken, he keys ENTR. The program then returns to the flashing VERB 01 NOUN 71 of R53 (paragraph 7.3.2.3.7) to redefine the celestial body and start marking over again.

When the astronaut is satisfied with the number and quality of marks he has taken, he keys PRO. This returns program control to R53, which sets the MARK INPUT

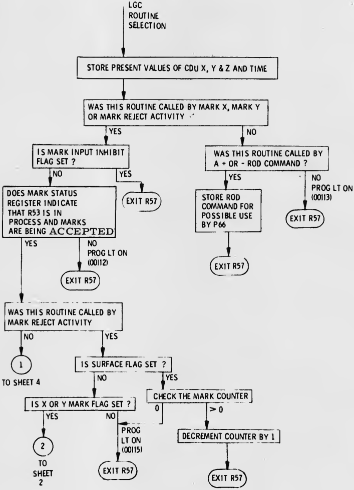

Figure 7.3.2-9. Markrupt Routine (R57) (Sheet 1 of 4)

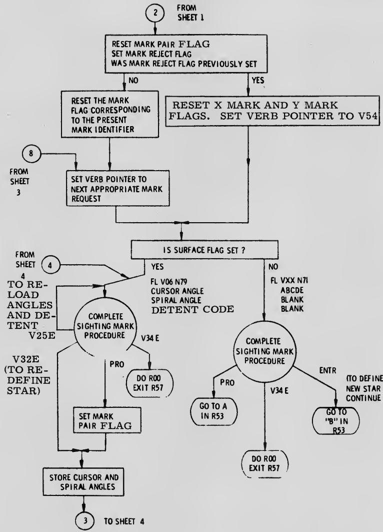

Figure 7.3.2-9. Markrupt Routine (R57) (Sheet 2 of 4)

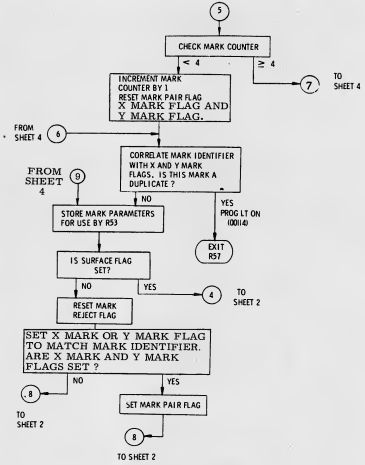

Figure 7.3.2-9. Markrupt Routine (R57) (Sheet 3 of 4)

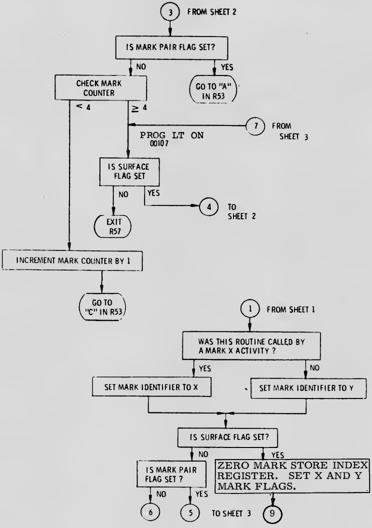

Figure 7. 3. 2-9. Markrupt Routine (R57) (Sheet 4 of 4)

INHIBIT flag to prevent additional marks from being incorporated. R53 then calculates the measured LOS vector to the target using the averaged X and Y mark data and returns control to R51, the Inflight Fine Align Routine.

7.3.2.3.9 Celestial Body Definition Routine.—R51 now calls the Celestial Body Definition Routine, R58 (Figure 7.3.2-10). The purpose of R58 is to obtain, either from storage, calculation, or crew input, the actual (not AOT-measured) celestial body vector in Basic Reference Coordinates. (The actual and measured vectors are compared later in the Sighting Data Display Routine.) R58 first checks the value of the stored target identification code as follows:

a. If the code is zero (planet or other celestial body), the crew sees a flashing VERB 06 NOUN 88 with the LGC assumed planet position vector components displayed in R1, R2, and R3. Corrected components can be loaded via VERB 25 ENTR or approved by keying PRO. Control is then returned to R51.

b. If the target identification code is 46 (sun), 47 (earth), or 50 (moon), R58 calculates the appropriate celestial body vector based on the LGC's stored ephemerides and returns to R51.

c. If the target is a star, the celestial body vector is obtained directly from storage. R58 is then completed and R51 again takes over.

R51 now calls the Auto Optics Positioning Routine (R52) for the second time and displays the LGC assumed detent and celestial body codes under flashing VERB 01 NOUN 70. These are approved or corrected as before (paragraph 7.3.2.3.5) and the astronaut repeats the procedures of auto optics positioning, marking, and celestial body definition for the second target. R51 then calls the Sighting Data Display Routine, R54 (Figure 7.3.2-11).

7.3.2.3.10 Sighting Data Display Routine.—This routine first calculates the actual angle between the two celestial bodies using the vectors obtained by the Celestial Body Definition Routine. R51 then calculates the measured angle between the two bodies using the AOT mark data and displays the difference between these two angles under flashing VERB 06 NOUN 05. R1 contains the sighting angle difference, to 0.01 deg. (The maximum acceptable value is 0.05 deg.) If the astronaut wants to try marking on a target pair again, he keys VERB 32 ENTR to recycle to R51, which requests "Please perform fine align" (paragraph 7.3.2.3.12). Any previously stored mark data will be lost.

When the astronaut is satisfied with the VERB 06 NOUN 05 sighting data, he keys PRO. R51 then calls the Gyro Torquing Routine, R55 (Figure 7.3.2-12).

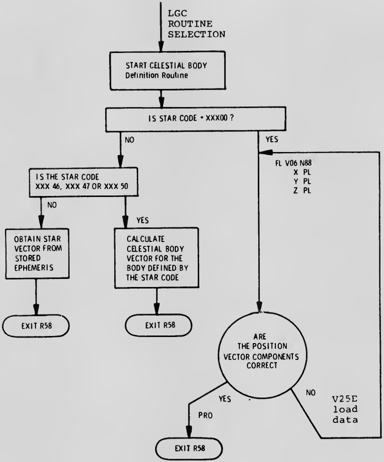

Figure 7.3.2-10. Celestial Body Definition Routine (R58)

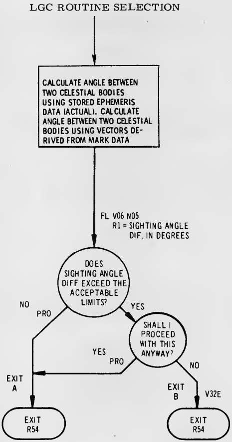

Figure 7.3.2-11. Sighting Data Display Routine (R54)

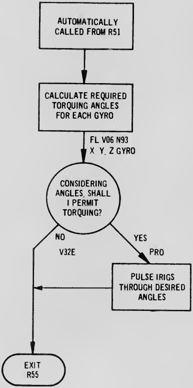

Figure 7.3.2-12. Gyro Torquing Routine (R55)

7.3.2.3.11 Gyro Torquing Routine.—R55 uses the two measured LOS vectors to the celestial bodies to calculate the difference between the actual and desired stable member orientations. The routine then calculates the gyro torquing angles required to eliminate this difference and displays them under flashing VERB 06 NOUN 93. R1, R2, and R3 contain the X, Y, and Z gyro torquing angles, respectively. If the astronaut decides that these angles are too large or that they could cause gimbal lock, he can bypass pulse torquing by keying VERB 32 ENTR. R55 then returns control to R51 (paragraph 7.3.2.3.12). If the astronaut keys PRO on the gyro torquing angles displayed, R55 pulse-torques the stable member through the angles required to bring the stable member into precise alignment with the desired orientation (which was stored in REFSMMAT after normal or pulse-torque coarse alignment).

7.3.2.3.12 Third Star Check.—The DSKY next flashes VERB 50 NOUN 25, checklist code 00014 ("Please perform fine align"), when any of the following conditions are met:

a. Coarse align pulse torquing (paragraph 7.3.2.3.2) has been completed
b. The astronaut has terminated R54 via VERB 32 ENTR (paragraph 7.3.2.3.10)
c. The astronaut has terminated R55 via PRO or VERB 32 ENTR.

The astronaut can now key ENTR to terminate the IMU Realignment Program, or he can key PRO to recycle within R51.

If the astronaut keys PRO, he sees flashing VERB 50 NOUN 25 with checklist code 00015 ("Please perform celestial body acquisition"). The astronaut can now check the accuracy of the realignment by having the LGC select a star pair and acquire it in the AOT. He accomplishes this by following the procedures discussed in paragraph 7.3.2.3.4. P52 can be terminated after the computer performs auto optics positioning via VERB 34 ENTR, or the celestial body mark procedures can be executed to repeat the entire sequence of mark taking, LOS vector computation, and fine align pulse torquing.

7.3.2.4 Program Alarms

The alarm codes that the astronaut might encounter during LM IMU realignment are:

a. Alarm 00107 indicates more than five mark pairs were taken. Key RSET and terminate marking by keying PRO.

b. Alarm 00111 occurs if the astronaut keyed PRO when no complete pair of marks was stored in the LGC. The computer flashes VERB 54 NOUN 71, requesting marks. Key RSET and perform normal marking.

c. Alarm 00112 indicates a mark or mark reject was attempted while the LGC was not accepting these inputs. Control is automatically returned to the interrupted job. Key RSET and continue.

d. Alarm 00113 indicates a hardware or software failure called R57 unnecessarily. Control is automatically returned to the interrupted job. Key RSET, continue operations, and refer to backup procedures for partial computer failure.

e. Alarm 00114 indicates a duplicate mark has been taken (X after X or Y after Y). Key RSET, monitor the DSKY mark request verb, and make the correct mark.

f. Alarm 00115 indicates a mark reject was attempted with no marks to reject. Key RSET and monitor DSKY mark request.

g. Alarm 00206 indicates zeroing the ICDUs by VERB 40 NOUN 20 was attempted by the astronaut but not allowed during gimbal lock. With the IMU in coarse align mode and gimbal lock, zero CDU encoding is accomplished by first commanding coarse alignment to zero as follows: key RSET; key VERB 41 NOUN 20 ENTR and load ENTR, ENTR, ENTR; key VERB 40 NOUN 20 ENTR.

h. Alarm 00207 indicates ISS turn-on not present for 90 sec. Key RSET and reinitiate ISS turn-on sequence.

i. Alarm 00210 indicates the IMU is not on. P52 is automatically terminated. Initiate the ISS turn-on sequence and, when the NO ATT light is extinguished, execute P51 to determine the stable member orientation and REFSMMAT.

j. Alarm 00211 indicates gimbal angles are not within 2 deg of commanded position after coarse alignment. To determine size of error, key VERB 06 NOUN 20 ENTR for display of present gimbal angles and VERB 06 NOUN 22 ENTR for desired gimbal angles. Continue the alignment and record the torquing angles. Then perform the third star alignment check (paragraph 7.3.2.3.12). If performing VERB 41 NOUN 20, try again.

k. Alarm 00217 can accompany alarm 00211 and indicates a bad return from ISS mode switching. Control is returned to P52 as usual. The bad return could also be due to a power failure during coarse or fine alignment. Key RSET and perform 00211 recovery procedures.

l. Alarm 00220 indicates IMU alignment not known (REFSMMAT flag reset). Perform P51 or, if the IMU alignment is known (for example, after docked alignment), set the REFSMMAT flag. To set this flag, key VERB 25 NOUN 07 ENTR. Then key 77 ENTR, 10000 ENTR, and 1 ENTR.

m. Alarm 00405 indicates the computer could not find two stars in the forward AOT detent at the present LM attitude. The astronaut can maneuver the LM and key VERB 32 ENTR to have the LGC try again, or he can key PRO when he acquires a star or planet himself. When he keys PRO, the computer flashes VERB 01 NOUN 70 and displays the detent and star code assumed by the computer.

n. Alarm 20105 indicates the AOT mark system is already in use and no marks are being accepted by the LGC. P52 is automatically terminated. Key RSET and reselect the desired program.

o. Alarm 31207 indicates no VAC areas are available for storing mark data. The LGC executes a software restart to the flashing VERB 01 NOUN 70 of the Auto Optics Positioning Routine, R52.

p. Alarm 31211 indicates an illegal interrupt of an extended verb in progress. The LGC executes a software restart to flashing VERB 01 NOUN 70, R52.

7.3.2.5 Program Coordination and Procedures

The following paragraphs discuss the use of P52 during a mission and miscellaneous procedures relevant to IMU realignment.

7.3.2.5.1 P52 Activities.—When the LM and CSM are docked and the LM ISS is first powered up, the LM stable member requires alignment to the landing site orientation. This can be accomplished without AOT sightings, and the CSM and LM given the same REFSMMAT, by following the procedure discussed in paragraph 7.3.2.5.2 below. P27 is used to uplink REFSMMAT to the LM after docked alignment.

After CSM/LM separation in lunar orbit, the CSM and LM stable members are each realigned to option 00003, REFSMMAT. When the LM stable member fine alignment is accomplished, the third star alignment check procedure in P52 can be used to calibrate the landing point designator (LPD) located in the LM left front window. The position of the LPD is keyed in as a COAS sighting (detent code 0 under flashing VERB 01 NOUN 70, R52). Zero deg azimuth and -40 deg elevation are keyed in when the LGC flashes VERB 06 NOUN 87. The calibration star should appear in the LPD when R60, the auto maneuver star acquisition routine, is performed. If the preflight calibration values, as determined by the ground from crew observations, disagree with the actual situation by more than 2 deg in azimuth or 0.5 deg in elevation, the ground updates the LPD calibration values stored in the LGC.

About one and a half hours before Powered Descent Initiation (PDI), P52, option 00003, is again executed. The gyro torquing angles are used to assess the amount of drift since the previous alignment. Before lunar liftoff, the LM stable member will be realigned by P57 to the landing site orientation at liftoff. After liftoff, P52 option 00003 is executed to realign to this orientation prior to targeting for CSI (P32).

The preferred option of the LM IMU Realignment Program can be used in coordination with prethrust and thrusting programs to move the stable member into an optimum orientation for an upcoming propulsion system burn. (Refer to paragraph 7.2.2.2.1.) A typical program sequence follows:

a. The astronaut keys in one of the P30's (prethrust targeting programs, subsection 5.3). This determines the time of ignition and velocity change.

b. The astronaut keys in a thrusting program: P40, P41, or P42 (subsection 6.3). The thrusting program computes a preferred IMU orientation and vehicle attitude and sets the PREFERRED ATTITUDE-COMPUTED flag. The astronaut then sees a flashing VERB 50 NOUN 18 ("Please perform maneuver to displayed FDAI angles").

c. If the astronaut wants to realign the stable member, he does not perform the auto maneuver. Instead, he terminates thrusting program at the flashing VERB 50 NOUN 18 and keys in P52. Since the PREFERRED ATTITUDE-COMPUTED flag is set, P52 automatically chooses and displays the preferred option code (00001) for crew approval. The astronaut can then realign the stable member to this option.

d. The astronaut then returns to the beginning of the thrusting program and executes the entire program.

7.3.2.5.2 Miscellaneous Procedures.—The docked alignment procedure is discussed here:

a. The CSM IMU is aligned to the landing site orientation and the LM crew notes the docking ring angle during inter-vehicle transfer.

b. CSM attitude is held at minimum deadband and the LM stable member is coarse aligned (VERB 41 NOUN 20) to angles in degrees as follows:
outer gimbal angle (LM) = 300 + docking ring number
-outer gimbal angle (CSM);
inner gimbal angle (LM) = inner gimbal angle (CSM) + 180;
middle gimbal angle (LM) = -middle gimbal angle (CSM).

c. LM CDUs are zeroed (VERB 40 NOUN 20), and CSM attitude hold can now be terminated.

d. The REFSMMAT flag is set as follows: VERB 25 NOUN 07 ENTR; 77 ENTR; 10000 ENTR; 1 ENTR. Bit 13 is confirmed to be set if VERB 01 NOUN 01 ENTR 77 ENTR produces 1, 3, 5, or 7 in the first digit of R1.

e. The DRIFT (gyro compensation available) flag is now set as follows: VERB 37 ENTR 51 ENTR; PRO; VERB 37 ENTR 00 ENTR.

f. The CM and LM pilots both key VERB 06 NOUN 20 and on the LM pilot's "Mark," they key ENTR to display the present gimbal angles.

g. The gimbal angles and time are voiced to the ground where the torquing angles are calculated for fine alignment. The desired torquing angles are then voiced to the LM.

h. The LM crew should verify that the minimum impulse mode has been commanded and then key VERB 42 ENTR.

i. When the LGC flashes VERB 21 NOUN 93, the gyro torquing angles are loaded. NOUN 20 can be used to monitor the current gimbal angles. Alignment is complete.

While the spacecraft are docked before PDI, an IMU drift check is performed. The ground notes any changes in the difference between the CSM and LM gimbal angles. If any gyro drift exceeds 1.5 deg per hour, either the CSM or LM IMU has failed.* Since the CSM IMU has been powered up since launch, with several realignment and drift checks, it is more probable that the LM IMU has failed if the change in the difference between the LM and CSM gimbal angles becomes too large.

If the AGS has a good alignment, it can be used to rapidly realign the LM IMU by the following procedure:

a. Maneuver the LM to (0,0,0) on the AGS FDAI ball.

b. Key VERB 41 NOUN 20 ENTR, ENTR, ENTR, ENTR. This coarse aligns the IMU to (0,0,0) gimbal angles.

c. Key VERB 40 NOUN 20, verify that the FDAI is at (0,0,0), and key ENTR. This zeros the ICDUs and recovers stable member inertial reference capability.

d. After 15 sec, key VERB 37 ENTR 51 ENTR and PRO on the first display. This sets the DRIFT flag. Then key VERB 37 ENTR 00 ENTR.

e. To set the REFSMMAT flag, key VERB 25 NOUN 07 ENTR, 77 ENTR, 10000 ENTR, 1 ENTR.

f. If the LGC has auto optics positioning capability, perform P52, REFSMMAT option.

7.3.2.6 Extended Verbs

The extended verbs discussed below are not executed during P52. They do, however, allow the crew to control the normal and gyro torque repositioning of the stable member. Table 7. 3. 2-II lists the extended verbs DSKY activity.

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* Refer to paragraph 7.2.2.5 for a discussion of the gyro drift measurement equations.

The Coarse Align ISS extended verb, VERB 41 NOUN 20, is used to coarse-align the gimbal angles to values specified by the astronaut (Figure 7.3.2-13). This verb is used to align the gimbals to zero (or any other value) when in coarse align mode with a gimbal lock. The astronaut keys VERB 41 NOUN 20 ENTR, loads the angles, and the computer commands the coarse align ISS mode to reposition the stable member. The specified gimbal angles can be displayed by keying VERB 16 NOUN 22 ENTR; the current gimbal angles can be monitored by keying VERB 16 NOUN 20 ENTR. The NO ATT light remains illuminated after VERB 41 NOUN 20 is completed. This extended verb should never be used during a process that requires the stable member to be at a known inertial orientation, because inertial reference is not maintained during coarse alignment.

The Fine Align extended verb, VERB 42 (Figure 7.3.2-14) is used to pulse torque the stable member and to switch the ISS from the coarse align to the fine align mode. The operator, after keying VERB 42 ENTR, observes flashing VERB 21 NOUN 93 and loads the gyro torquing angles. In flight, all torquing angles must be less than 100 deg and must be chosen to keep the middle gimbal angle less than 70 deg (gimbal lock imminent). Note that the coarse and fine align extended verbs provide neither a means of determining the stable member's inertial orientation nor a means of alignment to one of P52's alignment options.

The IMU CDU-Zero extended verb (VERB 40 NOUN 20) is used to switch the ISS from coarse align to fine align mode and to synchronize the ISS CDU counters and the CDU counters in the LGC (Figure 7.3.2-15). This verb cannot be entered when the ISS is in the coarse align mode with a gimbal lock. If a gimbal lock has occurred, VERB 41 NOUN 20 must precede VERB 40 NOUN 20. When VERB 40 NOUN 20 is executed, the NO ATT light will be turned off by the LGC.

TABLE 7.3.2-II

EXTENDED VERBS ASSOCIATED WITH LM IMU REALIGNMENT

VERB	Identification	Purpose	Remarks
V41 N20	Coarse align ISS extended verb	Coarse align stable member to gimbal angles specified by astronaut	Astronaut keys in V41 N20 ENTR to initiate coarse alignment. LGC then flashes V21 N22 requesting astronaut to load gimbal angles desired. Astronaut loads outer, inner, and middle gimbal angles in DSKY registers R1, R2, and R3, respectively. LGC then displays V41 while stable member is reoriented. The NO ATT light remains illuminated during coarse alignment and after the coarse align ISS extended verb has terminated.
V42	Fine align ISS extended verb	Pulse torque stable member through angles indicated by astronaut	Astronaut keys in V42 ENTR. LGC then flashes V21 N93 requesting astronaut to load delta gyro angles. Astronaut then loads outer, inner, and middle gimbal delta gyro angles into registers R1, R2, and R3, respectively. LGC then displays V42 while pulse torquing is in progress, and the NO ATT light is extinguished.
V40 N20	IMU CDU Zero extended verb	Recover ISS inertial reference capability and synchronize ISS CDU counters and LGC CDU counters	Astronaut keys V40 N20 ENTR. LGC then extinguishes NO ATT light, sets ICDU zero discrete, clears and zeroes LGC ICDU counters. It then enables DAP AUTO and HOLD modes.

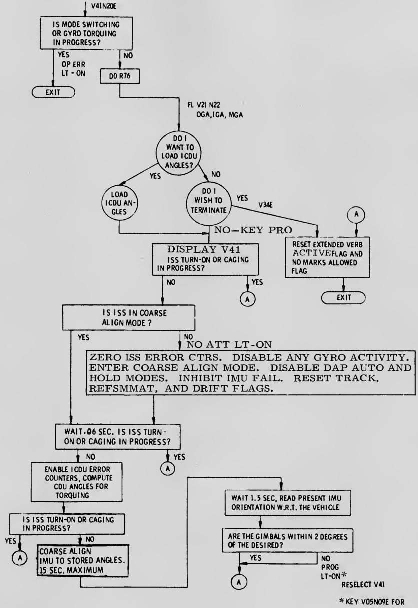


Figure 7.3.2-13. Coarse Align ISS Extended Verb (V41 N20)

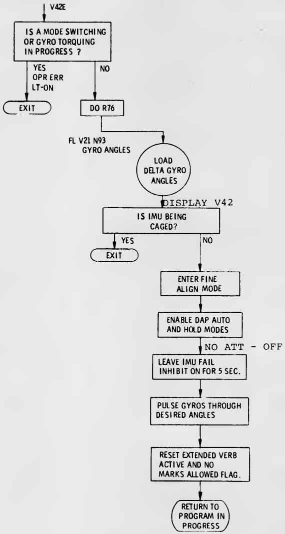
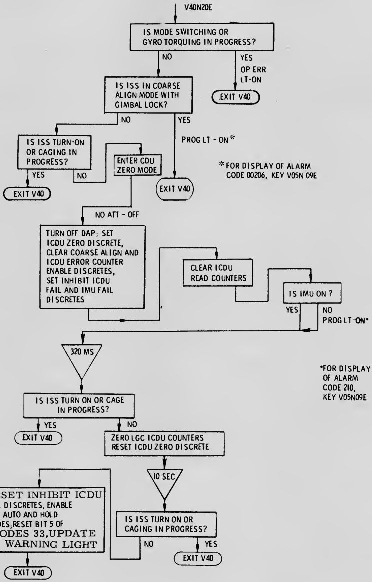


Figure 7.3.2-14. Fine Align IMU Extended Verb (V42)



* FOR DISPLAY OF ALARM CODE 00206, KEY V05N 09E

•FOR DISPLAY OF ALARM CODE 210, KEY V05N09E

Figure 7.3.2-15. IMU-ICDU Zero Extended Verb (V40 N20)

7.3.3 P57, Lunar Surface Alignment Program

P57 provides the crew with the capability to align or realign the IMU while the LM is on the lunar surface, using one of three types of orientation: (1) preferred (2) landing site (3) REFSMMAT. Within each of these types of orientation are four techniques available to the crew for completing the IMU alignment. The techniques are identified as 0 through 3 and are described below. If the alignment technique selected is other than 0, the program is designed to perform an initial alignment using the vectors of technique 0. After this initial alignment is completed, the program automatically recycles to perform the IMU realignment using the technique specified by the crew. Information obtained from the alignment is displayed via the DSKY to the crew and includes such data as the following:

a. Type of alignment
b. Time of alignment
c. Lunar gravity vector error angle
d. Position, including detent, azimuth, and elevation of the Alignment Optical Telescope when sighting celestial bodies
e. Gyro and gimbal angles
f. Landing site coordinates.

The displays associated with P57 are shown in Table 7.3.3-I.

7.3.3.1 Related Routines

Three routines are directly related to the Lunar Surface Alignment Program and are all called automatically by the program. One of the directly related routines calls an additional routine; this routine in turn calls another routine. Thus, P57 actually has the following five related routines:

a. AOT Mark Routine (R53)
b. Sighting Data Display Routine (R54)
c. Markrupt Routine (R57)
d. Celestial Body Definition Routine (R58)
e. Lunar Surface Sighting Mark Routine (R59).

When using P57 techniques 2 or 3 (refer to paragraph 7.3.3.3), optical sightings on a celestial body (navigation star, planet, or sun) are required. The Lunar Surface Sighting Mark Routine (R59) performs AOT sightings on these celestial bodies. R59 then automatically calls the AOT Mark Routine (R53) to process the sighting

TABLE 7.3.3-I

PROGRAM DISPLAYS (SHEET 1 OF 2)

DSKY	Initiated By	Purpose	Condition	Register
FL V04 N06	P57	Option code for assumed IMU orientation selection	Option code ID (R1) Option code (R2) X = 1 = Preferred 2 = Nominal 3 = REFSMMAT 4 = Landing site	R1 00001 R2 oooox R3 Blank
FL V06 N34	P57	Time at which the LM position vector is defined for a landing site orientation	T (Align)	R1 ooxxx hr R2 oooxx min R3 oxx. xx sec
FL V05 N06	P57	Option code for assumed alignment technique	Option code ID (R1) Option code (R2) Stored data code (R3) C = 1 REFSMMAT defined C = 0 No REFSMMAT defined D = 1 LM attitude available D = 0 LM attitude not available	R1 00010 R2 oooox R3 00CD0
FL V06 N04	P57	Gravity error angle	GRAV ERR ANGLE (difference between present and previously defined error angle.)	R1 xxx. xx deg R2 Blank R3 Blank
FL V01 N70	R59	AOT detent code and star code	AOT detent/star code A, B = 00 C = detent 1 = left 2 = center 3 = right 4 = right rear 5 = center rear 6 = left rear 7 = back-up optical system (not used on lunar surface) D, E, star code:00 planet; 01/45 star; 46, 47, 50, Sun, Earth Moon, respectively	R1 ABCDE (Octal) R2 Blank R3 Blank

TABLE 7.3.3-I

PROGRAM DISPLAYS (SHEET 2 OF 2)

DSKY	Initiated By	Purpose	Condition	Register
FL V06 N79	R59	Cursor and spiral angle, and AOT position code	Cursor angle Spiral angle Position code 1, 2, 3 = forward positions 4, 5, 6 = rear positions	R1 xxx.xx deg R2 xxx.xx deg R3 xxxxx.
FL V01 N71	R53	AOT detent/star code	AOT detent and star code (same as N70 above)	R1 ABCDE R2 Blank R3 Blank
FL V06 N87	R53	Back-up optical system azimuth and elevation LOS	Optical azimuth Optical elevation	R1 xxx.xx deg R2 xxx.xx deg R3 Blank
FL V54 N71	R53	Mark X or Y reticle line/star intersection	Mark X and/or Y reticle/star intersection (same as N71 above)	R1 ABCDE R2 Blank R3 Blank
FL V06 N88	R58	Assumed planet position	XPL 1/2 unit YPL Position vector ZPL Components	R1 .xxxxx R2 .xxxxx R3 .xxxxx
FL V06 N05	R54	Sighting angle difference	Sighting angle difference = measured minus catalog values	R1 xxx.xx deg R2 Blank R3 Blank
FL V06 N93	P57	Gyro torquing angles	X Gyro angle Y Gyro angle Z Gyro angle	R1 xx.xxx deg R2 xx.xxx deg R3 xx.xxx deg
FL V06 N22	P57	Resulting ICDU gimbal angles	OG IG MG	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
FL V50 N25	P57	Please perform fine align	Option code 00014 = fine align	R1 00014 R2 Blank R3 Blank
FL V06 N89	P57	Landing site coordinates	LAT LONG/2 ALT	R1 xx.xxx deg R2 xx.xxx deg R3 xxx.xx n.mi.

marks taken by the crew. However, in order for the crew to load the spiral and cursor angles while taking marks, R53 calls a portion of the Markrupt Routine (R57). With the processed information from R53, the Celestial Body Definition Routine (R58) then establishes the planet position vectors for the celestial body being used for the IMU alignment. P57 then transforms the LOS vectors in reference coordinates into desired IMU coordinates, calls the Sighting Data Display Routine (R54) that calculates the difference between the actual (stored) and the indicated (measured) sighting angles, and displays this information to the crew. The crew then decides whether to continue with the alignment using the available information or to take new sighting information and start the alignment process again.

7.3.3.2 Coordinate Systems

7.3.3.2.1 Basic Reference Coordinate System.—The Basic Coordinate System is an orthogonal inertial coordinate system whose origin is located at either the moon's or earth's center of mass; its orientation is defined as the line of intersection of the mean earth equatorial plane and the plane defined by the mean orbit of the earth (ecliptic) at a specified time. The X-axis is along this line of intersection with the positive sense in the direction of the ascending node of the ecliptic at the equator; the Z-axis is along the mean earth North pole; and the Y-axis completes the right-hand triad.

This coordinate system becomes moon-centered when the estimated vehicle distance from the moon first falls below approximately 38000 miles. This coordinate system again becomes earth-centered when the distance to the moon first exceeds this value. All navigation stars and lunar-solar ephemerides are referenced to this coordinate system, as are all state vectors and stable member orientations.

7.3.3.2.2 IMU Stable Member Coordinate System.—The IMU stable member coordinate system depends on the current IMU alignment. The origin of the IMU stable member coordinate system is the center of the IMU stable member. The primary alignment orientations used in P57 are as follows:

a. Preferred Alignment

$\underline{u}_{XSM} = \underline{u}_{TD}$

$\underline{u}_{YSM} = \text{UNIT} (\underline{u}_{XSM} \times \underline{r})$ If $\underline{r}$ not parallel to $\underline{u}_{TD}$

or $= \text{UNIT} (\underline{u}_{XSM} \times \underline{v})$ If $\underline{r}$ parallel to $\underline{u}_{TD}$

$\underline{u}_{ZSM} = \underline{u}_{XSM} \times \underline{u}_{YSM}$

where $\underline{u}_{TD}$ = unit vector in desired thrust direction at ignition

$\underline{r}$ = position vector at ignition

$\underline{v}$ = velocity vector at ignition

b. Local Vertical

$\underline{u}_{XSM}$ = UNIT ($\underline{r}$) at t_{align}
$\underline{u}_{YSM}$ = UNIT ($\underline{v} \times \underline{r}$)
$\underline{u}_{ZSM}$ = $\underline{u}_{XSM} \times \underline{u}_{YSM}$
where $\underline{r}$ and $\underline{v}$ represent the vehicle state at alignment time (t_{align})

c. Lunar Landing

$\underline{u}_{XSM}$ = UNIT ($\underline{r}_{LS}$) at t_L
$\underline{u}_{ZSM}$ = UNIT $[(\underline{r}_C \times \underline{v}_C) \times \underline{u}_{XSM}]$
$\underline{u}_{YSM}$ = $\underline{u}_{ZSM} \times \underline{u}_{XSM}$
where $\underline{r}_{LS}$ = lunar landing site vector at predicted landing time (t_L), $\underline{r}_C$ and $\underline{v}_C$ are CSM position and velocity vectors as maintained by the LGC.

d. Lunar Launch Time

Same as c except $\underline{r}_{LS}$ is the launch site vector at launch time (t_L).

7.3.3.3 Techniques

7.3.3.3.1 Technique 0.—This technique is a quick means for alignment in case of emergency launch. The IMU is driven to the desired orientation using the present LM attitude. Either the ATTITUDE flag or REFSMMAT flag, or both, must be set. A 00701 alarm occurs if neither is set.

7.3.3.3.2 Technique 1.—This technique is selected by the astronaut whenever a complete alignment or realignment is to be made by using the computed lunar gravity vector and the present LM attitude data. A 00701 alarm occurs if neither ATTITUDE flag nor REFSMMAT flag is set. Both flags may be set.

7.3.3.3.3 Technique 2.—This technique is selected by the astronaut whenever a complete alignment or realignment is to be made by sighting on two celestial bodies (usually stars) with the AOT. It is not necessary for either the ATTITUDE flag or REFSMMAT flag to be set.

7.3.3.3.4 Technique 3.—This technique is selected when a complete alignment or realignment is to be made by determining the lunar gravity vector with the IMU accelerometers and sighting on one celestial body with the AOT. It is not necessary for either the ATTITUDE flag or the REFSMMAT flag to be set.

7.3.3.4 P57 Logical Flow Description

Several techniques are available to the crew for completing the alignment of the IMU based either on landing site orientation, preferred orientation, or REFSMMAT as described in paragraph 7.3.3.3. The resultant accuracy of the IMU to the specified orientation depends on the technique that the crew selects. This selection is dictated by the circumstances at the time of alignment. The program description that follows is based on these techniques, 0 through 3, respectively.

The crew selects P57 by keying VERB 37 ENTR 57 ENTR into the DSKY. (See Figure 7.3.3-1.) The program immediately checks to determine if the inertial subsystem (ISS) is on. If the ISS is not on, the PROG alarm light goes on. By keying VERB 05 NOUN 09 ENTR into the DSKY, the crew may determine a 00210 alarm code indication. (Refer to paragraph 7.3.3.5.) If the ISS is on and operational, the crew sees a flashing VERB 04 NOUN 06 on the DSKY with registers 1 (R1) and 2 (R2) reading 00001 and 00003, respectively. The 00001 in R1 indicates that R2 specifies the assumed IMU orientation option. The 00003 in R2 indicates that the assumed option is REFSMMAT. If this option is not the one desired by the crew, VERB 22 ENTR may be keyed into the DSKY and another option selected. (See Table 7.3.3-I.) The nominal option (00002) is not allowed in P57.

If the orientation option is preferred (00001), REFSMMAT (00003), or landing site (00004), the technique of alignment must be determined. If the orientation option is 00004, however, the time of alignment t_{ALIGN} must also be determined prior to determination of technique of alignment; t_{ALIGN} is equal to the ascent time of ignition, $t_{IG(AS)}$. If all three registers contain zeros when t_{ALIGN} is displayed, the landing site orientation will be defined for a t_{ALIGN} automatically selected by the LGC as being the present time. Regardless of the value of t_{ALIGN}, it is used to compute the landing site orientation. Upon completion of this computation and storage of its value, the previously-stored preferred orientation is lost.

The next display that the crew sees is a flashing VERB 05 NOUN 06, which displays the assumed alignment technique, the assumed alignment technique option code, and a data code in registers R1, R2, and R3, respectively. (See Table 7.3.3-I.) This display requires that the crew either key in PRO or key in the desired alignment technique by keying in VERB 22 ENTR and loading the desired code in R2.

7.3.3.4.1 Technique 0.—As stated in paragraph 7.3.3.3, if technique 0 alignment is desired, either the REFSMMAT flag or the ATTITUDE flag or, both, must be set. If just the REFSMMAT flag is set, the LM attitude in moon-fixed coordinates is

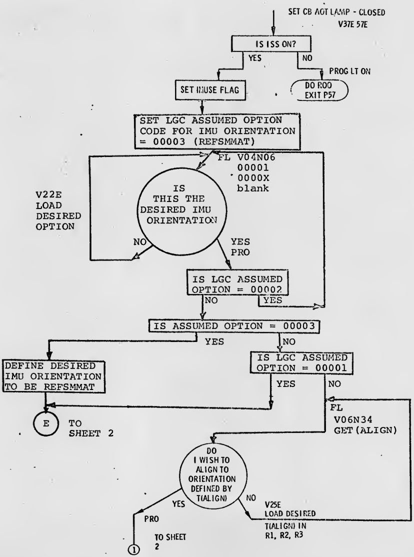


Figure 7.3.3 -1. Lunar Surface Alignment Program (P57) (Sheet 1 of 5)

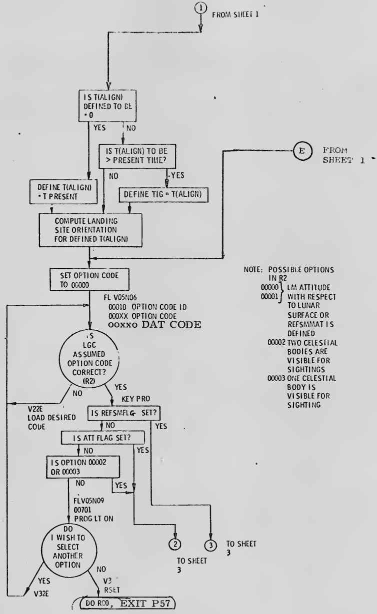


Figure 7.3.3-1. Lunar Surface Alignment Program (P57) (Sheet 2 of 5)

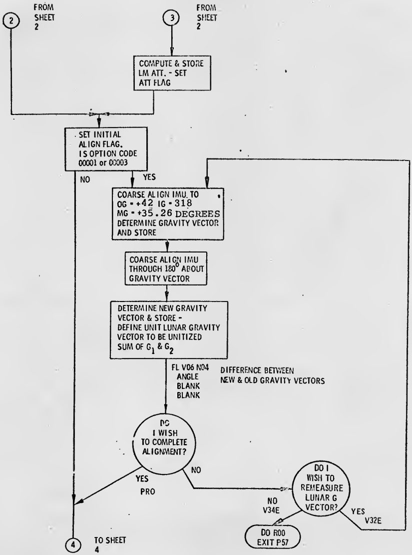


Figure 7. 3. 3-1. Lunar Surface Alignment Program (P57) (Sheet 3 of 5)

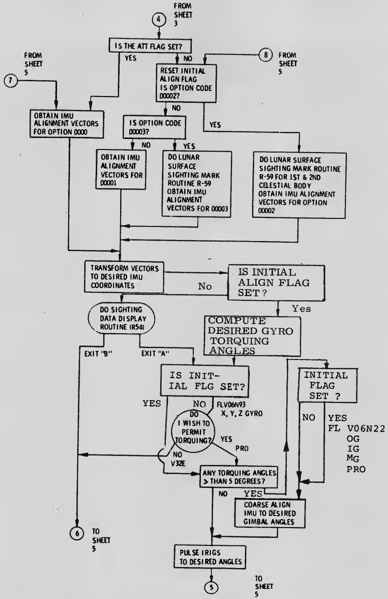


Figure 7.3.3-1. Lunar Surface Alignment Program (P57) (Sheet 4 of 5)

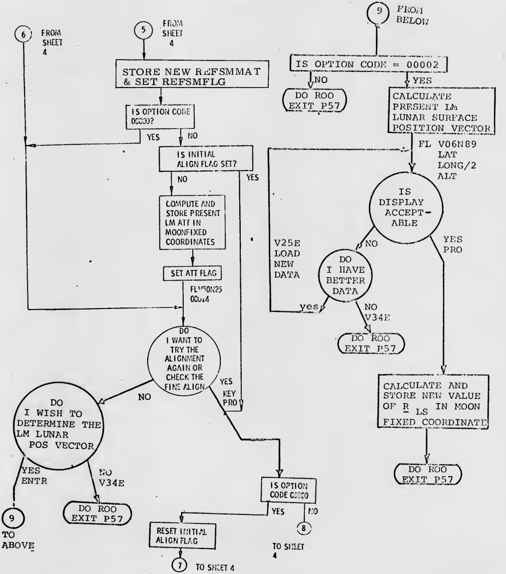


Figure 7.3.3-1. Lunar Surface Alignment Program (P57) (Sheet 5 of 5)

computed and stored by using REFSMMAT. Then the ATTITUDE flag is set. If just the ATTITUDE flag is set, it is not necessary to compute the LM attitude in moon-fixed coordinates. This sequence is common to all four alignment techniques. If the technique is other than 0, however, the INITIAL ALIGN flag is reset. After setting the ATTITUDE flag, the INITIAL ALIGN flag is set, and the unit LOS vectors are defined. (Refer to Table 7.3.3-II for source of vectors used in technique 0.)

The four IMU alignment vectors (S_A, S_B, S'_A, S'_B), are obtained as follows. The stored LM attitude vectors (Y and Z) are transformed from the moon-fixed coordinate system (MFCS) to basic reference coordinates and are defined as S'_A, S'_B, respectively. The Y and Z navigation base unit vectors define the orientation of the Y and Z LM axes with respect to the IMU stable member coordinate system and are denoted as S_A and S_B, respectively. Vectors S'_A and S'_B are then transformed from reference coordinates to desired IMU coordinates. The desired gyro-torquing angles are computed, and a check is made to determine if any of these angles are greater than 5 degrees. If not, the gyros are pulsed through the desired angles to align the IMU, and the REFSMMAT is defined to be the desired IMU orientation. A flashing VERB 50 NOUN 25 display then requests the performance of a fine alignment (code 00014). If the crew does not wish to fine align, the program may be terminated by keying in ENTR or VERB 34 ENTR, the normal exit from technique 0.

7.3.3.4.2 Technique 1.—The IMU is aligned to the desired orientation defined by the previous t_{ALIGN} display using the present REFSMMAT (or a stored LM attitude with respect to the lunar surface) and determination of the lunar gravity vector.

The LM attitude is computed and stored in moon-fixed coordinates as in technique 0. The gravity vector is then determined in the following way. The desired gimbal angles are set to +42 degrees, -42 degrees, and +35.25 degrees (OG, IG, and MG respectively), and the inertial subsystem is coarse aligned. The NO ATT light will be on indicating that the IMU is in the coarse align mode. The TRACK flag, DRIFT flag, and REFSMMAT flag are all reset. At the completion of the coarse alignment, if the gimbals are not within 2 degrees of the desired values, the PROG alarm light will come on. (Refer to paragraph 7.3.3.5, alarms 00211 and 00217.) If the system did coarse align correctly, the NO ATT light will go off indicating that the ISS is now inertial. The accelerometer outputs are monitored for approximately 40 seconds giving a gravity vector in stable member coordinates. These are unitized and transformed into navigation base coordinates, and a 1/2-unit gravity vector is stored. The gimbal angles to rotate the stable member 180 degrees are calculated, the ISS coarse aligned to these angles, and the 1/2-unit gravity vector is determined and stored as above. A flashing VERB 06 NOUN 04 will display the error between the

TABLE 7. 3. 3-II

SOURCES OF IMU ALIGNMENT VECTORS IN P57

Alignment Technique	Sources of IMU Alignment Vector			
	Basic Reference Coordinate System		Present IMU Stable Member Coordinate System	
	$\underline{S}'_A$	$\underline{S}'_B$	$\underline{S}_A$	$\underline{S}_B$
0	LM Y-axis stored in MFCS	LM Z-axis stored in MFCS	Present LM Y-axis	Present LM Z-axis
1	Landing Site stored in MFCS	LM Z-axis stored in MFCS	Gravity Vector Determination Routine	Present LM Z-axis
2	One or more of the following: 1. LGC star catalog 2. Loaded by astronaut 3. Ephemeris (i. e., SUN, EARTH)		AOT Sighting	AOT Sighting
3	Landing Site stored in MFCS	Same as technique 2 above	Gravity Vector Determination Routine	AOT Sighting

previously determined gravity vector and the unitized sum of the two 1/2-unit gravity vectors just determined. Until P57 is performed for the first time, the LGC assumes that the lunar gravity vector is parallel to the LM X-axis if the Landing Confirmation Program (P68) has been completed. If P68 has not been completed, the VERB 06 NOUN 04 display is meaningless on the first pass through the program. If a remeasure of the lunar gravity vector is desired, the crew must key in VERB 32 ENTR (recycle). If a completion of alignment is desired, the crew must key in PRO. This will complete the alignment as in technique 0 starting with the unit LOS vectors definition. (See Table 7.3.3-II.)

Upon completion of pulsing the gyros through the desired angles to align the IMU, a check is made to determine whether or not the alignment technique is 0. If it is not 0, the INITIAL ALIGN flag is reset and the angle between the actual and indicated alignment vectors is computed and displayed to the crew via a flashing VERB 06 NOUN 05 display in the Sighting Data Display Routine (R54). (See Figure 7.3.3-2.) If the angle is within acceptable limits, the crew keys PRO. P57 will compute the desired gyro torquing angles and display them in a flashing VERB 06 NOUN 93. If these angles are less than 5 degrees, the alignment will be continued as in technique 0 except that the LM attitude will be computed and stored in moon-fixed coordinates. If the angle determined in R54 is out of limits, the crew can key in recycle (VERB 32 ENTR) and start the final alignment procedure.

7.3.3.4.3 Technique 2.—Whenever a complete alignment or realignment is to be performed on the lunar surface using sightings on two celestial bodies, technique 2 must be used. When this technique is used, it is not necessary for either the REFSMMAT flag or the ATTITUDE flag to be set; the initial alignment (technique 0) is bypassed and the Lunar Surface Sighting Mark Routine (R59) is called immediately. If either flag is set, however, technique 0 alignment is completed. P57 then calls R59. (See Figure 7.3.3-3.) R59 is used to perform AOT sightings on celestial bodies while the LM is on the lunar surface. When the computer first enters R59, it determines whether or not the REFSMMAT flag is set. If it is not set, the computations are immediately transferred to the AOT Mark Routine (R53) which will be described later. For the present, it is assumed that the REFSMMAT flag is set. Thus, the crew sees a flashing VERB 01 NOUN 70 display indicating the AOT detent position and the star code. (See Table 7.3.3-I.) The crew can then key in the star code for the celestial body on which it desired to sight. When the proper information is displayed to the crew, it can key in PRO. If the crew has selected a star for its sightings, the computer will calculate, in navigation base coordinates, the star LOS from the star data and the optical axis for the presently defined AOT position code.

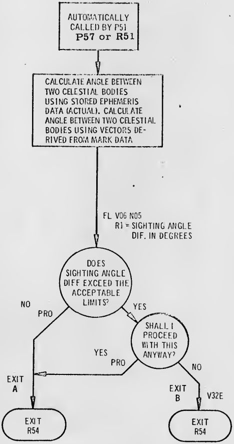


Figure 7.3.3-2. Sighting Data Display Routine (R54)

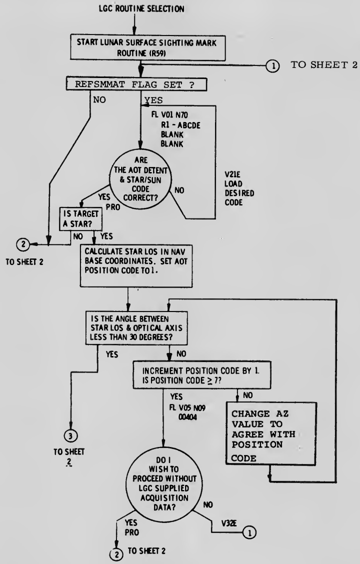


Figure 7.3.3-3. Lunar Surface Sighting Mark Routine (R59) (Sheet 1 of 2)

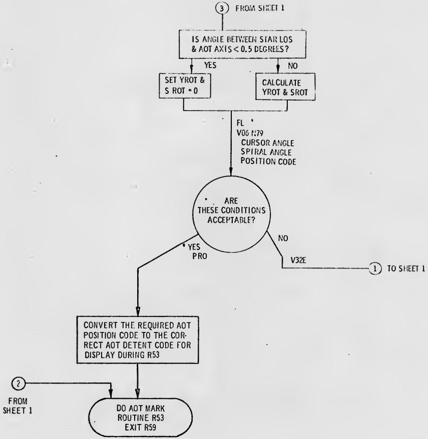


Figure 7.3.3-3. Lunar Surface Sighting Mark Routine (R59) (Sheet 2 of 2)

If the angle between the star LOS and the optical axis is greater than 30 degrees, the position code will be incremented by 1 each time it is checked until the angle is less than 30 degrees. If the AOT position code is incremented through the six AOT positions and the angle between the star LOS and the optical axis is still greater than 30 degrees, a flashing VERB 05 NOUN 09 display will indicate an alarm code 00404 (see paragraph 7.3.3.5), allowing the crew to select another star and repeat the process, or to proceed to R53 without LGC supplied data.

If the angle between the star LOS and optical axis is less than 30 degrees, the cursor and spiral angles are calculated and displayed along with the position code via a flashing VERB 06 NOUN 79. (See Table 7.3.3-I.) The AOT position code is converted to the correct AOT detent code and R53 is called.

The AOT Mark Routine, R53, (see Figure 7.3.3-4) will process the sighting marks on the celestial bodies. While the LM is on the lunar surface, only the AOT may be used for sighting on celestial bodies. Upon initial entry into R53, several checks are made to determine if it is possible to use the routine. (See paragraph 7.3.3.5, alarm codes 20105, 31211, and 31207.) The first display the crew will see in this routine is a flashing VERB 01 NOUN 71 indicating the AOT detent code and star code. (See Table 7.3.3-I.)

If the codes are not those determined previously in R59, the crew may key in VERB 21 ENTR, load the desired codes, and PRO. The next display the crew will see is flashing VERB 54 NOUN 71 requesting a please perform mark X or mark Y reticle line/star intersection. While the LM is on the lunar surface, marks are taken singly by pushing either the MARK X or the MARK Y pushbutton. This is usually accomplished between the measurement and the recording of the angle at the point where the cursor and the star are aligned, and the angle where the spiral and the star are aligned. (See Figure 7.3.3-5.)

By depressing either the MARK X or MARK Y pushbutton, the VERB 06 NOUN 79 display in the Markrupt Routine, R57 (see Figure 7.3.3-6), comes up allowing the crew to load the angles just recorded into registers R1 and R2 by keying in VERB 24 ENTR and then loading the angles. Up to five marks may be taken on a particular celestial body by keying in VERB 32 ENTR after each cursor and spiral angle load. If more than five marks are taken, the PROG alarm light will come on. (See paragraph 7.3.3.5, alarm code 00107.) The LGC will average all the LOS to define a final LOS on a particular celestial body.

After each mark, the crew has the option to terminate marking by keying PRO; continue marking on the same celestial body (with the restriction noted above) by

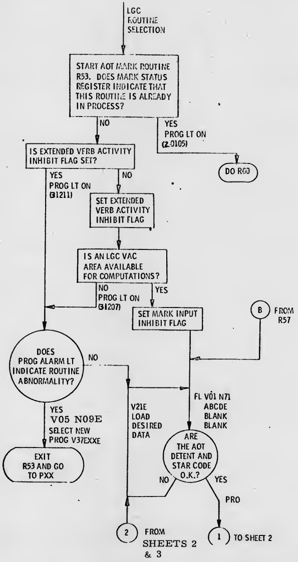


Figure 7.3.3-4. Sighting Mark Routine (R53) (Sheet 1 of 3)

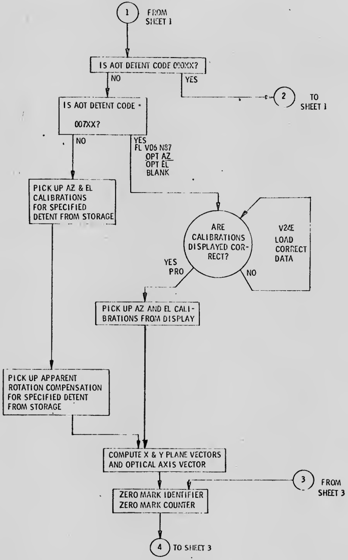


Figure 7.3.3-4. Sighting Mark Routine (R53) (Sheet 2 of 3)

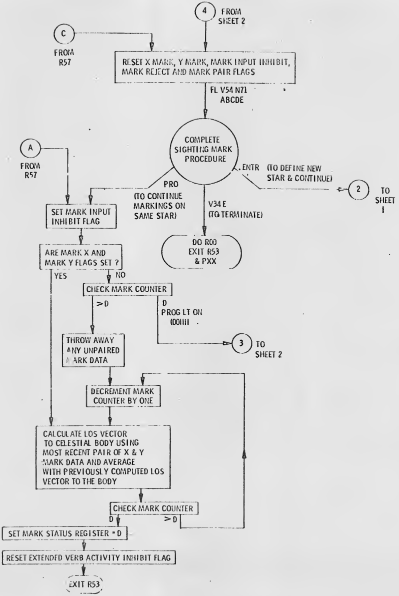


Figure 7. 3. 3-4. Sighting Mark Routine (R53) (Sheet 3 of 3)

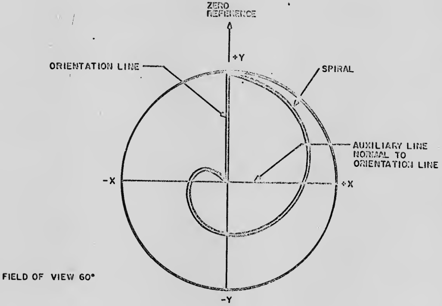


Figure 7.3.3-5. Alignment Optical Telescope Reticle Pattern

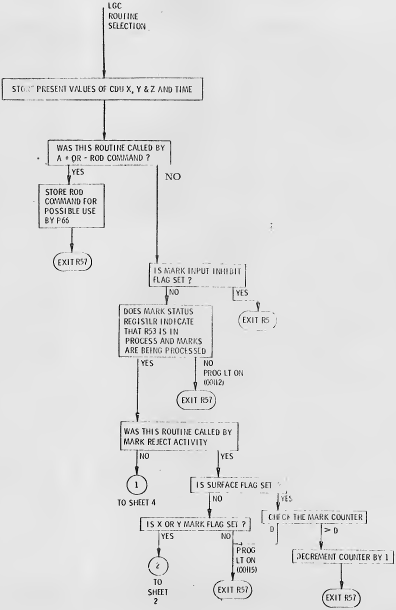


Figure 7.3.3-6. Markrupt Routine (R57) (Sheet 1 of 4)

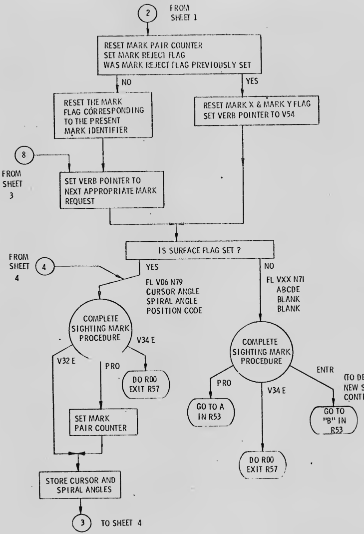


Figure 7.3.3-6. Markrupt Routine (R57) (Sheet 2 of 4)

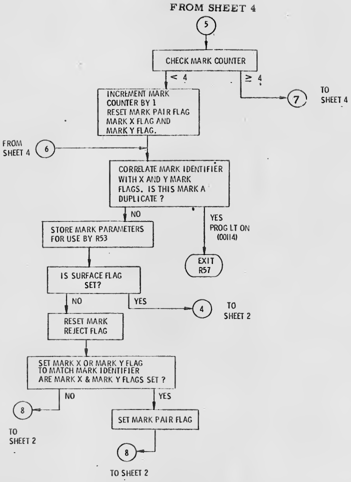


Figure 7. 3. 3-6. Markrupt Routine (R57) (Sheet 3 of 4)

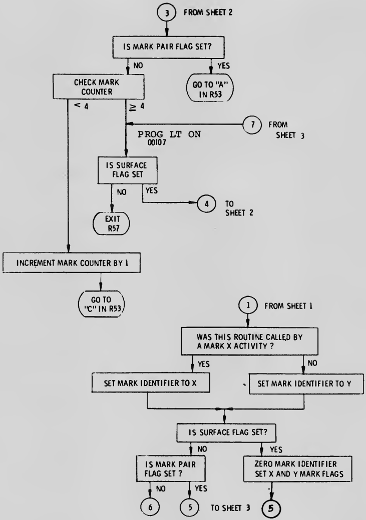


Figure 7.3.3-6. Markrupt Routine (R57) (Sheet 4 of 4)

keying in VERB 32 ENTR (recycle); discard all data on the present celestial body and select a new one by keying in ENTR on the VERB 54 NOUN 71 display, defining the new body, and starting marking; or terminate the entire alignment by keying in VERB 34 ENTR (terminate).

This marking procedure must be performed on two celestial bodies. Their LOS vectors must then be computed with respect to the present stable member to desired IMU coordinates. Once these LOS vectors, together with others obtained from the LGC star catalog or loaded by the crew, or computed from ephemeris data using the Celestial Body Definition Routine, R58 (see Table 7.3.3-I and Figure 7.3.3-7), have been determined, the remaining steps of the alignment process are the same as technique 0.

7.3.3.4.4 Technique 3.—This technique is selected when the complete IMU alignment is to be made by determining the lunar gravity vector, as in technique 1, and sighting one celestial body, as in technique 2.

When using any of these techniques, a request to perform a fine align (VERB 50 NOUN 25 code 00014) is accomplished by keying a PRO from this display. When the crew has keyed in PRO from the VERB 50 NOUN 25 display, the initial align flag has been reset (except in technique 0). The IMU alignment vectors are obtained for the technique being used to align the IMU, as described above, and a realignment is accomplished.

7.3.3.5 Program Alarms

Viewing a PROG alarm light on the DSKY, the crew keys VERB 05 NOUN 09 ENTR for a display of the alarm code—if the code has not already been displayed by the CMC. After taking corrective action, the crew keys RSET to turn off the PROG light and alarm and continues with the program. Possible alarms encountered during P57 are as follows:

a. Alarm 00210 is displayed if the IMU is not operating when P57 is first entered.
b. Alarms 00211 and 00217 are displayed, if at the end of a coarse alignment the gimbals are not within 2 degrees of the desired values.
c. Alarm 00701 is displayed if neither the present REFSMMAT nor a stored LM attitude is available.
d. Alarm 31211 is displayed when there is an illegal interrupt by an extended verb.
e. Alarm 00404 is displayed if in technique 2, two stars are not available in any detent position of the AOT.

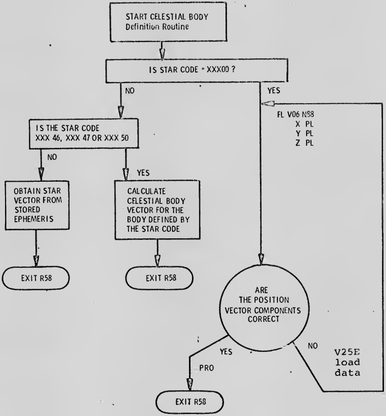


Figure 7.3.3-7. Celestial Body Definition Routine (R58)

f. Alarm 20105 is displayed if, when the crew wants to start processing marks, the mark register indicates that the AOT mark system is in use.

g. Alarm 31207 is displayed if there are no VAC areas available for the computation and processing of the marks.

h. Alarm 00111 is displayed on PROCEED from the NOUN 71 display if there is not enough data (Mark counter = 0) to compute a star vector.

i. Alarm 00107 is displayed if more than five marks have been taken on a single celestial body.

The ISS must be on and at either a known or an unknown orientation in order to align the IMU using P57. If the ISS is not on, alarm code 00210 will alert the crew to press the IMU OPERATE circuit breaker and allow 15 minutes for warm-up before re-initializing P57.

When using alignment techniques 1 or 3 and prior to the start of coarse alignment of the ISS, the outer gimbal, inner gimbal, and middle gimbal are set to +42 degrees, -42 degrees and +35.25 degrees, respectively. Upon completion of the coarse align, if the gimbals are not within 2 degrees of these values, alarm codes 00211 and 00217 will alert the crew and a realignment may be accomplished. Following the NOUN 04 display, a VERB 34 ENTR may be keyed in to terminate the current calculation, and P57 entered again by keying in VERB 37 ENTR 57 ENTR and selecting technique 1 or 3 again. Or VERB 32 ENTR (recycle) may be keyed in to recycle to the point where the expected gimbal angles are set. When using this method, the gravity vector that has been previously calculated and stored is then compared to the recalculation rather than to the originally defined gravity vector.

In NOUN 70 when a star code is selected, the AOT is set to 1 and the angle between the star LOS and the optical axis is calculated. If the difference is greater than 30 degrees, the AOT position is incremented by 1. If upon searching all 7 positions the difference is still greater than 30 degrees, a flashing VERB 05 NOUN 09 is displayed automatically with alarm code 00404. The crew may key in VERB 32 ENTR and recycle to a point from which to select a different star and determine the angle between that star and the AOT optical axis, or may key in PRO and start taking marks via the AOT Mark Routine (R53).

When the alignment telescope marking system is in use and the crew desires to start processing additional marks, the PROG alarm light may go on, indicating that it is impossible at this time to process additional marks. Alarm code 20105 will be displayed by keying in VERB 05 NOUN 09. If this alarm does occur, the program will automatically go to R00 and the whole marking process will have to be re-initiated via the calling program. The alarm code displayed could also be 31207 indicating that no VAC areas were available for storing parameters for computations of mark information. If this alarm occurs, the computer does an automatic restart, releasing all the VAC areas, and recycles to the beginning of R53.

Register 1 of the NOUN 71 display shows the AOT detent and star codes. Marks on the indicated star are made singly by depressing either the MARK X pushbutton, or the MARK Y pushbutton. If for any reason the mark counter equals 0 when PRO is keyed on NOUN 71, the PROG alarm light will come on. Upon keying VERB 05 NOUN 09, an alarm code 00111 will come up. This situation may be remedied by taking a mark, keying in the NOUN 79 data, and then keying PRO. After each mark, the crew may either terminate marking by keying in PRO; continue marking on the same celestial body (if less than five marks are already stored in the LGC); discard all data, select a new celestial body and continue marking by keying in ENTR; or terminate the whole alignment by keying in VERB 34 ENTR (terminate).

The mark counter in the LGC keeps track of the number of marks taken on a particular celestial body. If, while the LM is on the lunar surface, the number of marks registered by the counter exceeds five, the PROG alarm light will come on. The crew, by keying in VERB 05 NOUN 09, may determine that the alarm code is 00107, indicating that more than five marks have been taken on that particular celestial body.

7.3.3.6 Restart

P57 is restart protected. Should a restart occur, the program will return to one of several predetermined points, depending on where in the program the restart occurred. The program will then continue to completion.

SECTION 8.0

ENTRY/DESCENT

(TBF)

BLANK

SECTION 9.0

ADDITIONAL EXTENDED VERBS AND ROUTINES

BLANK

SUBSECTION 9.1

INTRODUCTION
(TBF)

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SUBSECTION 9.2

ADDITIONAL CMC EXTENDED VERBS AND ROUTINES

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9.2.1 R03, Digital Autopilot (DAP) Data Load—CMC

R03 allows the crew to load and verify CMC DAP data and provides the crew with the means for selecting appropriate coast autopilots. The computer logic is so arranged that, after selecting R03 and entering or verifying data, a single extended verb will allow the appropriate DAP to become active.

To function properly, autopilots in the CMC need the following types of information:

1. Mass of the vehicle and approximate location of the center of gravity (cg)
2. Configuration of the vehicle (for example, SIVB, CSM alone)
3. Quad information (for example, which quads are enabled in general, which are to be used for X-translation and roll)
4. Deadband width, maneuver rate.

Good knowlege of vehicle cg is important during maneuvers in order to eliminate or minimize transients resulting from poor knowlege of the location of the center of gravity. Accurate knowlege of the vehicle mass and configuration minimizes fuel expenditure during RCS DAP operation.

Vehicle mass and center of gravity are updated by the TVC DAP during SPS maneuvers. RCS maneuvers and the coast autopilots, however, do not update such information. Further, when the vehicle changes configuration, there is no onboard program that automatically calculates the new mass and center of gravity. Therefore, R03 must be used after a change in vehicle configuration, and is usually checked before each thrusting maneuver.

9.2.1.1 Computational Sequence

The computational sequence of R03 is shown in Figure 9.2.1-1. After VERB 48 ENTR is received from the DSKY, R03 checks to determine whether the TVC DAP, or any extended verb is active. If so, R03 illuminates the OPR ERR light and terminates. If not, VERB 04 NOUN 46 is flashed for astronaut approval or change. NOUN 46 contains the DAP data code. Every octal digit assumes individual importance, and is, therefore, treated separately as an alphameric letter in Table 9.2.1-I. Each octal digit (i.e., each letter in the table) pertains to a different aspect of the DAP. A flashing VERB 06 NOUN 47 follows, showing the CSM and LM weights for approval or change. Usually, the ground voices up such information. After PRO is received to the NOUN 47 display, NOUN 48 is flashed, displaying the SPS

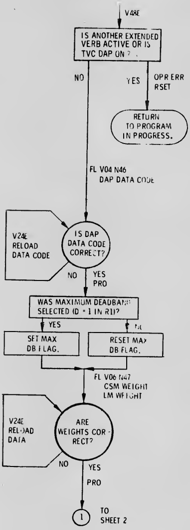

Figure 9. 2. 1-1. CMC Digital Autopilot (DAP) Data Load Routine (R03) (Sheet 1 of 2)

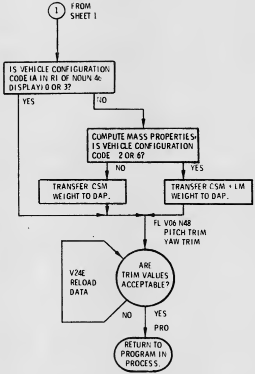

Figure 9. 2. 1-1. CMC Digital Autopilot (DAP) Data Load Routine (R03) (Sheet 2 of 2)

TABLE 9. 2. 1-I

R03 DISPLAYS (SHEET 1 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
FL V04 N46	R03	DAP configuration data	R1 of VERB 04 NOUN 46 must be loaded with the correct code, as follows: A Vehicle configuration code 0 = no DAP 1 = CSM 2 = CSM+LM (ascent+descent) 3 = SIVB 6 = CSM+LM (ascent only) B Quad AC for +X translation code 0 = do not use quad 1 = use quad C Quad BD for +X translation code 0 = do not use quad 1 = use quad D Deadband code 0-0. 5 deg 1-5. 0 deg E Maneuver rate code 0-0. 05 deg/sec 1-0. 2 deg/sec 2-0. 5 deg/sec 3-2. 0 deg/sec NOTE: If both B and C display zero, 4-jet translation will be used.	R1 xxxxx* octal
FL V04 N46	R03	Data code	R2 of VERB 04 NOUN 46 must be loaded with the correct code, as follows: A Quad AC or BD roll code 0 = use BD 1 = use AC B Quad A Code 0 = do not use quad 1 = use quad C Quad B Code 0 = do not use quad 1 = use quad	R2 xxxxx* octal

*The most significant digit (i.e., leftmost digit) refers to A; the next most significant digit refers to B, and so on.

TABLE 9.2.1-I

R03 DISPLAYS (SHEET 2 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
			D Quad C code 0 = do not use quad 1 = use quad E Quad D code 0 = do not use quad 1 = use quad	
FL V06 N47	R03	CSM weight		R1 xxxxx lbs
FL V06 N47	R03	LM weight		R2 xxxxx lbs
FL V06 N48	R03	Pitch engine trim gimbal angle		R1 xxx. xx deg
FL V06 N48	R03	Yaw engine trim gimbal angle		R2 xxx. xx deg

engine trim gimbal angles (hence, by implication, the cg) for approval or change. A PRO response to the NOUN 48 display terminates R03.

Changes from one RCS DAP to another are made automatically, at termination of R03. But a transition from one of the following configurations (1) Saturn DAP, (2) RCS DAP, (3) no DAP to another requires execution of VERB 46 ENTR.

9.2.1.2 Program Alarms

The OPR ERR light is illuminated if the TVC DAP is on, any extended verb is operating, or if there is a priority display on the DSKY when R03 is keyed in.

9.2.1.3 Restrictions and Limitations

PRO is required to enter all data. VERB 34 ENTR will not work. Pairs A and C or B and D quads cannot be failed.

9 2.1.4 Restarts

R03 is not restart protected. Should a restart occur, the astronaut must reselect R03.

9.2.2 (TBD)

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9.2.3 R30, Orbital Parameters Display—CMC

VERB 82 ENTR initiates R30, which computes orbital parameters. The parameters computed by R30 can be used to monitor the progress of thrusting maneuvers, or to check the current orbit during coasting flight.

9.2.3.1 Inputs

R30 inputs are delineated in Table 9.2.3-I.

If AVERAGEG is running—i.e., during powered flight—there are no astronaut inputs to R30. The routine simply uses the current state vector, as updated by AVERAGEG, to calculate the displayed parameters. If AVERAGEG is not running—i.e., during coasting flight—there are two astronaut inputs to R30:

1. Choice of vehicle—LM or CM
2. Time for which the orbital parameters are to be calculated.

Input 2 is necessary because R30 calculates orbital parameters using calculations that do not take perturbation effects into account. These calculations are discussed in more detail in paragraph 9. 2. 3. 6.

9.2.3.2 Outputs

R30 outputs are delineated in Table 9.2.3-II.

The following parameters are always computed:

1. Apogee altitude
2. Perigee altitude
3. Time of free fall to the orbital interface* (TFF), or
4. Time from perigee, TPER, if the current orbit does not intersect the orbital interface.

In addition, if the current major mode is P11 (Earth-orbit-insertion Monitor Program) or P00(CMC Idling Program), R30 also computes the miss distance,

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*The orbital interface is 35, 000 feet above the current landing site radius in lunar orbit, and 300, 000 feet above launch pad radius in earth orbit.

TABLE 9.2.3-I

R30 INPUTS*

DSKY	Initiated By	Purpose	Condition	Register
FL V04 N12	R30	Assumed vehicle code. Initially displays 00001, indicating CM. VERB 22 ENTR 2 ENTR indicates LM is to be assumed vehicle.	Request astronaut to indicate assumed vehicle	R1 00002 R2 oooox
FL V06 N16	R30	Initially displayed as all zeros, indicating current time. If other than current time, is desired, it should be loaded via VERB 25 ENTR, in ground elapsed time (GET).	Time at which the calculations are to be valid	R1 ooxxx. hrs R2 oooxx. min R3 oxx. xx sec

*No astronaut inputs are required when AVERAGEG is running.

TABLE 9.2.3-II

R30 OUTPUTS

DSKY	Initiated By	Purpose	Condition	Register
FL V16 N44	R30	These apsidal altitudes measured above launch pad radius, when in the earth's sphere, and above the latest landing site, when in the moon's sphere.	Apogee altitude Perigee altitude	R1 xxxx. x n. mi. R2 xxxx. x n. mi.
		Once computed, counts down. Sign convention is in text.	Time to interface altitude (free fall)	R3 xxBxx min, sec
NOUN 32 ENTR (keyed after FL VERB 16 indicates R30 calculations are completed).	Astronaut	Computed when current orbit does not intersect the interface altitude, and then counts down. Set to zero otherwise.	Time to perigee (free fall)	R1 ooxxx. hrs R2 oooxx. min R3 oxx. xx sec
NOUN 50 ENTR (keyed after FL VERB 16 indicates R30 calculations are completed).	Astronaut	Computed during P11 and P00	Splash error Perigee altitude Time to interface (free fall)	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min, sec

SPLERROR, between the splashpoint currently stored in the CM computer and the expected splashpoint arising from the current trajectory.

9.2.3.3 Options

The options discussed in this paragraph are as follows:

1. Choice of vehicle
2. Choice of NOUN to monitor

If AVERAGEG is running, the astronaut has no choice of vehicle; the CM is always the vehicle for which the parameters are calculated. Otherwise, the choice of vehicle clearly depends on which vehicle's orbital parameters the astronaut needs.

The astronaut can monitor three nouns, NOUN 44, NOUN 32, and NOUN 50. In most cases, NOUN 44, which R30 flashes automatically, gives all the information computed by R30; it contains apogee altitude, perigee altitude, and time of free fall to the interface altitude. An exception is when the current orbit does not intersect the interface altitude. Then R30 calculates the time of free fall to perigee in hr, min, and sec; this display can be called in NOUN 32.

If P00 or P11 is running, NOUN 50 is the desired display, since NOUN 50 shows the splash error, as well as perigee altitude and time of free fall to the interface altitude. If the apogee is above 300, 000 feet, and the perigee is below 300, 000 feet, the splash error is displayed as the distance between the predicted and the desired abort target. If either of these conditions is not satisfied, as in the early stages of boost, or when the CM is already in orbit, the splash error is displayed as the distance between the present position vector and the desired abort target.

9.2.3.4 Computational Sequence

Figure 9.2.3-1 illustrates the computational sequence of R30. After the astronaut selects R30, via VERB 82 ENTR, R30 determines whether another extended verb is active. If so, R30 illuminates the OPR ERR light and terminates. If the astronaut still desires R30, he must terminate the other extended verb and reselect R30.

If no other extended verb is operating, R30 next determines whether AVERAGEG is running. If so, R30 calculations are updated about every 2 seconds. If not, the

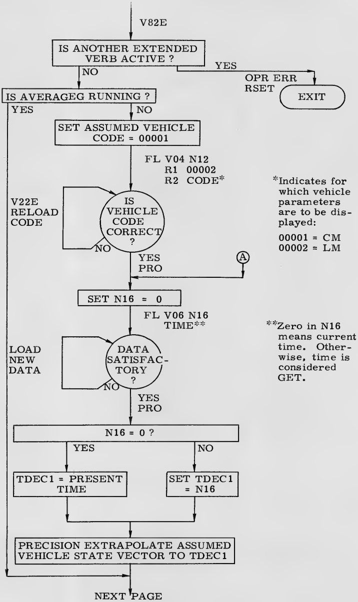
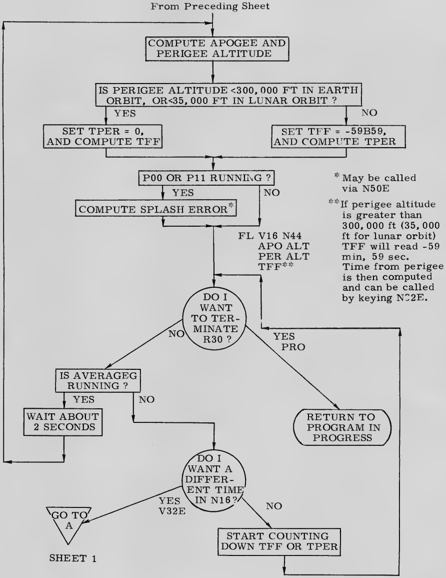


Figure 9.2.3-1. Orbital Parameters Display-CMC (R30) (Sheet 1 of 2)



* May be called via N50E

**If perigee altitude is greater than 300,000 ft (35,000 ft for lunar orbit) TFF will read -59 min, 59 sec. Time from perigee is then computed and can be called by keying N32E.

Figure 9.2.3-1. Orbital Parameters Display-CMC (R30) (Sheet 2 of 2) calculations are done once, with the exception that the displayed times are made to count down.

9.2.3.4.1 R30 AVERAGEG Calculations.—During AVERAGEG operation, R30 begins calculation of the outputs listed in paragraph 9.2.3.2 as soon as the CM computer can schedule them—that is, as soon as AVERAGEG is completed for the current cycle. R30 uses the current state vector, and its associated time, updates its calculations approximately every two seconds, depending on the availability of computer time and flashes the results in a VERB 16 NOUN 44 display. If P11 is running, the astronaut should key in NOUN 50 ENTR to monitor the splash error. R30 automatically terminates when AVERAGEG terminates (i.e., at selection of a new program). If the astronaut wishes to terminate R30 before AVERAGEG terminates, he can respond to the flashing VERB 16 NOUN 44 or NOUN 50 with a PRO.

9.2.3.4.2 R30 Coasting Flight Calculations.—If AVERAGEG is not running, R30 must have two inputs from the astronaut (1) the assumed vehicle, and (2) the time at which the calculations are to be valid. Accordingly, R30 flashes VERB 04 NOUN 12, requesting choice of vehicle, and follows a PRO response to that display with a flashing VERB 06 NOUN 16, requesting the desired time. After a PRO response to the second display, R30 uses Coasting Integration to obtain the orbit at the time indicated by NOUN 16, and begins calculations of the orbital parameters. If the current orbit intersects the interface altitude, R30 calculates TFF, sets TPER to zero, and begins counting down. If the current orbit does not intersect the interface altitude, R30 sets TFF to -59B59, calculates TPER, and begins counting down.

Since R30's calculations are conic, based on the orbit extrapolated to the time indicated by NOUN 16, different results will be obtained from different NOUN 16 times. If a different time is desired, the astronaut can key VERB 32 ENTR in response to flashing VERB 16 NOUN 44, after which R30 flashes VERB 06 NOUN 16, requesting a new time. A PRO response to flashing VERB 16 NOUN 44 terminates R30.

9.2.3.4.3 Sign Conventions.—The sign convention for TFF is as follows: the DSKY display is negative and decreasing (in magnitude) as the interface altitude approaches.* Between the interface altitude and perigee altitude, TFF is positive and increasing. When perigee is passed, R30 continues to display positive increasing time. For coasting-flight elliptical trajectories after perigee, however, a recycle (VERB 32

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*The maximum display is ±59B59. Therefore, although the internal calculations may be counting down, the DSKY will continue to display ±59B59 until the value is less than one hour.

ENTR) would result in a display of negative time from next arrival at orbital interface. TPER is always negative and decreasing in magnitude, except for outbound hyperbolic and parabolic trajectories, when it is positive and increasing.

9.2.3.5 Procedures

When AVERAGEG is running, the astronaut keys in VERB 82 ENTR, and, if no other extended verb is running, R30 begins its computations and flashes VERB 16 NOUN 44. If P11 is running, the astronaut keys in NOUN 50 ENTR to obtain the estimate of splash error. During P40 maneuvers, the astronaut should key PRO to terminate R30 before the expected cutoff time, in order to allow important P40 displays to come up. (Extended verb displays have priority over non-priority program displays.)

When AVERAGEG is not running, the astronaut keys in VERB 82 ENTR. If no other extended verb is running, R30 flashes VERB 04 NOUN 12, requesting choice of vehicle. A PRO response indicates the CM is the assumed vehicle. A VERB 22 ENTR 2 ENTR response followed by PRO indicates the LM is the assumed vehicle. After the vehicle choice is made, R30 flashes VERB 06 NOUN 16, requesting the time of calculation validity. Initially, all zeros are displayed. A PRO response to all zeros in NOUN 16 indicates the astronaut desires the current time. To load a different time, the astronaut keys VERB 25 ENTR, loads the desired time in ground elapsed time (GET) and keys PRO, to obtain the flashing VERB 16 NOUN 44. Expected time of perigee is usually used when the current time is not desirable, for example, in the middle of transearth or translunar coast. If several times are to be used, the astronaut can recycle (VERB 32 ENTR, in response to flashing VERB 16 NOUN 44, 50, or 32) and load the new times into NOUN 16. If NOUN 44 indicates that the current orbit does not intersect the interface altitude (i.e., when R2 is greater than 49.4 n. mi. around the earth, or 5.8 n. mi. around the moon), the astronaut keys in NOUN 32, to obtain the time to perigee.

If the CM is approaching entry and the current major mode is P00, the astronaut keys in NOUN 50 ENTR when VERB 16 NOUN 44 flashes, to get the estimate of splash error.

R30 can be terminated by keying PRO to the flashing VERB 16 NOUN 44, NOUN 50, or NOUN 32, or by selecting a new major mode.

9.2.3.6 Restrictions and Limitations

A flashing display from an extended verb, such as R30, takes priority over a flashing display from a major mode. The operation of R30, therefore, should be restricted to those times when important displays requiring immediate astronaut action are not expected.

During simulations, R30 has been known to cause bailout restarts (alarm codes 31201 or 31202) during periods of high computer activity. Some periods of high activity are during Lambert maneuvers, during P11, and when both P20 and a targeting program are running. These restarts are of little significance, except that R30 activity is terminated by the restart. If the crew still desires R30, they can reselect it. Since such restarts are often a matter of coincidence, reselection may not cause another restart.

The calculations used in R30 are conic. Thus, not only will these calculations produce meaningless results when the input time places the spacecraft in the middle of transearth or translunar coast, but in the following specific instances, they may result in a 21302 (square root negative number) POODOO abort:

1. From TEI +1.3 hours until sphere crossing (i.e., post-TEI, when the magnitude of the position vector is greater than 4333 n. mi.)
2. From the sphere crossing until LOI minus 3 hours (i.e., pre-LOI, when the magnitude of the position vector is greater than 7743 n. mi.).

9.2.3.7 Alarms

The OPR ERR light will illuminate if R30 is called when another extended verb is running. The alarms mentioned in paragraph 9.2.3.6 are the only ones expected during R30. They are as follows:

a. Alarm codes 31201 and 31202, a coreset overflow and a VAC area overflow, respectively. They may occur during operation of P11, P20, or P40/P41. Should they occur the crew can reselect R30.

b. Alarm code 21302, the square root of a negative number. This is caused by using the conic calculations in R30 with a time that places the spacecraft in the middle of transearth or translunar coast. Refer to paragraph 9.2.3.6. Recovery procedures are the reselection of R30 with a different time in NOUN 16. Since a NOUN 16 time is not available when AVERAGEG is running, R30 should not be selected during transearth or translunar midcourse maneuvers.

9.2.3.8 Restarts

R30 is not restart protected. Should a restart occur, the astronaut must reselect the routine.

B L A N K

9.2.4 R36, Rendezvous Out-of-Plane Display—CMC

R36 computes and displays parameters related to the out-of-plane characteristics of the current orbital configuration, and allows the astronaut to target maneuvers designed to achieve coplanar orbits.* Such maneuvers might be targeted by the following programs:

a. P30—targets out-of-plane maneuvers not timed with the typical rendezvous sequence maneuvers.
b. P32—targets coelliptic sequence initiation (CSI) maneuvers.
c. P33—targets constant delta height (CDH) maneuvers.
d. P34—targets transfer phase initiation (TPI) maneuvers.
e. P35—targets transfer phase midcourse (TPM) maneuvers.

The routine calculates the parameters on the basis of the stored LM and CSM state vectors, and the following two astronaut inputs:

a. The assumed vehicle**
b. The time at which the calculations are to be valid [specified time, or T(EVENT)].

Using these inputs, R36 computes and displays the following:

1. Y, the distance the specified (assumed) vehicle will be from the plane of the other vehicle at the specified time, i.e., the out-of-plane distance
2. $\dot{Y}$, the rate of change of Y, i.e., the out-of-plane velocity
3. ψ, the angle between the line-of-sight from the assumed vehicle to the other vehicle, and the +x-direction of the assumed vehicle's local vertical coordinate frame, at the specified time.

For the astronaut, the most significant of these displays is $\dot{Y}$, the out-of-plane velocity, because it allows him to target for a coplanar orbit. Each of the targeting programs listed above displays the $\Delta\underline{v}$(LV) for the astronaut's approval or modification. The

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*In general, it is desirable to carry out a rendezvous under circumstances in which the LM and the CSM orbits are coplanar.

**The assumed vehicle is usually the one that is to do an out-of-plane maneuver.

astronaut then loads the negative of the $\dot{Y}$ into the Y component (register 2) of the $\Delta\underline{v}$(LV) display. This value is designed to produce a node 90 deg later. If the out-of-plane velocity ($\dot{Y}$) of the assumed vehicle is nulled at a particular point by thrusting an equal $\Delta\underline{v}$ in the opposite direction, then that point becomes an antinode, and 90 deg later, a node will occur. If the out-of-plane velocity is then nulled at the node, the two orbits become coplanar. (A more detailed explanation of the orbital mechanics involved in out-of-plane maneuvers is included in the introduction to the targeting programs, subsection 5.1.)

9.2.4.1 Inputs and Outputs

As mentioned above, R36 calculates the parameters displayed using two astronaut inputs, i.e., the assumed vehicle and the time at which the calculations are to be valid. If the astronaut desires the present time, as he might during P35, he can indicate the present time by supplying all zeros for the time.

The outputs of R36 are displayed via flashing VERB 06 NOUN 90. Inputs and outputs to R36 are listed in Tables 9.2.4-I and 9.2.4-II, respectively. Note that, since the desire is to null out the $\dot{Y}$, the crew must change the sign when loading $\dot{Y}$ into R2 of the $\Delta\underline{v}$(LV) targeting display. Figure 9.2.4-1 presents a flowchart of R36.

9.2.4.2 Computational Sequence

When the astronaut keys in R36, via VERB 90 ENTR, the CMC first checks to determine if any other extended verb is running . If so, R36 is terminated, and the OPR ERR light illuminates to inform the astronaut that R36 has terminated. The astronaut must then terminate the other extended verb, so that R36 can be activated.

If no other extended verb is active, R36 flashes VERB 04 NOUN 12, to request that the astronaut indicate which vehicle is to be used in the calculations. R1 will contain 00002, the option code for the specified vehicle. R2 will contain 00001; R3 will be blank. If R2 is left unchanged, the CM will be the specified vehicle; if R2 is changed to 00002, the LM will be the specified vehicle. When R2 contains the correct code, the astronaut should key PRO, in response to the flashing VERB 04 NOUN 12 display.

Next, R36 flashes VERB 06 NOUN 16 requesting T(EVENT). T(EVENT) is first displayed as the current value stored into the registers containing t_{IG}. This will either be the t_{IG} of the last maneuver or target $\Delta\underline{v}$, or that of the next maneuver. If that is not the desired time, T(EVENT) should be loaded in ground elapsed time (GET). If the present time is desired, all zeros should be loaded.

TABLE 9.2.4-I

R36 INPUT

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	LM-CSM option request CSM assumed option	Option code	FL V04 N12	R1 00002	Indicates that the astronaut should make choice of LM or CM for active vehicle.
2.	CM or LM option code	Active vehicle code	FL V04 N12	R2 00001, initially; 00002, if LM desired, and so keyed in by the astronaut.	CMC will display 00001 first. If astronaut desires that LM be assumed, he should load 00002 into R2.
3.	Time when display parameters are to be valid	T(EVENT)	FL V06 N16	R1 ooxxx. hrs R2 oooxx. min R3 oxx. xx sec	Astronaut should load desired time in GET, unless he desired the present time, in which case, he should load all zeros.

TABLE 9.2.4-II

R36 OUTPUT

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Distance active vehicle is from plane of passive vehicle at T(EVENT)	Y	FL V06 N90	R1 xxx. xx n. mi.	
2.	Rate at which Y is changing	$\dot{Y}$	FL V06 N90	R2 xxxx. x fps	The negative of this value - when T (EVENT) equals the time of ignition for an out-of-plane maneuver, and the assumed vehicle is the one expected to do the maneuver - must be loaded into the Y component of the DELTA V (LV) display of the proper targeting program.
3.	Angle between the LOS and the forward direction measured in the local horizontal plane	ψ	FL V06 N90	R3 xxx. xx deg	

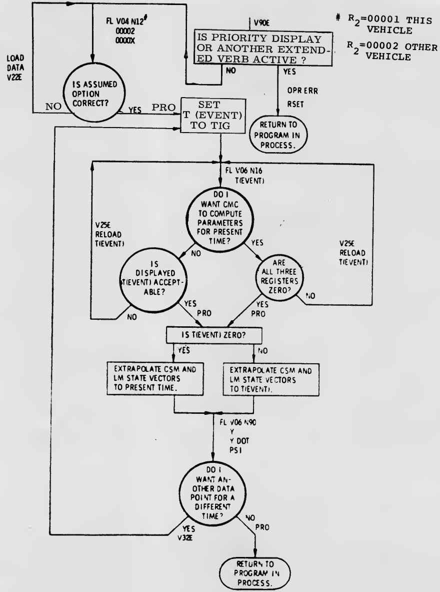

Figure 9.2.4-1. Rendezvous Out-of-Plane Display Routine (R36)

Then, the CMC extrapolates the state vectors to the indicated time, and computes the parameters to be displayed. The parameters are displayed via a flashing VERB 06 NOUN 90 display. If the astronaut responds to the flashing VERB 06 NOUN 90 display with a VERB 32 ENTR, R36 will recycle, allowing a different time to be entered into NOUN 16. If the astronaut responds to the flashing VERB 06 NOUN 90 with a PRO, the program will terminate. To obtain information about the vehicle that was not the assumed vehicle, the astronaut must terminate R36 and then reselect the routine via VERB 90 ENTR.

9.2.4.3 Restrictions and Limitations

There is no reason to believe that for a particular T(EVENT), $\dot{Y}$(CSM) will equal -$\dot{Y}$(LM), since one vehicle is usually behind the other. Conceivably, one vehicle could be at a node, and the other at an antinode. The correct vehicle (that is, the one that will do the maneuver) must be specified and the sign must be changed when keying in the out-of-plane maneuver into R2 of the $\Delta \underline{v}$(LV) display.

R36 cannot be used when another extended verb is active. R36 should not be called while AVERAGEG is running. Should this occur, the information displayed by R36 will probably be inaccurate.

9.2.4.4 Restarts

R36 is not restart protected. Should a restart occur while R36 is operating, R36 must be reselected.

9.2.4.5 Coordination

R36 may be run at any time (with the restrictions given above). The ISS need not be running or aligned for R36.

SUBSECTION 9.3

ADDITIONAL LGC EXTENDED VERBS AND ROUTINES

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