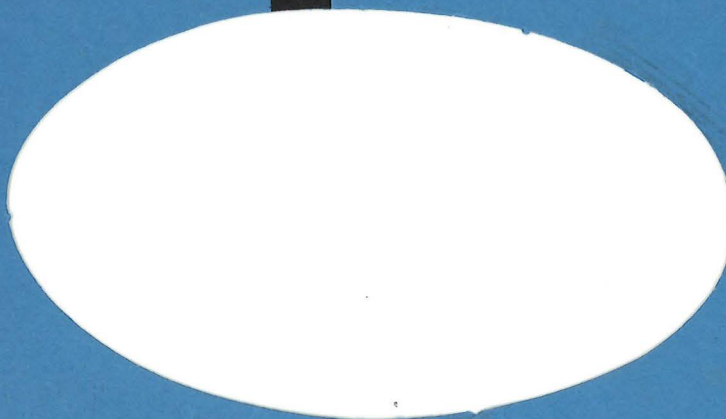


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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

# APOLLO

GUIDANCE, NAVIGATION  
AND CONTROL



**MIT**

CAMBRIDGE MASSACHUSETTS 02139

**CHARLES STARK DRAPER  
LABORATORY**

# APOLLO

## GUIDANCE, NAVIGATION AND CONTROL

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### USERS' GUIDE TO SKYLARK GN&CS MAJOR MODES AND ROUTINES

January 1973

# MIT

CAMBRIDGE, MASSACHUSETTS, 02139

## CHARLES STARK DRAPER LABORATORY

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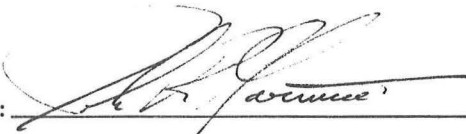
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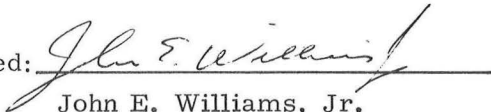
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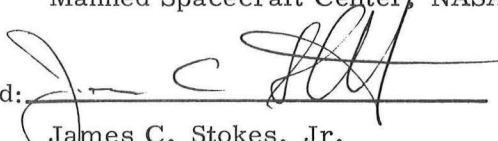
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## PREFACE

This document describes selected design considerations and functional and procedural techniques necessary to give the reader a basic understanding of the SKYLARK GN&CS major modes, routines, and extended verbs.

The overall format of the document remains the same as that of the APOLLO Users' Guide. Some inconsistency exists in format, however, among the different sections. Those COLOSSUS programs that did not change significantly for SKYLARK have not been rewritten for this document. Rather, they have undergone minor editorial changes to reflect the SKYLARK program. The format and content of these sections, however, is basically that of the APOLLO Users' Guide. Those portions of this document that were written specifically for the SKYLARK Users' Guide—and, therefore, reflect design change from COLOSSUS to SKYLARK—include

- ♦ paragraph 4.2.1.3, R27, VHF Range Rate Mark Processing Routine
- ♦ paragraph 4.2.5, P25, Contingency VHF Range Rate
- ♦ section 5, Prethrusting
- ♦ paragraph 6.2.4, P48, Rendezvous Thrust Monitor
- ♦ section 7, Alignment
- ♦ section 11, Docked DAP

These portions of the document are structured differently from the others reflecting a new—and hopefully successful—approach to presenting the user a more integrated and comprehensive explanation of current material.

Section 8—which would otherwise have described the entry programs—has not been written, or included in the Contents. Additionally, P38 has not been included in the document, although it has been shown in the Contents.





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SECTION 1.0

INTRODUCTION

## INTRODUCTION

The purpose of this document is to provide crewmembers and mission controllers with a higher-level description of major modes and routines documented in the current Guidance System Operations Plan (GSOP). To do this has required in some instances, however, a review of hardware components, as, for example, the descriptions of the IMU Gimbal Assembly and command module (CM) optics in the "Alignment" section.

The scope, therefore, comprises APOLLO Guidance Computer (AGC) software, plus limited discussions of system hardware when, in the judgement of the writers, such discussions help illuminate the purpose and operation of the individual software programs.

The Users' Guide is organized along the lines of GSOP Section 4, with sections assigned to prelaunch, boost, coasting-flight navigation, prethrusting, powered flight, alignment, entry, and to additional extended verbs and routines not described in the earlier sections. In addition; the document contains a section on the docked DAP. As a rule, each section is divided into two subsections, an introduction, and the command module computer (CMC) programs. Each subsection, in turn, is divided into paragraphs describing the individual programs. In some instances, however (e.g., MINKEY Rendezvous) an entire mission sequence is presented, when the sequence rather than the operation of an individual program is the first interest.

In general, each paragraph gives (1) a summary of the guidance and control theory governing the program's application, (2) a discussion of the operational context, (3) an amplified description of crew procedures, and (4) functional flow diagrams of the computer program and the related routines.



SECTION 2.0

PRELAUNCH

## 2.1 INTRODUCTION TO PRELAUNCH

A requirement of the Apollo Mission is that the orientation of the Inertial Measurement Unit (IMU) be known at launch, so that PIPA acceleration during boost can be correctly integrated into the onboard state vector. In addition, the IMU should maintain a fixed orientation relative to the launch site. Since the earth is rotating, however, this orientation is continually changing with respect to an inertial coordinate system. The IMU must, therefore, undergo continual torquing before launch. The amount of torquing is determined by using a gyrocompass routine to determine North and using the accelerometers to determine vertical; thus the program can compute an earth-fixed coordinate system. For the CSM, x is aligned along the launch axis, z along the vertical axis, and y completes the triad.

## 2.2 CMC PRELAUNCH PROGRAMS

The programs listed below constitute the prelaunch alignment capabilities of the Command Module Computer (CMC):

- P01, Initialization
- P02, Gyrocompassing
- P03, Optical Verification of Gyrocompassing

In addition, P00, the CMC Idling Program, and P06, the CMC Power Down Program, are also included in this subsection for numerical convenience—although these two programs can be used at various times throughout the mission.

### 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 OWS state vectors extrapolated to current time, unless extrapolation is specifically terminated.

#### 2.2.1.1 Computational Modes

P00 operates in either of 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 ( $\Delta t$ ), the CSM state vector is extrapolated, by precision integration, to approximately the present; (3) the OWS 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  $\Delta t$  is a function of the magnitude of the conic position vector ( $r_{con}$ ) and the gravitational constant of the primary body ( $\mu_e$ ).] 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:

$$\Delta t_{max} = \text{minimum} \left( \frac{0.3 |r_{con}|^{3/2}}{\sqrt{\mu_e}}, 4000 \text{ sec} \right)$$

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 ( $\Delta t$ ).
2. P00 idles until crew reselects VERB 37 ENTR xx ENTR.

#### 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).

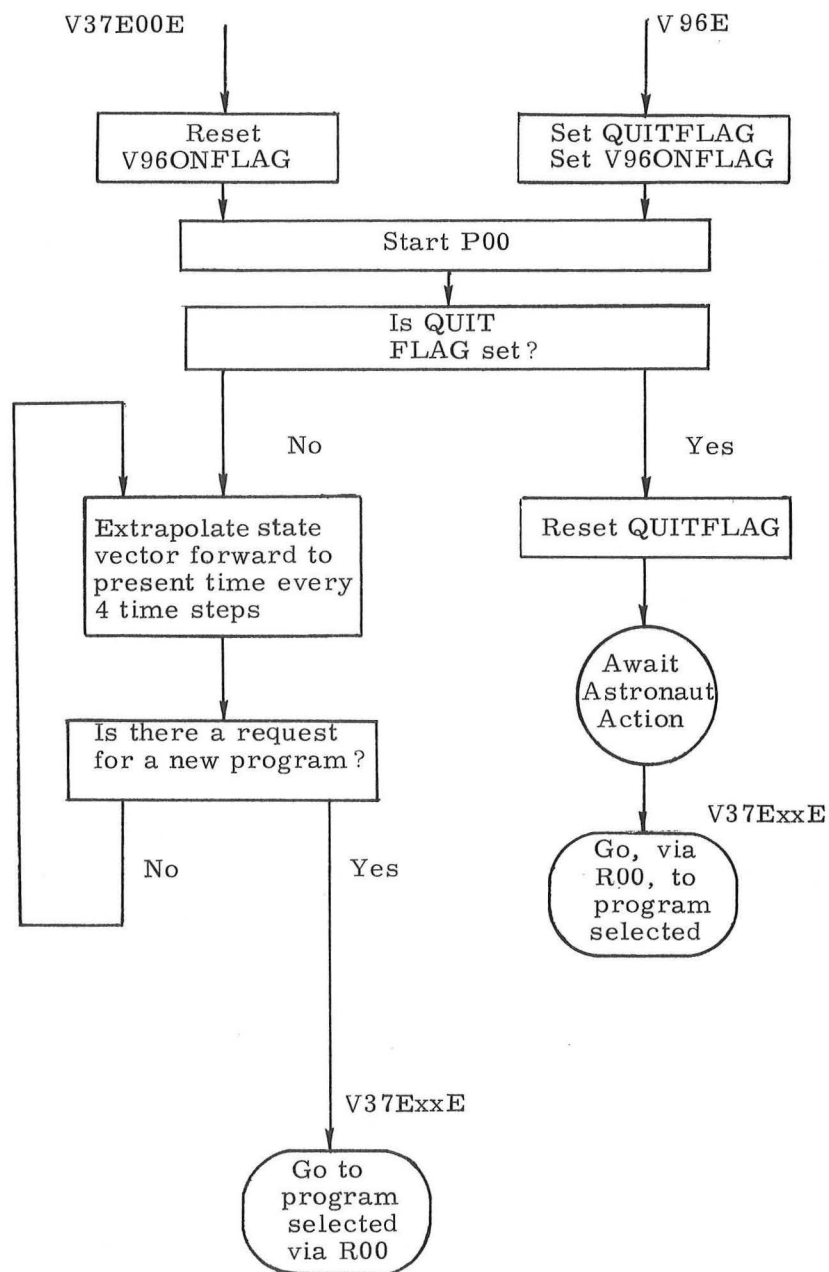


Figure 2.2.1-1. CMC Idling Program (CSM P00)



#### 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 autopilots (CSM alone DAP or docked DAP). (See Section 11 of this document.) Gimbal-lock must be avoided during manual 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 either Digital Autopilot Data Load Routines (R03 or R04).

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, marking display, or priority display is active, 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 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 when the CSM alone DAP is active and that selected the last time Routine R04 was performed

TABLE 2.2.1-1

CMC IDLING PROGRAM (CSM P00) DSKY PROCEDURES (SHEET 1 OF 2)

No.	Entry Point	Display	Prog. No.	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 V37E00E; if entered by V96E, no extrapolation takes place.	During attitude maneuvers, monitor FDAI ball or key in VERB16 NOUN 20 ENTR to monitor the CDU angles to prevent gimbal lock. Calculation of the gimbal angles is 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-3 and C-1 through C-4.)	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. Upon crew's ENTR, exit R60/R62.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to perform maneuver. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes non-flashing V06 N18 display to return until maneuver has completed; then FL V50 N18 returns. PRO again repeats the sequence; ENTR terminates R60/R62.
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 non-flashing V06 N18 returns to FL V50 N18 when maneuver finishes and operation returns to step B-2.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03 or R04) when last performed. Any RHC input terminates automatic maneuver and returns to FL V50 N18. If MGA reaches $\pm 75$ deg, maneuver terminates and may be completed manually.

TABLE 2.2.1-I  
CMC IDLING PROGRAM (CSM P00) DSKY PROCEDURES (SHEET 2 OF 2)  
RENDEZVOUS FINAL ATTITUDE ROUTINE (R63) INTERFACE

No.	Entry Point	Display	Prog. No.	Purpose	Register	CMC Operation	Crew Action	Remarks
C-1	R63 (VERB 89 ENTR)	FL V06 N78	00	Requests yaw and pitch angles for desired attitude.	R1 xxx.xx Gamma R2 xxx.xx Rho R3 Blank  R1 is yaw angle R2 is pitch angle	Upon crew's PRO calculate the final gimbal angles for the desired attitude.	Depress PRO to compute angles; use V24E to change tracking attitude angles, then depress PRO.	
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 desired tracking attitude.	Depress PRO to accept angles; use V32E to recycle. 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. Upon crew's ENTR, exit R60/R63.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to perform maneuver. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes non-flashing V06 N18 display to return until maneuver has completed; then FL V50 N18 returns. PRO again repeats the sequence, ENTR terminates R60/R63.
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 non-flashing V06 N18 returns to FL V50 N18 when maneuver finishes and operation returns to C-3.	Maneuver rate will be prescribed by the DAP Data Load Routine (R03 or R04) when last performed. Any RHC input terminates automatic maneuver and returns to FL V50 N18. If MGA reaches $\pm 75$ deg., maneuver terminates and may be completed manually.

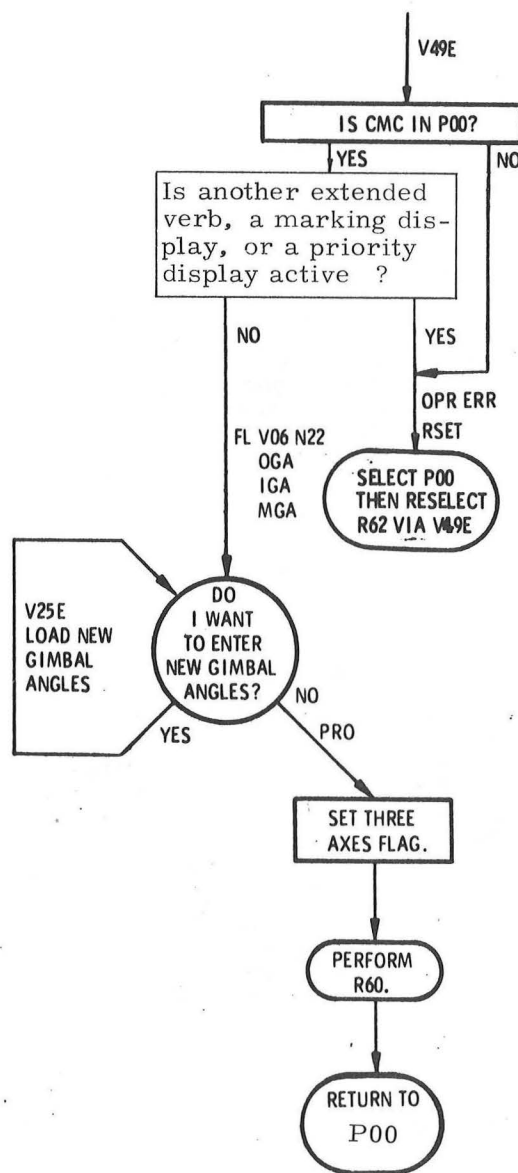


Figure 2. 2. 1-2. Crew-defined Maneuver Routine (CSM R62)

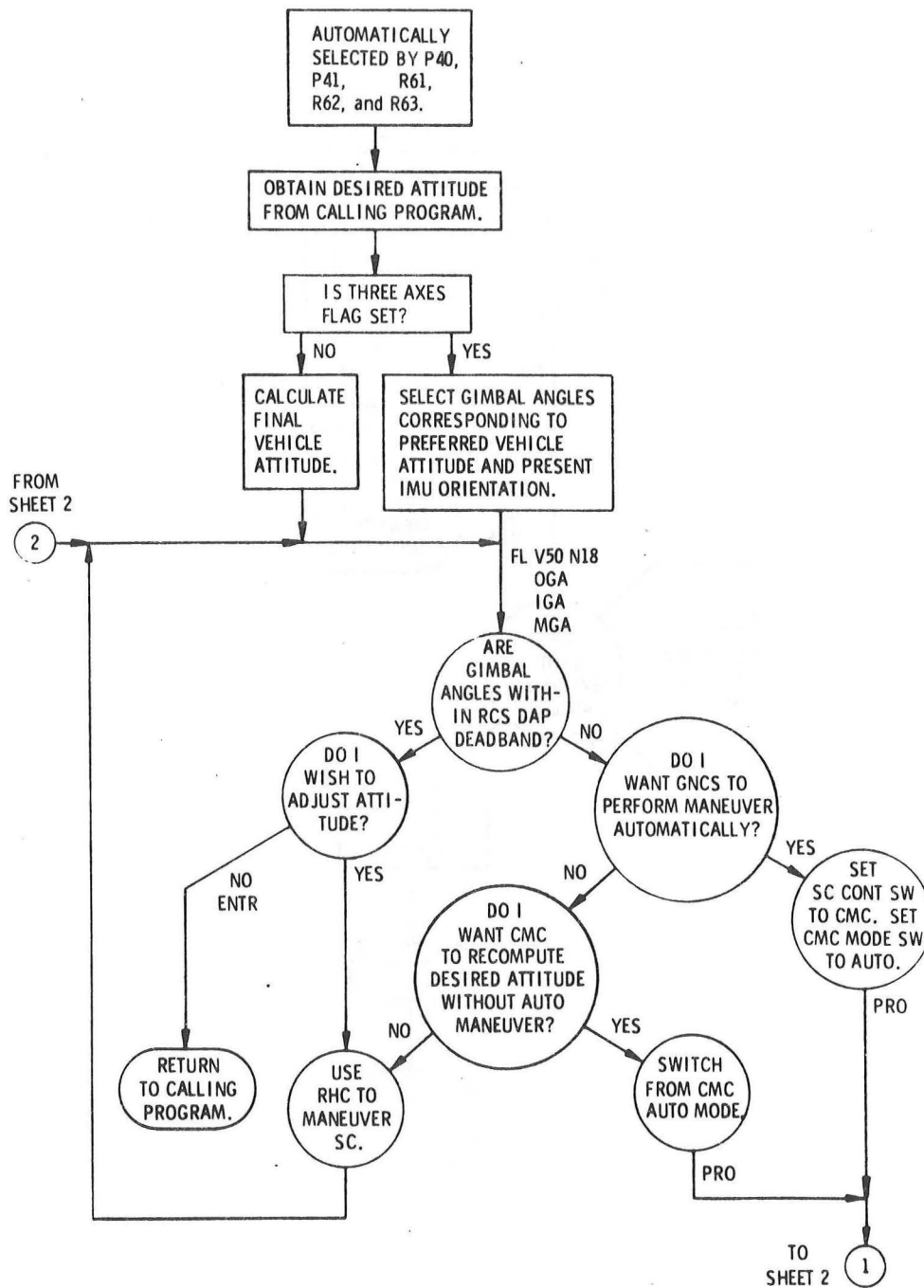


Figure 2.2.1-3. Attitude-maneuver Routine (CSM R60) (Sheet 1 of 2)

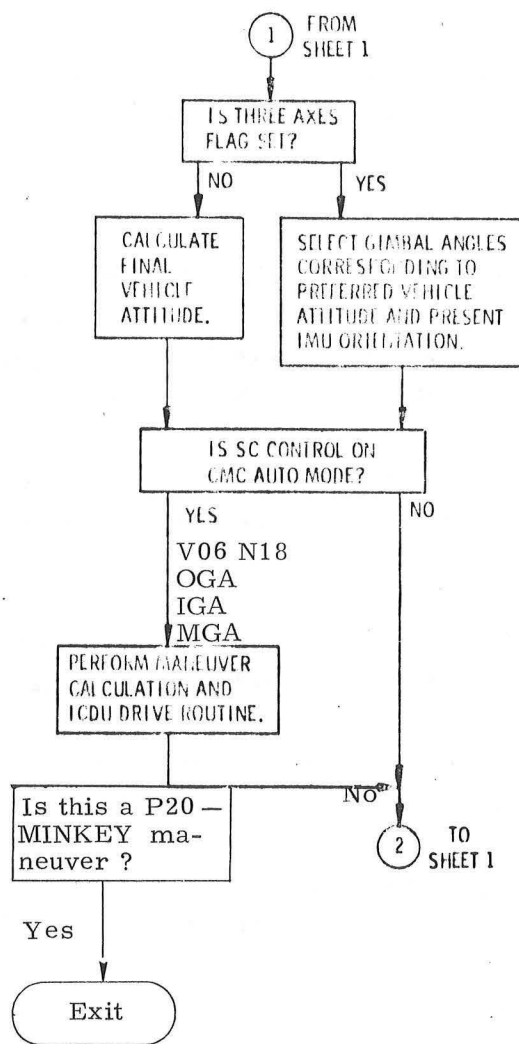


Figure 2.2.1-3. Attitude-maneuver Routine (CSM R60) (Sheet 2 of 2)

when the docked DAP is active. 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 a desired CSM orientation. 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. For automatic maneuvers, Routine R03 must be performed before R63 is called; the CMC MODE switch must be placed in AUTO. Routine R63 can only be called from P00.

Keying VERB 89 ENTR, the crew observes an immediate flashing VERB 06 NOUN 78 (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, marking display or priority display 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) generates a PROG alarm.

Assuming no error or alarm condition, register R1 of the VERB 06 NOUN 78 display will contain gamma equal to zero; register R2 will contain rho equal to zero for the desired tracking axis; register R3 will be blank. If a different spacecraft axis is desired, the crew must key VERB 24 ENTR and load the correct data in registers R1 and R2. PRO then causes R63 to extrapolate the CSM and OWS 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



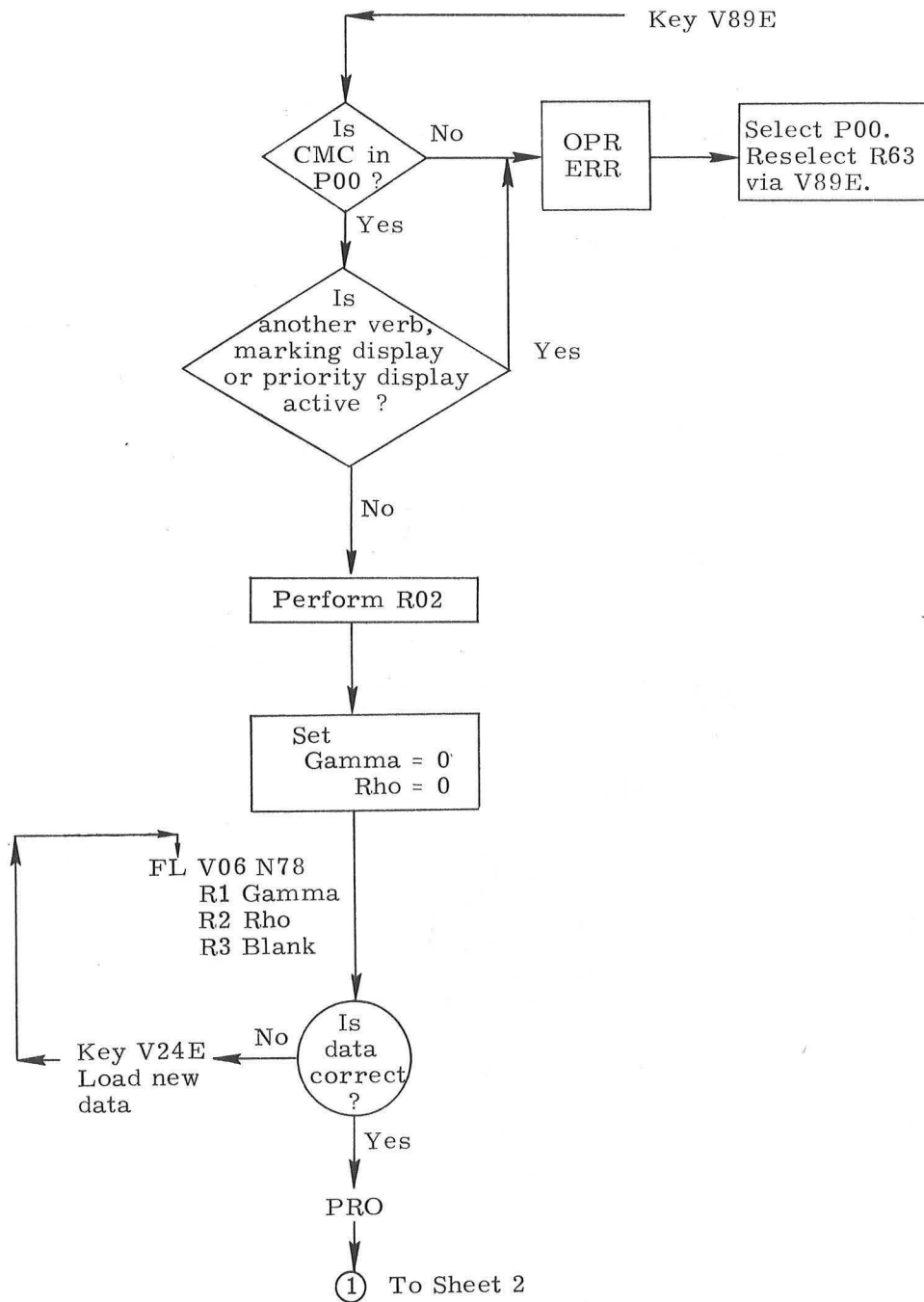


Figure 2.2.1-4. Rendezvous Final-attitude Routine  
(CSM R63) (Sheet 1 of 2)

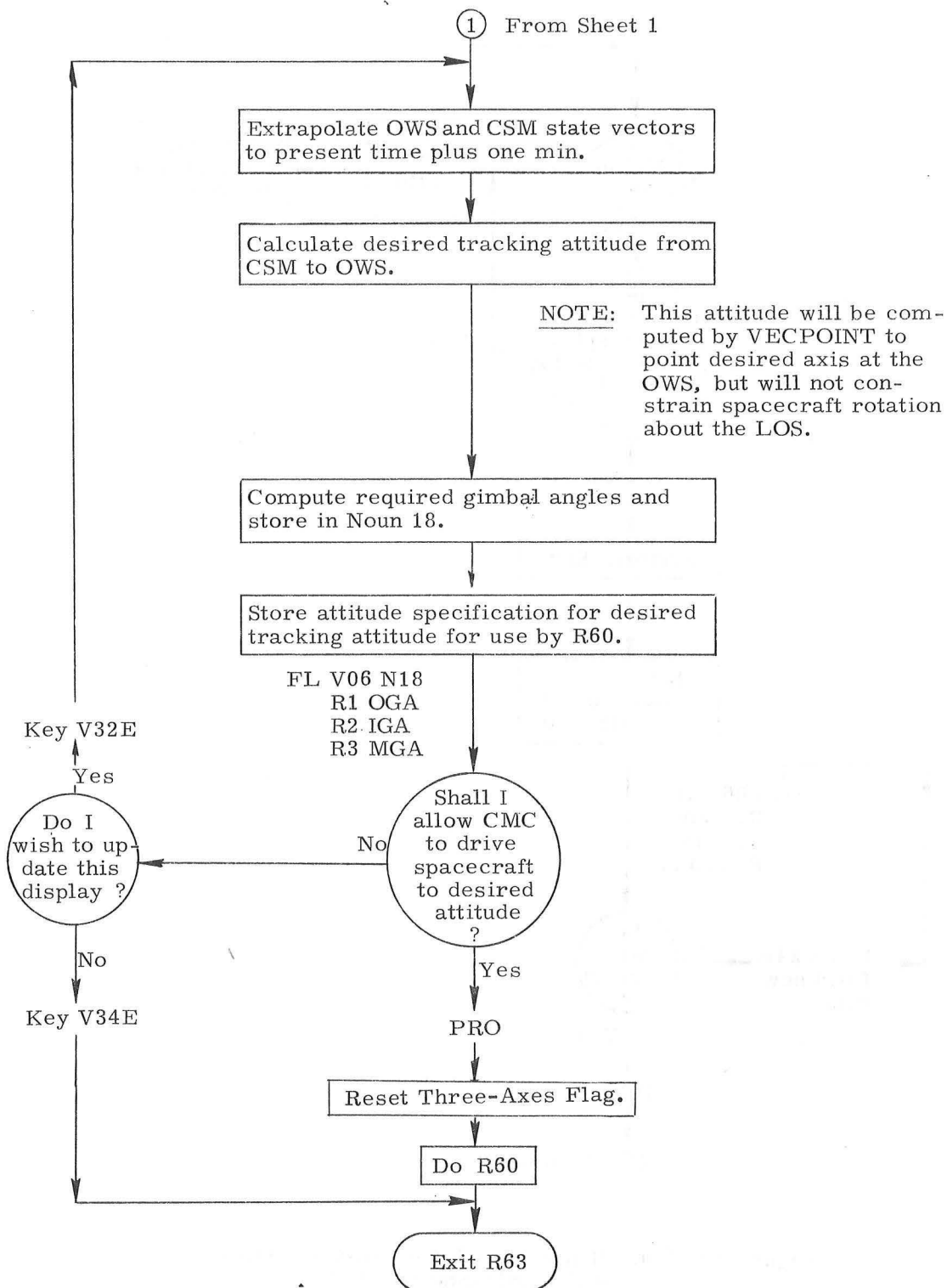


Figure 2.2.1-4. Rendezvous Final-attitude Routine (CSM R63) (Sheet 2 of 2)

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 specified axis at the OWS 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)
- d. Coarse-align OCDU (V41N91).

2.2.1.4.3.1 DSKY Light Test (V35).—This 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 only the OPR ERR light to illuminate.

NOTE.—A restart occurring during the performance of V35 can put the IMU into coarse align. After the restart, the crew would observe illumination of the NO ATT light. Recovery procedure is to perform P51.

2.2.1.4.3.2 Load FDAI Error Needles (V43).—This extended verb (Figure 2.2.1-6) was designed primarily for pre-flight groundcheck of the FDAI error needles. The crew can use VERB 43 to load some desired angles into the error needles, and then watch the action of the needles to determine if they are functioning properly. VERB 43 can also be called anytime P00 is operating and neither of the following conditions exists:

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

---

\* Although defined as a regular verb, VERB 35 is included here with the P00-restricted extended verbs.

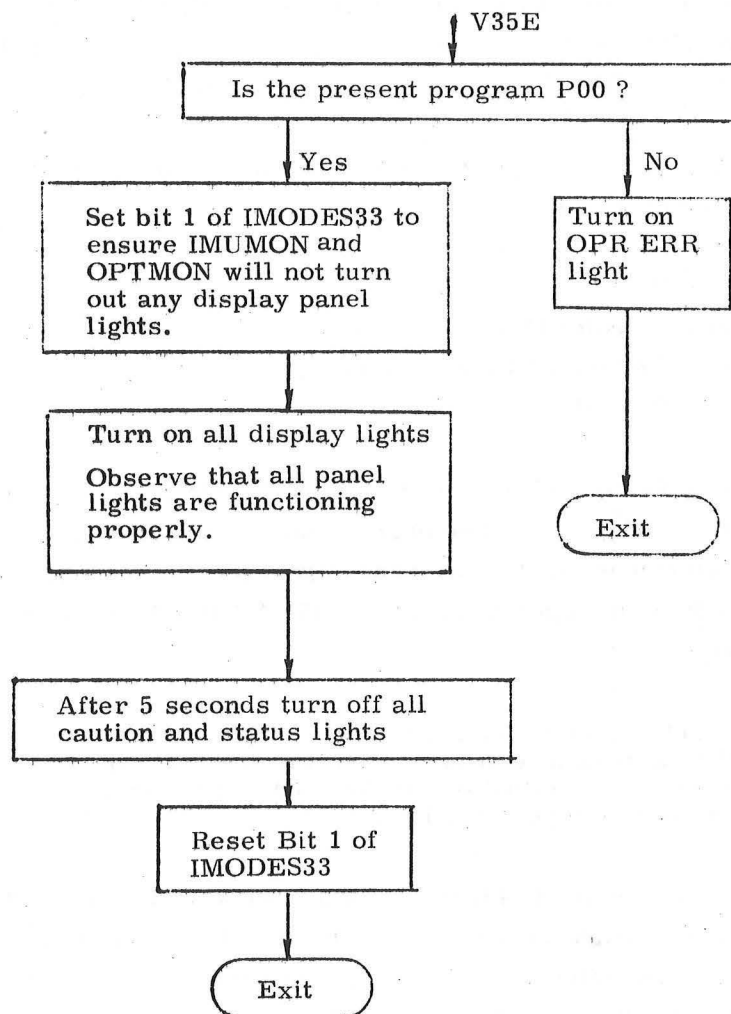


Figure 2.2.1-5. DSKY Light Test (CSM Regular Verb V35)

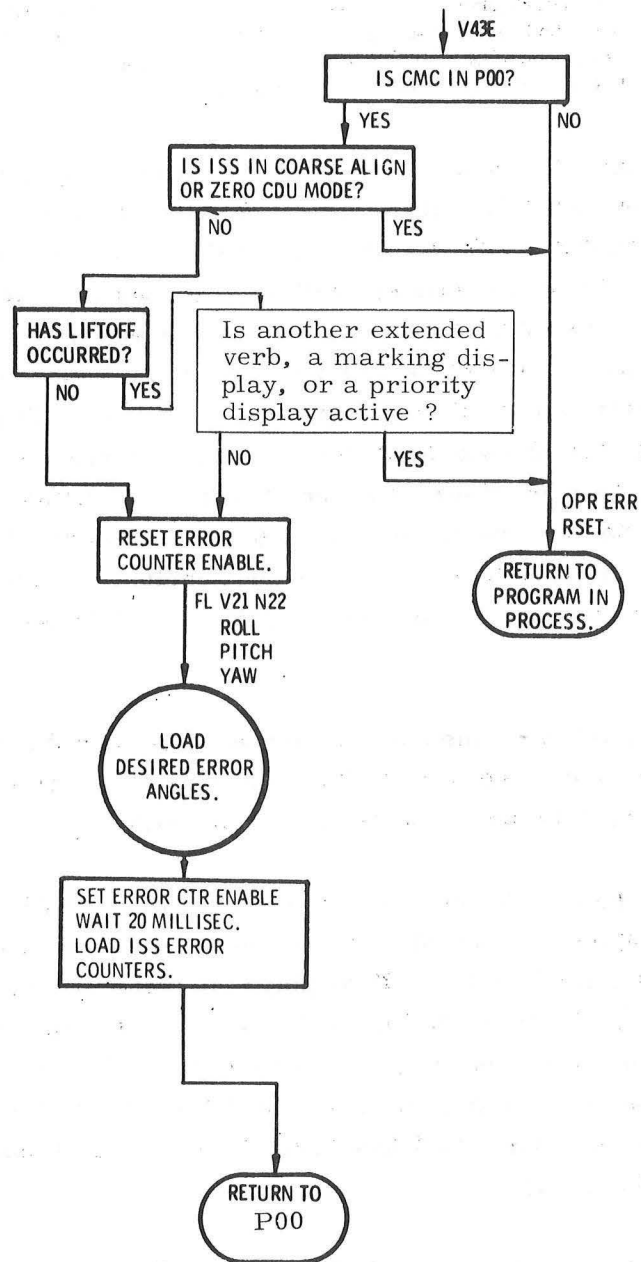


Figure 2.2.1-6. Load IMU Attitude Error Needles (CSM Extended Verb V43)

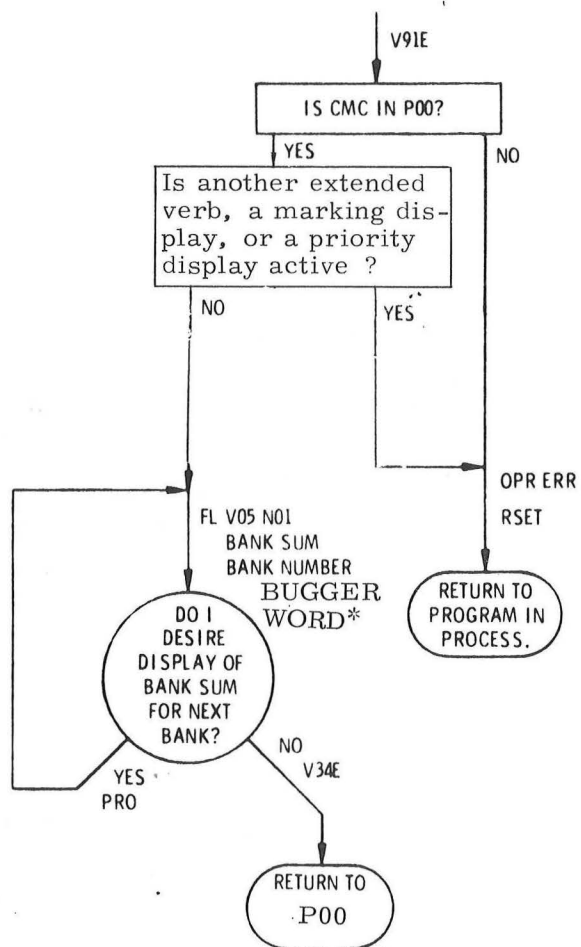
NOTE.—To use this checkout procedure inflight, the crew must first change the RCS DAP configuration code to zero (no DAP) via R03, and then key in VERB 46 ENTR, which executes the switchover to the no-DAP configuration. If VERB 43 is entered, however, while the DAP is updating the error needles, the crew must re-initialize the DAP via VERB 45 or 46 to overcome the resulting bias to the needles.

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  $\pm 16.88$  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 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  $R1 = R2$ , 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 the  $R1 = R2$ , and so on, repeating the procedure until the last bank (43) has been checked. To terminate VERB 91, the crew keys VERB 34 ENTR.

2.2.1.4.3.4 Coarse-align OCDU (V41N91).—VERB 41 NOUN 91 (Figure 2.2.1-8) is used to drive the optics to shaft and trunnion angles specified by the crew. The process can be performed only when P00 is operating and no other extended verb, marking display, or priority display is active.



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

Figure 2.2.1-7. Display on DSKY the Sum of Each Bank (CSM Extended Verb V91)

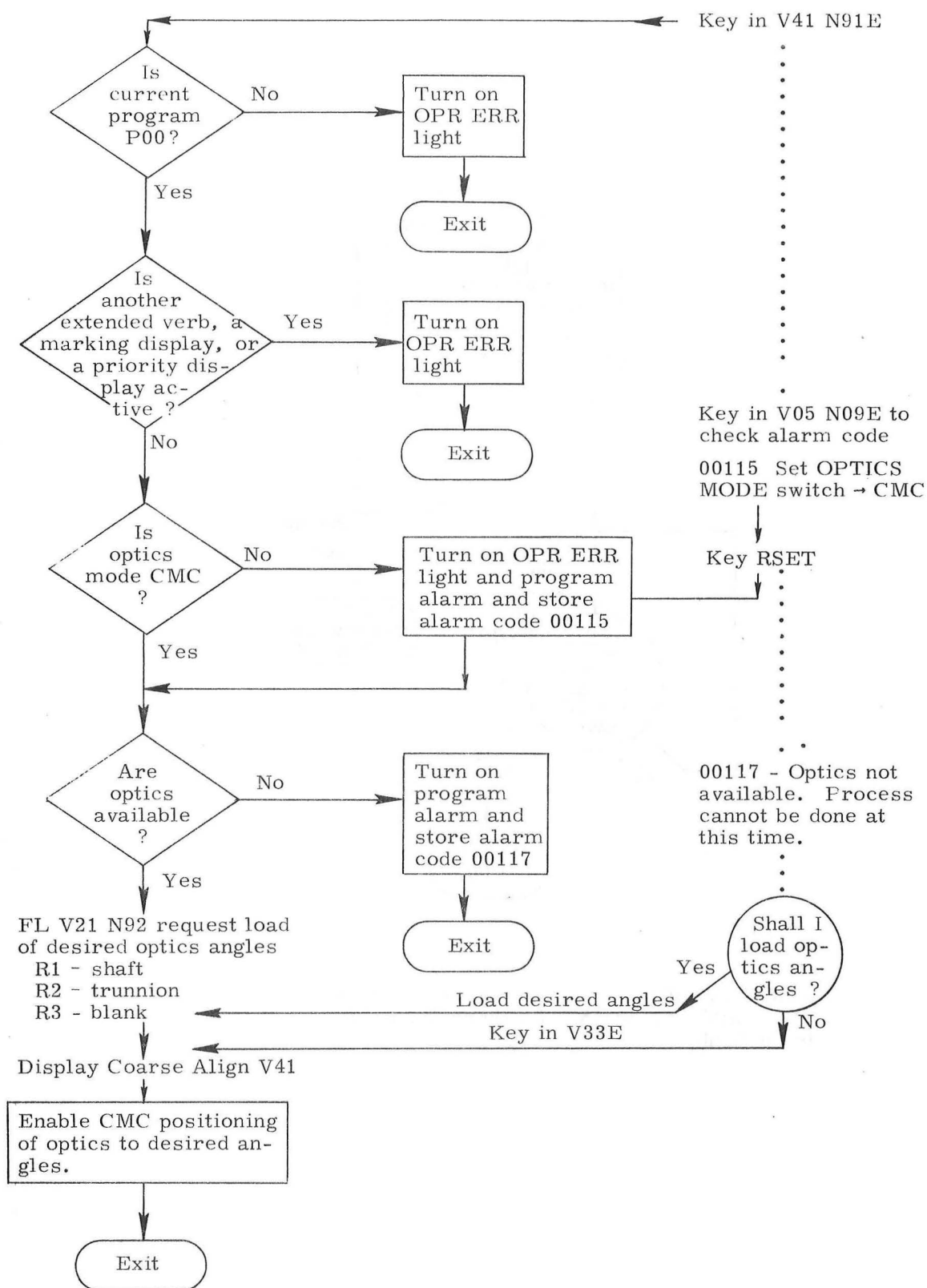


Figure 2.2.1-8. Coarse-align OCDU (CSM Extended Verb V41 N91)



After keying VERB 41 NOUN 91 ENTR, the crew observes a flashing VERB 21 NOUN 92—unless one of the following alarm conditions exists:

- a. If the current program is not P00, or if another extended verb, a marking display or a priority display is active, the CMC illuminates the DSKY OPR ERR light and exits.
- b. If the optics are not available, the CMC turns on the PROG alarm, stores alarm code 00117, and exits.\*

If the OPTICS MODE switch is not in the CMC position, however, the CMC illuminates the OPR ERR light on the DSKY, turns on the PROG alarm and stores alarm code 00115. The crew can key VERB 05 NOUN 09 ENTR to have the alarm displayed, put the OPTICS MODE switch to the CMC position, and key RSET to continue.

If none of the above conditions is present, VERB 21 NOUN 92 flashes requesting load of the desired optics angles. All registers are blank until the crew loads the desired shaft and trunnion angles into registers R1 and R2, respectively. If the crew does not choose to load the optics angles, he keys VERB 33 ENTR and the CMC uses stored angle values. In both cases, the CMC then displays the coarse align VERB 41 for crew observation, enables positioning of the optics to the desired angles and exits.

#### 2.2.1.5 Restrictions and Limitations

If VERB 96 is used to halt integration during Rendezvous Navigation (P20), CSM-OWS state-vector synchronization may be lost, and the W-matrix 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 listed and explained below.

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\* This alarm is not expected since V41 N91 is restricted to P00.

NOTE.—An alarm appears in both R1 and R3 of NOUN 09 if it is the only alarm; in both R2 and R3 if it is the second alarm; and only in R3 if it is the third alarm. R3 always contains the latest alarm. Further, R3 is not cleared by depression of RSET; R1 and R2 are so cleared.

- a. Alarm 00115 indicates that the OPTICS MODE switch is not in the CMC position. This alarm may occur during operation of the Coarse-Align OCDU Extended Verb VERB 41 NOUN 91. Correction is to set the OPTICS MODE switch in the CMC position and key RSET to continue.
- b. Alarm 00117 indicates that the optics are not available at this time and, therefore, the process of driving the optics to the desired angles cannot be performed. This alarm may occur during operation of Extended Verb V41N91. Since the CMC exits the VERB 41 NOUN 91 process upon storing the alarm code, the crew must choose another time to coarse-align the OCDU angles.\*
- c. Alarm 01520 is generated if a VERB 37 request is made with the IMU (1) in its 90-sec turn-on period, (2) being caged, and (3) being zeroed.

It will also be generated if the VERB 37 request is made for a program other than P00 after the entry DAP has been started in P62, during P77 integration, P06, and during state-vector integration performed in P00 and in P20, options 1, 2, and 5.

Correction is to wait until the COMP ACTY light is not on continuously—or until IMU moding is complete—and then to reselect via VERB 37, or, if in P06 or in P62/P67, to select P00 and then the desired program.

- d. Alarm 00210 indicates IMU not operating when Routine R02 is performed at the beginning of the Rendezvous Final-attitude Routine (R63). Correction is to power up the IMU before selecting R63.
- e. Alarm 00220 indicates IMU not aligned to CMC-known orientation (no REFSMMAT) when R02 is performed at the beginning of the Rendezvous Final-attitude Routine (R63). Correction is to perform the IMU-Orientation-Determination Program (P51) before selecting R63.
- f. 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.

---

\*This alarm is not expected since V41 N91 is restricted to P00.

#### 2.2.1.7 Restarts

P00 is restart protected.

#### 2.2.2 P01, Initialization

P01 initializes the platform and provides stable-member orientation for gyrocompassing by P02.

Before starting P01, the crew ensures that the following locations are initialized. These locations are nominally pad loaded.

AZIMUTH—azimuth of launch vehicle

LATITUDE—latitude of launch vehicle

LAUNCHAZ—launch azimuth for IMU

PBIASX,Y,Z—PIPA bias compensation—3 compensated accelerometer terms.

PIPASCFX,Y,Z—PIPA scale factor error compensation—3 compensated accelerometer scale-factor terms.

NBDX,Y,Z—Gyro bias compensation—3 compensated gyro bias drift terms.

ADIAX,Y,Z—Gyro input axis compensation—3 compensated gyro acceleration sensitive input axis drift terms.

ADSRAX,Y,Z—Gyro spin reference axis compensation—3 compensated gyro acceleration sensitive spin reference axis drift terms.

To start P01, the crew keys

VERB 37 ENTR 01 ENTR

The IMU then coarse aligns to the desired orientation.

$$\begin{array}{rcl} \text{XSM} & = & \begin{array}{ccc} 0 & -1/2(\cos(\text{AZIMUTH})) & 1/2(\sin(\text{AZIMUTH})) \\ 0 & 1/2(\sin(\text{AZIMUTH})) & 1/2(\cos(\text{AZIMUTH})) \\ -1/2 & 0 & 0 \end{array} \end{array}$$

When the coarse alignment is completed, CMC enters P02.

### 2.2.3 P02, Gyrocompassing

The purpose of P02 is to provide the proper stable-member orientation for launch. P02 cannot be called via VERB 37. Rather, it is entered automatically when the IMU has been coarse aligned to the desired orientation in P01. Upon entry, P02 performs a leveling routine for 640 seconds; this routine maneuvers the x- and y-inertial components (i.e., gyros and accelerometers) into a plane that is perpendicular to the local vertical. Figure 2.2.3-1 is a diagram of this leveling loop.

After the leveling routine is completed, the gyrocompass routine is started and continues to run until the lift-off discrete (set by the Saturn Instrument Unit) is detected; P11 is then entered automatically. P02 also stops and P11 is selected automatically if the backup lift-off discrete is set by the crew's keying VERB 75 ENTR. The gyrocompass routine provides a known azimuth alignment at liftoff. Figure 2.2.3-2 is a diagram of the gyrocompass loop.

At any time during P02, the crew can change the launch azimuth by keying VERB 78 ENTR, observing the VERB 06 NOUN 29 display of present launch azimuth in R1, and loading the desired launch azimuth via VERB 21. When satisfied with the contents of NOUN 29, the crew keys PRO. Should the launch azimuth be changed during P02, the CMC torques the IMU to the new launch azimuth. The program then re-enters the leveling routine for 320 seconds, and the IMU gyrocompasses to the new launch azimuth.

### 2.2.4 P03, Optical Verification of Gyrocompassing

P03 provides the crew with an optical check for verification of stable-member alignment during gyrocompassing before launch. The crew verifies alignment by using the Apollo optics to take sightings on two targets whose azimuth and elevation are known. From these two sightings, two line-of-sight vectors are computed and compared to the desired vectors revealing any azimuth error.

Optical verification should not be attempted, however, until the IMU has been continuously gyrocompassing for a minimum of 30 minutes to ensure accurate results. In addition, before starting P03 the OPT ZERO switch must be put in the ZERO position for fifteen seconds, and then returned to the OFF position.

#### 2.2.4.1 P03 Crew Procedures

Ensure that the IMU has been continuously gyrocompassing for at least 30 min. Set the OPT ZERO switch to ZERO for 15 sec, then return switch to OFF position.

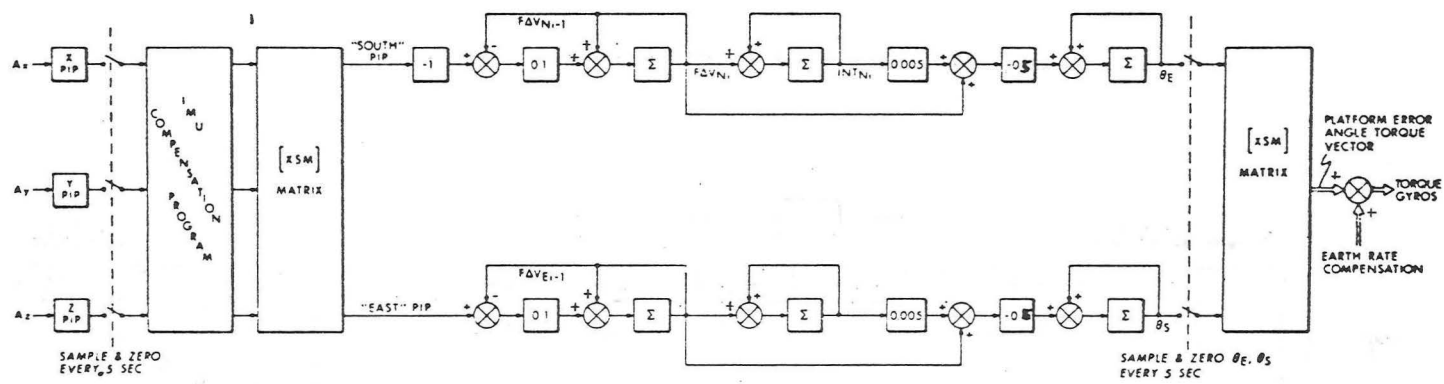


Figure 2.2.3-1. Vertical Erection Loop for Prelaunch Alignment

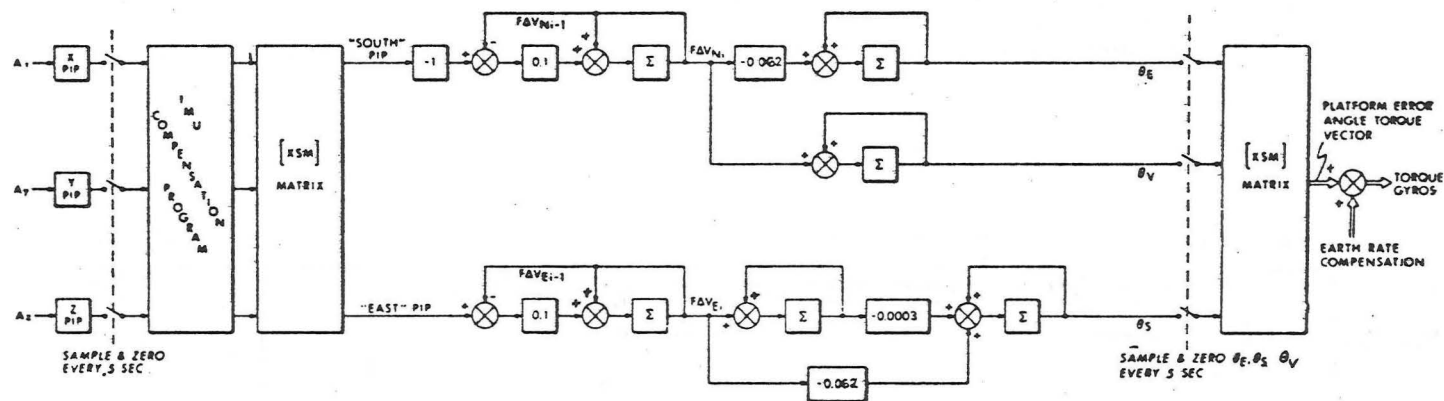


Figure 2.2.3-2. Azimuth Alignment Loop for Prelaunch Alignment

1. Key VERB 65 ENTR

Observe the major mode indicator change to 03, and the appearance of azimuth and elevation display of the first target.

FL VERB 06 NOUN 41

R1	xxx.xx deg	Azimuth
R2	xx.xxx deg	Elevation
R3	00001 Target	ID

2. VERB 24 ENTR/PRO

To correct data, key VERB 24 ENTR and load new data.

When data is satisfactory, key PRO and observe the display of azimuth and elevation of the second target.

FL VERB 06 NOUN 41

R1	xxx.xx deg	Azimuth
R2	xx.xxx deg	Elevation
R3	00002 Target	ID

3. VERB 24 ENTR/PRO

To correct data, key VERB 24 ENTR and load new data.

When data is satisfactory, place OPT MODE switch in CMC position, key PRO, and observe the display of marking request.

NOTE.—The azimuth and elevation data for each target is converted to a half unit line-of-sight vector in the desired stable member coordinate system XSM<sub>DESIRED</sub>—which then becomes the desired line of sight vector for each target, and is designated as T<sub>1</sub> and T<sub>2</sub>. The CMC then computes the shaft and trunnion angles to automatically position the optics to point at target 1 for marking.

FL VERB 51

4. MARK

Place OPT MODE switch in MAN. Depress MARK pushbutton when the target is centered and observe display requesting mark termination.

FL VERB 50 NOUN 25

R1 00016  
R2 Blank  
R3 Blank

5. MARK REJECT/PRO

To reject mark, depress MARK REJECT; program recycles to FL VERB 51 N25 (with R1 = 00016).

To accept mark, key PRO. Position OPT MODE switch to CMC.

NOTE.—Upon crew's positioning of OPT MODE switch to CMC, shaft and trunnion angles are computed to automatically position the optics for marking on target 2.

Repeat marking procedure for target 2.

NOTE.—From mark data, CMC computes line-of-sight vectors  $T_1$  and  $T_2$  in the actual stable-member coordinate system. Using  $T_1$ ,  $T_2$  and  $T_1$ ,  $T_2$  the rotation required to align the IMU to the desired XSM is computed and displayed as gyro-torquing angles.

FL VERB 06 NOUN 93

R1 xx.xxx deg x  
R2 xx.xxx deg y  
R3 xx.xxx deg z

6. PRO/VERB 34 ENTR

To reduce azimuth error to zero, key PRO.\*

To terminate optical verification, key VERB 34 ENTR.

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\* This procedure was designed for testing and is not normally performed by crew.



### 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, i.e., the normal condition when the computer is not in use. Maximum average power dissipation of the CMC during the standby condition brings the computer down from 70 watts to 15 watts. P06 was designed to be used mainly during such periods as coasting flight and eat and sleep periods. In practice, however, CMC Power Down is not nominally used. (An exception is the emergency power down of the CMC during the APOLLO 13 flight.)

#### 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<sub>8</sub>, indicating the need for a crew response. The crew responds by keying the CMC to the standby condition using the PRO key. The crew depresses PRO and holds it until the STBY light comes on and the DSKY goes blank. (To transfer the CMC from standby to the operate condition, the crew depresses the PRO pushbutton—and holds it—until the STBY light goes out.)

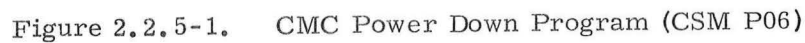
Once the program has been selected, the CMC will be shut down unless a computer restart is performed (VERB 69 ENTR) before the depression of PRO for the standby condition. After P06 selection, the CMC will not honor a new program request (VERB 37 ENTR xx ENTR), a terminate (VERB 34 ENTR), a VERB 33 ENTR, 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 inertial state vectors and GET.

The standby period can be permitted to last indefinitely. If the CMC is left in standby more than 23.3 hours, however, 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.

During initialization, P06 has restart protection. Should a restart occur at this time, the crew sees the RESTART light illuminate, but the program continues. Should a restart occur after initialization, however, the crew must reselect P06.



SECTION 3.0

BOOST

### 3.1 INTRODUCTION TO BOOST

P11, discussed in this section, constitutes the boost capability of the Command Module. This powered-flight program provides initialization data for the computer and monitoring capabilities for the crew. The program's calculations are based on pad-loaded coefficients representing the nominal attitude profile for boost to earth orbit; these coefficients are then used by the Attitude Error Subroutine as discussed in paragraph 3.1.1.2.3.

### 3.1.1 P11, Earth-orbit-insertion Monitor

The primary function of P11 is to monitor the progress of the launch vehicle from liftoff until earth orbit has been achieved. In conjunction with this function, P11 performs the following:

- 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 CMC state vector at liftoff and starts the AVERAGEG cycle, using the computed state vector.
- d. Computes REFSMMAT.
- e. Monitors attitude errors, altitude, velocity, and rate of altitude change.
- f. Provides the means for automatic (CMC) control of the launch vehicle should the Saturn inertial platform fail.

P11 outputs are the liftoff time, the reference ephemeris time of liftoff, REFSMMAT, the DSKY NOUN 62 display, the FDAI needles display of attitude errors, and steering signals to the Saturn instrumentation unit (IU) in case of CMC takeover of the launch vehicle.

Table 3.1.1-I gives the DSKY displays for P11; Table 3.1.1-II lists the extended verbs.

#### 3.1.1.1 P11 Saturn Takeover

During P11, the crew should monitor the L/V RATE and the L/V GUID lights. Illumination of both of these lights, or of the L/V GUID light alone, indicates that the Saturn launch vehicle instrumentation unit has signaled failure of its inertial platform to the spacecraft. The crew must then set the LAUNCH VEHICLE GUIDANCE switch to the CMC position, allowing the CMC to assume automatic control of the launch vehicle. Automatic control can be used—during P11—for all boost stages of the Saturn vehicle. During the S-I stage, automatic control provides polynomial guidance for the launch vehicle; during the S-IVB stage, however, automatic control provides only attitude-hold commands.

Should it become necessary, the crew can assume manual control (stick function) of the launch vehicle and issue control signals to the instrumentation unit using the rotational hand controller (RHC). Manual control can also be selected during all stages of Saturn. (Although selection of manual control is most likely to occur during the S-IVB stage, the software does not

TABLE 3.1.1-I

## DSKY DISPLAYS ASSOCIATED WITH CSM P11

DSKY	Initiated by	Purpose	Condition	Register
V06N62	P11	Display	Inertial velocity (VI) Rate of altitude change (HDOT) Altitude (H)	R1 xxxxx. fps R2 xxxxx. fps 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
FL V16 N32	Astronaut (R30) Key N32E	Display time from perigee in R30		R1 oxxxx. hr R2 oooxx. min R3 oxx. xx sec
FL V16 N50	Astronaut (R30) Key N50E	Display splash error in R30	$\Delta r$ miss distance Perigee Time of free fall	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min,sec

TABLE 3.1.1-II

## EXTENDED VERBS USED WITH CSM 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.



preclude its selection during the S-I stage.) To facilitate the speed of manual takeover, register R1 of NOUN 46 should be preloaded with a DAP configuration code of 3, via R03. This procedure is usually performed before liftoff. To begin manual takeover, then, the crew (1) ensures that the LAUNCH VEHICLE GUIDANCE switch is in the CMC position (2) keys VERB 46 ENTR into the DSKY to activate the DAP, and (3) provides control signals to the launch vehicle using the RHC.

Entry of VERB 46 during the S-I stage terminates polynomial guidance and allows the crew RHC commands to control Saturn flight. Similarly, entry of VERB 46 during the S-IVB stage terminates the Attitude Error Subroutine and leaves only crew-initiated RHC commands for launch vehicle control.

#### 3.1.1.2 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 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.

3.1.1.2.1 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

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



receipt of the liftoff discrete. The clock zeroing and the reference ephemeris time are not changed for the remainder of the mission unless updated by P27.

3.1.1.2.2 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.\*

3.1.1.2.3 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. This subroutine operates in two modes:

1. Display mode—attitude error needles only.
2. Saturn takeover mode— dc output voltage from ICDUs sent to the Saturn instrumentation unit to command attitude of entire vehicle during automatic takeover.

NOTE.—In this mode, the FDAI attitude error needles display contains a constant bias computed at takeover.

3.1.1.2.4 Display Subroutine.—Using the results of each AVERAGEG cycle, the Display subroutine computes the Saturn launch vehicle inertial velocity (VI), the rate of change of altitude (H-dot or HDOT), and the altitude (H) above the launch-pad radius. The subroutine updates the display of these quantities (VERB 06 NOUN 62) every 2 seconds following the AVERAGEG cycle.

### 3.1.1.3 P11 Procedures

Figure 3.1.1-1 is a flowchart of P11. Since P11 is automatically selected by P02,

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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.

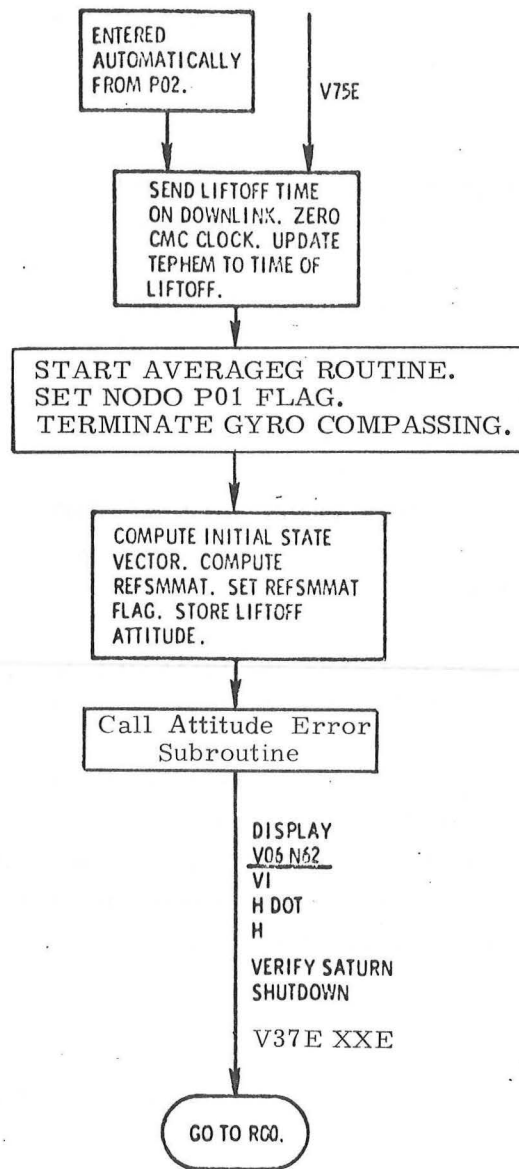


Figure 3.1.1-1. Earth-orbit-insertion Monitor Program (CSM P11)

the crew must first monitor the DSKY for display of major mode 11. The recommended procedure for the backup mode is that the crew key VERB 75 into the DSKY during P02. Then, after liftoff, if P11 does not begin automatically—11 is not displayed—the crew need only key ENTR to initiate P11.

As the Attitude Error subroutine begins, the crew can monitor the FDAI attitude error needles' indication of launch vehicle attitude error. 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 and roll needles should remain close to zero at all times. After the CMC pitch polynomial calculations exit, the desired attitude will be held constant until a new program is selected.

The DSKY will display VERB 06 NOUN 62, updating the display every 2 seconds after the AVERAGEG cycle, through the three boost stages until P00 is selected following S-IVB shutdown. The crew monitors 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.

#### 3.1.1.4 Auxiliary Routine

The crew can call the Orbital-parameters Display Routine (R30) during P11 by keying in VERB 82 ENTR. (Refer to paragraph 9.2.3 for a description 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. SPLERROR, an approximate indication of landing point miss distance, can be called by keying NOUN 50 ENTR.

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.

#### 3.1.1.5 Alarms

There are no program alarms associated with P11.

#### 3.1.1.6 Restarts

P11 is restart protected.

SECTION 4.0

COASTING FLIGHT NAVIGATION

## 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). The data contribute to maintaining current estimates of the CSM and OWS state vectors.

The CSM coasting flight navigation programs are as follows:

- P20 Universal Tracking and Rendezvous Navigation (paragraph 4.2.1)—Options 0 and 4
- P21 Ground-track Determination (paragraph 4.2.2)
- P29 Time of Longitude (paragraph 4.2.4)

### 4.1.1 Mission Phases

Coasting flight navigation can be used during the rendezvous and earth orbit mission phases.

#### 4.1.1.1 Rendezvous Navigation

Rendezvous navigation is used to update one of the two state vectors (usually the CSM's). 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 and the COAS; VHF range-link data, acquired automatically. The CSM 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.

#### 4.1.2 Recursive Navigation

Navigation 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<sup>\*</sup> 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 ( $\omega$ ), 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<sup>\*\*</sup> represents the interrelationship of these elements as an ellipsoid of six dimensions (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 (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 statistical weighting 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

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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"

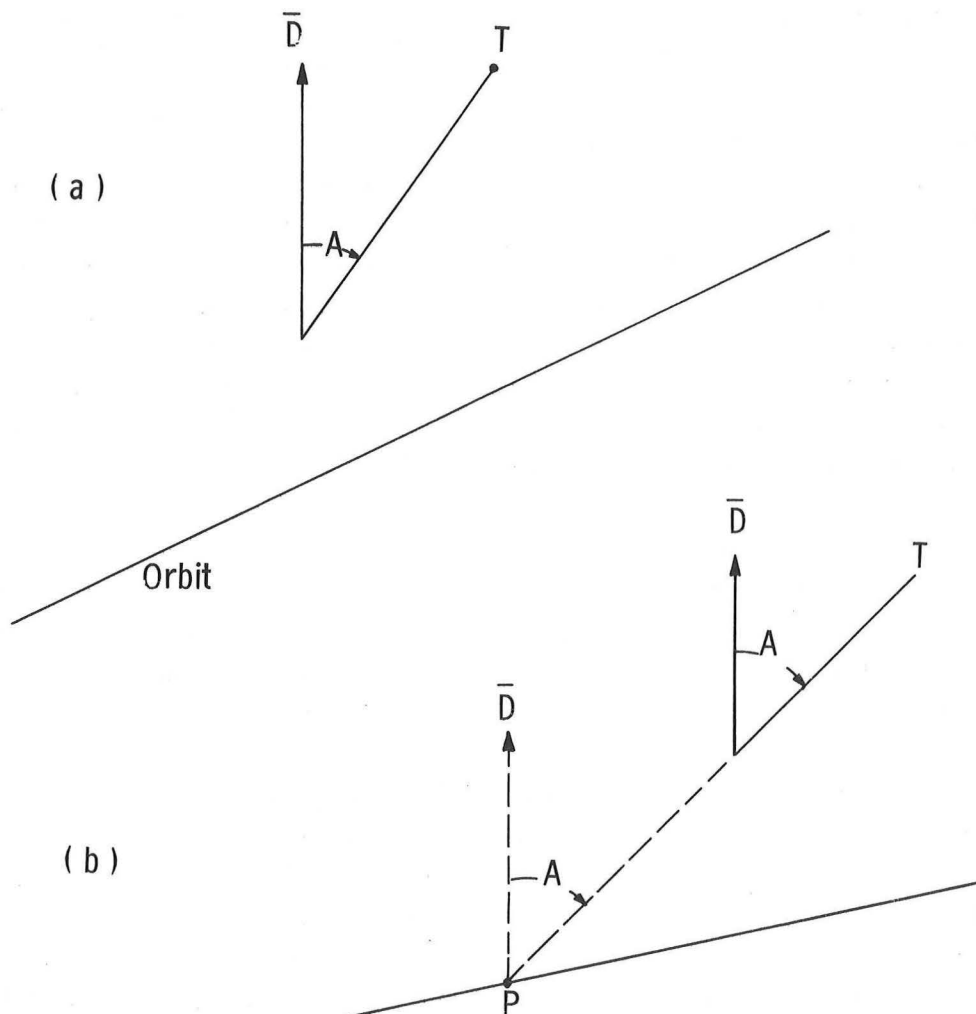


Figure 4.1.2-1. One-dimensional Example of Geometric Determination in Recursive Navigation

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 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.

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 reflecting the covariances between the elements of the state



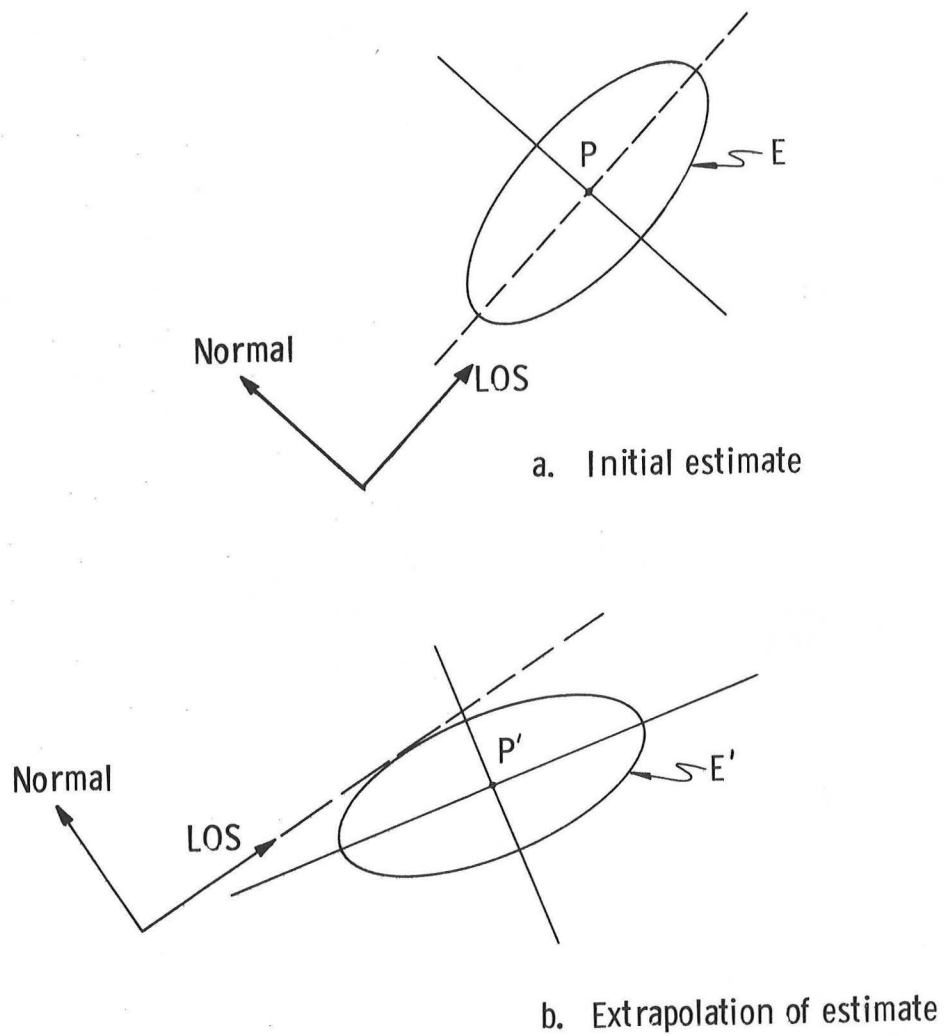


Figure 4.1.2-2. Two-dimensional Example of Extrapolation

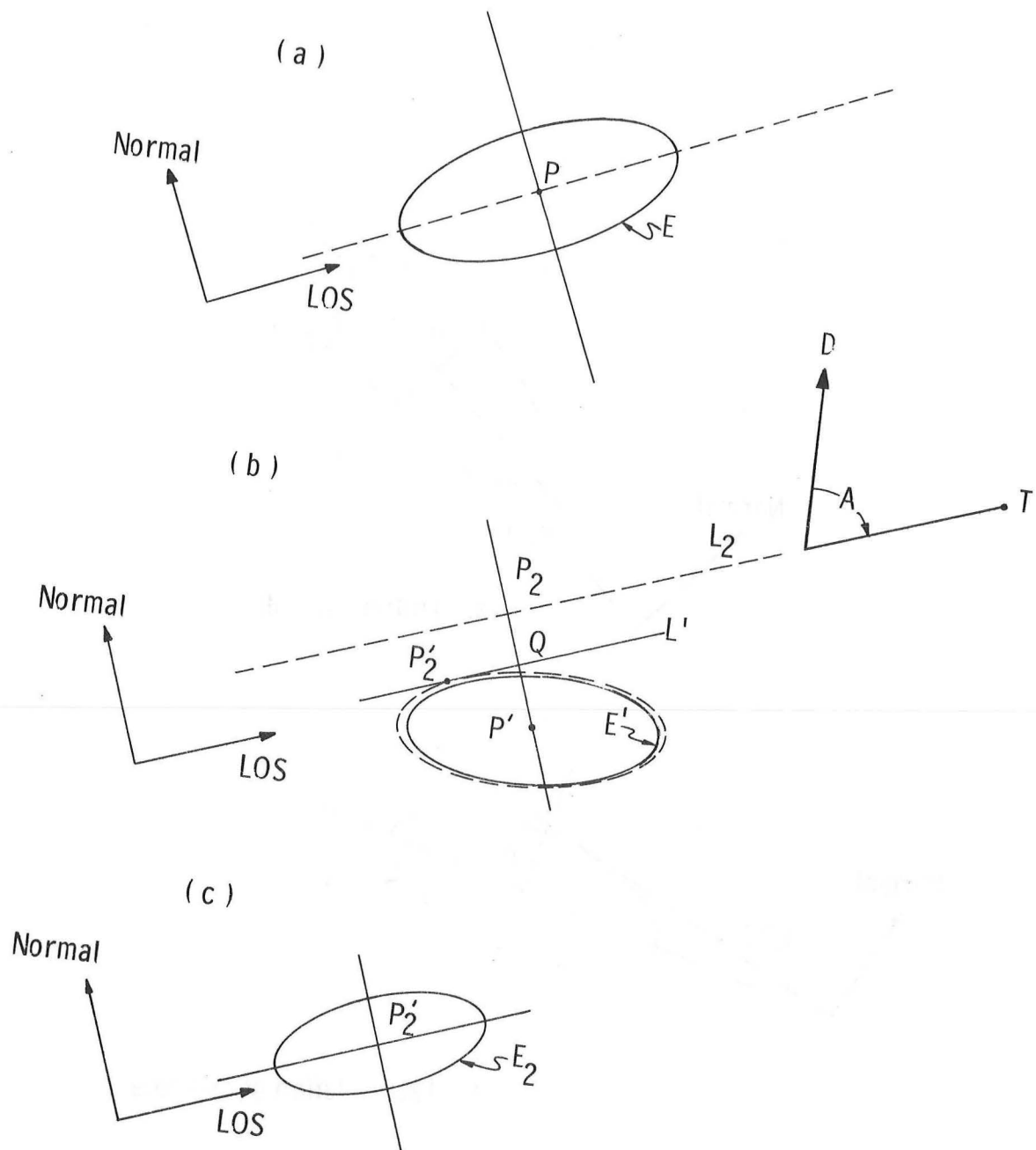


Figure 4.1.2-3. Two-dimensional Example of Correlation

vector inherent in the estimates. For computational convenience,<sup>\*</sup> 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.

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.

#### 4.2.1 P20, Universal Tracking and Rendezvous Navigation

The CMC Universal Tracking and Rendezvous Navigation Program (P20) has two independent functions—tracking and navigation. The tracking function applies to any mission situation requiring the CSM to track a designated body with a specified pointing vector or to any mission situation requiring the CSM to rotate at a constant rate around a specified vector. The navigation function applies only to the Rendezvous Navigation Mode of P20.

Regardless of function, P20 can always be started by the conventional VERB 37 ENTR 20 ENTR. If the Rendezvous Navigation Mode is to be used, however, the simplest way to start P20 is by calling an appropriate Rendezvous Targeting Program. (See paragraph 4.2.1.2.) Depending upon the tracking option selected, P20 continues in the background when the crew selects any of the navigation, targeting, or alignment programs listed (with allowable options) in Table 4.2.1-I. Only the rendezvous targeting programs (P31-36 and P38) and the Rendezvous Final Program (P37), however, start P20 if it is not already running. (Refer to Figure 4.2.1-1 for a flow diagram of P20 initial conditions. The figure also lists the conditions of "permanent" P20 termination.) The nominal use for each of the P20 starting conditions is as follows:

<u>Initial Condition</u>	<u>Use</u>
A	To select P20 nonrendezvous options (1, 2, or 5)
B	To return to P20 (nonMINKEY) from another program
C	To initiate rendezvous mode of P20 (MINKEY or Manual)
D	To initiate MINKEY when P20 rendezvous mode (Manual) is operating
E,F	To continue P20 (nonMINKEY) in background of another program

Observe that Initial-condition A is the primary condition for initiating the P20 Nonrendezvous Mode, that Initial-condition C is primary for initiating the P20 Rendezvous Mode.

##### 4.2.1.1 P20 Nonrendezvous Mode

The nonrendezvous mode of P20 comprises Options 1, 2, and 5. Options 1 and 5 allow the crew to specify any spacecraft vector and DAP deadband and have the

TABLE 4.2.1-I  
PROGRAMS ALLOWING P20 TO RUN IN BACKGROUND

Program Number	Compatible Options				
	0	1	2	4	5
P21*	X	X	X	X	X
P27		X	X		X
P29*	X	X	X	X	X
P30	X	X	X	X	X
P31-P38	X			X	
P37				X	
P52			X		
P54			X		

\*Tracking only (no navigation)

Options

0. . . . . Point a specified spacecraft vector at the OWS. Do not constrain rotational attitude about this pointing vector. (Use VECPOINT.)
1. . . . . Point a specified spacecraft vector at a celestial body. Do not constrain attitude about this vector. (Use VECPOINT.)
2. . . . . Rotate at a specified rate about a specified spacecraft vector.
4. . . . . Same as Option 0, but constraining attitude about the pointing vector to a specified value (OMICRON).
5. . . . . Same as Option 1, but constraining attitude about pointing vector to a specified value (OMICRON).

- Initial-condition A. —VERB 37 ENTR 20 ENTR when P20 is either active\* and in PROG lights or not active.
- Initial-condition B. —VERB 37 ENTR 20 ENTR when P20 is active\* but not in FROG lights, i. e., temporarily terminated or running in the background.
- Initial-condition C. —VERB 37 ENTR xx ENTR when the rendezvous mode of P20 is inactive\* and where xx is the number of a MINKEY-compatible program (P31—P38).
- Initial-condition D. —VERB 37 ENTR xx ENTR when the rendezvous mode of P20 is active\* and where xx is the number of a MINKEY-compatible program (P31—P38).
- Initial-condition E. —VERB 37 ENTR xx ENTR when the rendezvous mode of P20 is active\* and where xx is the number of a P20-compatible program that is incompatible with MINKEY.
- Initial-condition F. —VERB 37 ENTR xx ENTR when the nonrendezvous mode of P20 is active\* and where xx is the number of a P20-compatible program.

---

\* Once P20 is started, by any means, it is considered active until 'permanently' terminated by one of the following:

VERB 96 ENTR  
 VERB 56 ENTR  
 VERB 37 ENTR 00 ENTR  
 VERB 37 ENTR 06 ENTR  
 VERB 34 ENTR in response to the following P20 displays—

FL VERB 04 NOUN 06 (R1 = 00024)  
 FL VERB 06 NOUN 78  
 FL VERB 06 NOUN 79  
 FL VERB 06 NOUN 34  
 FL VERB 01 NOUN 70  
 FL VERB 06 NOUN 88  
 FL VERB 06 NOUN 49  
 FL VERB 50 NOUN 18

Figure 4.2.1-1. Initializing Conditions for Starting the Universal Tracking and Rendezvous Program (CMC P20)—(Sheet 1 of 4)

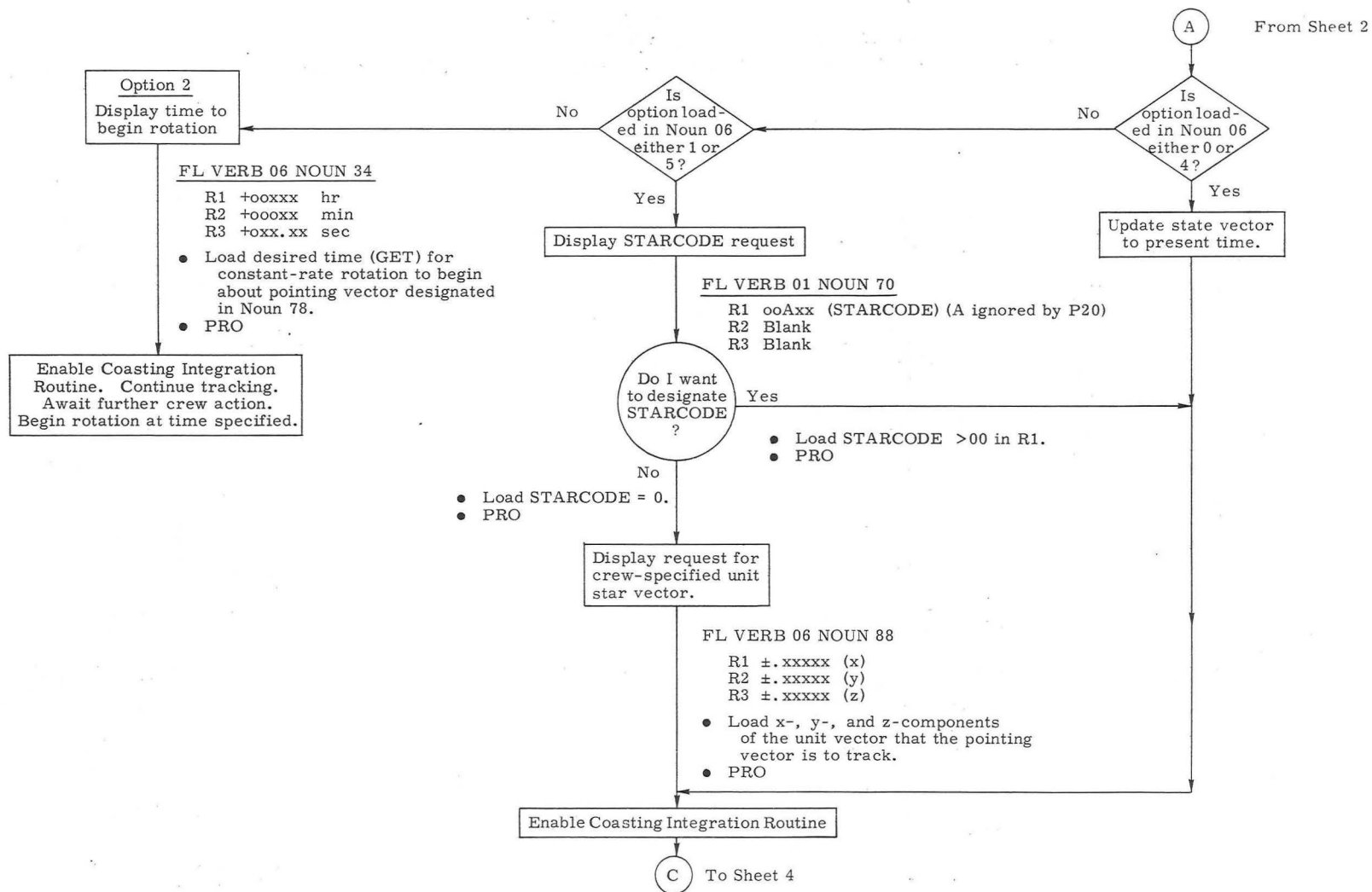


Figure 4.2.1-1. Initializing Conditions for Starting the Universal Tracking and Rendezvous Program (CMC P20) - (Sheet 2 of 4)

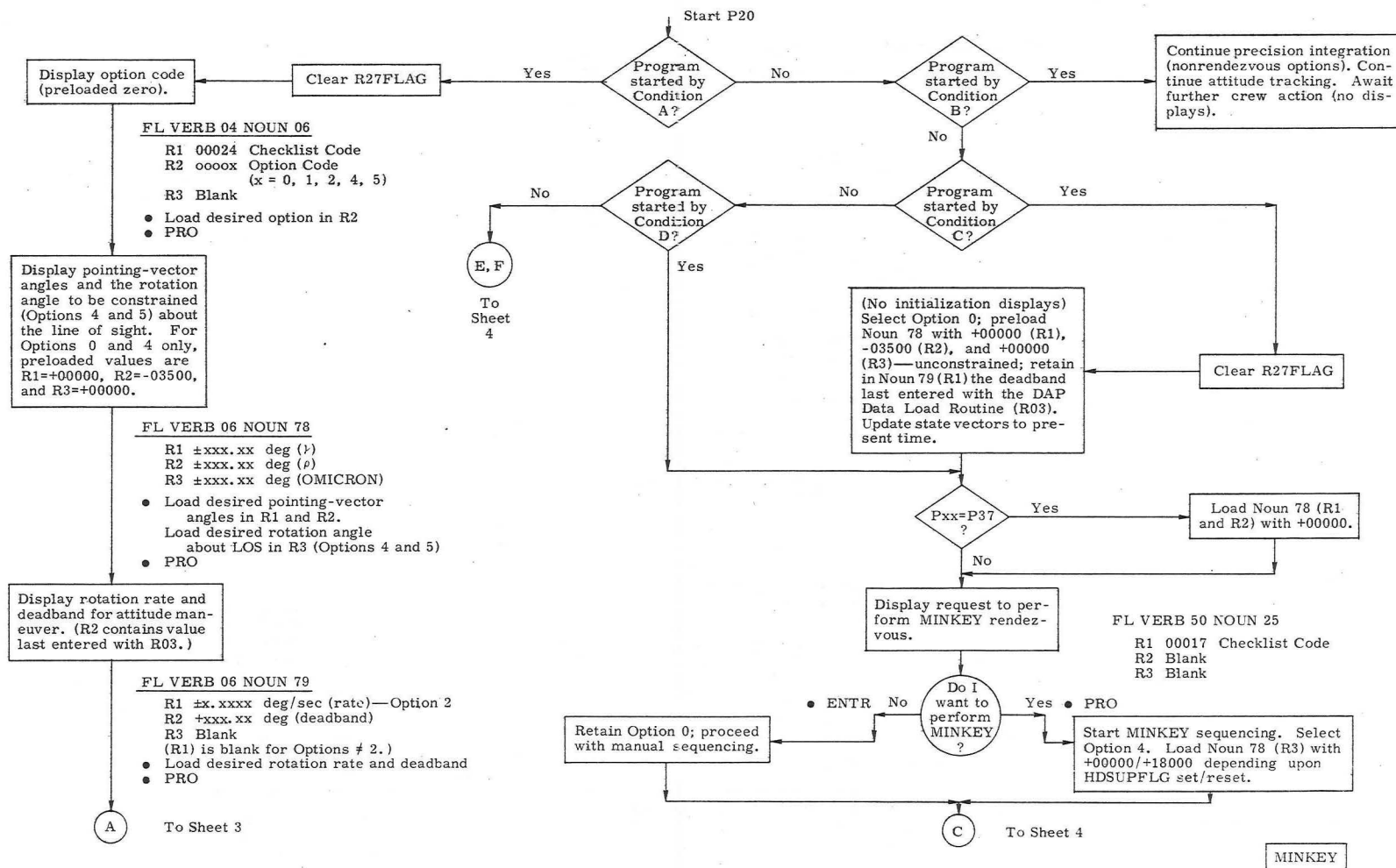


Figure 4.2.1-1. Initializing Conditions for Starting the Universal Tracking and Rendezvous Program (CMC P20) - (Sheet 3 of 4)



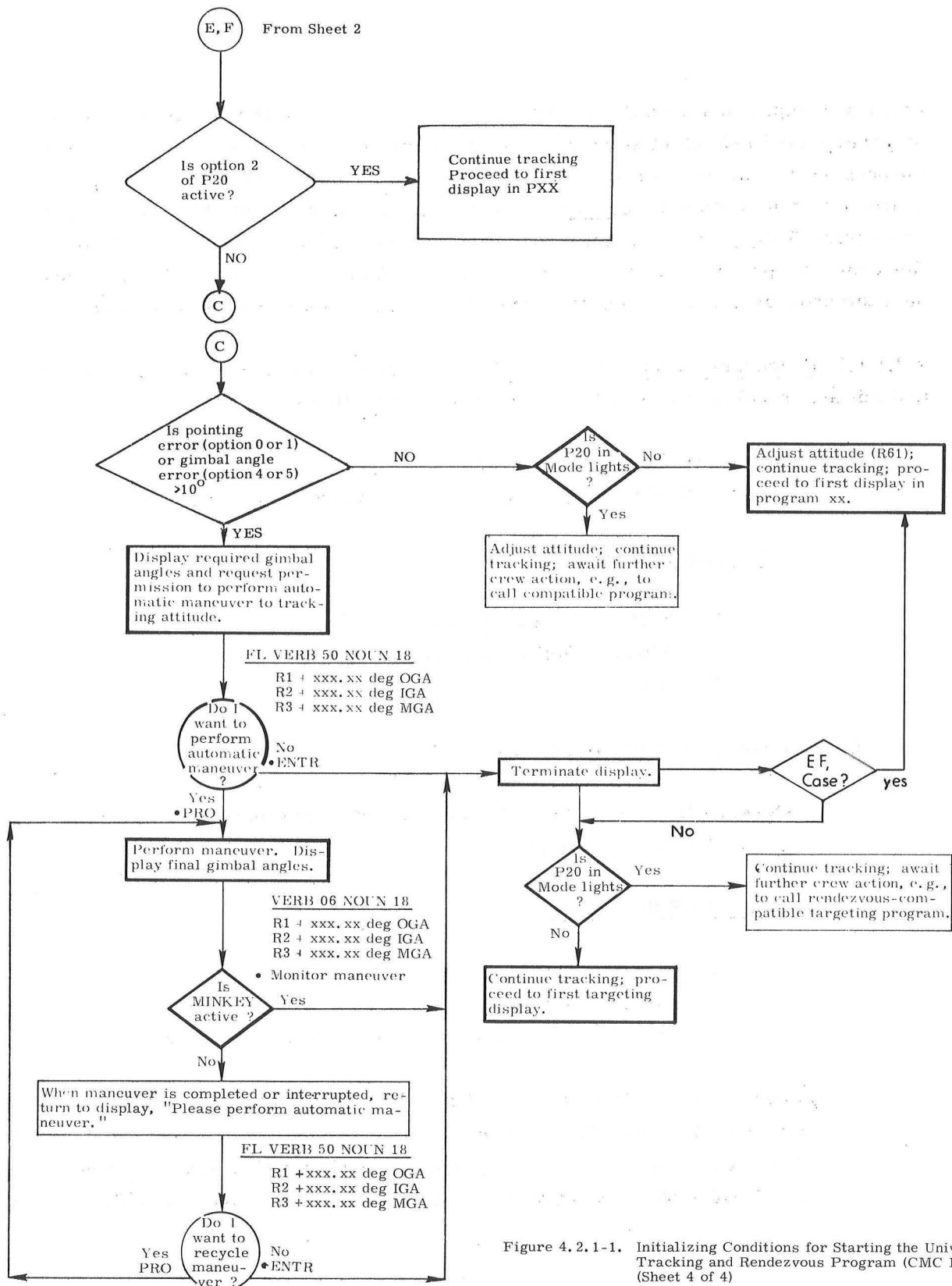


Figure 4.2.1-1. Initializing Conditions for Starting the Universal Tracking and Rendezvous Program (CMC P20)—(Sheet 4 of 4)

program compute and execute an attitude maneuver for pointing the specified vector at a crew-specified celestial body. Once the required attitude has been established, the program continues to track the designated target. The difference between Options 1 and 5 is that Option 1 does not constrain rotation angle about the line of sight, and Option 5 does constrain this angle to a crew-specified value. Option 2 allows the crew to specify a rotation rate, a DAP deadband, and an execution time and have the program initiate a constant-rate rotation about a specified spacecraft vector.

**4.2.1.1.1 Procedures (Options 1 and 5).**—To specify a spacecraft pointing vector and initiate tracking of a celestial body, proceed as follows:

1. Key VERB 37 ENTR 20 ENTR

Observe flashing display of option code (zero preloaded):

FL VERB 04 NOUN 06

R1 00024 Checklist Code  
 R2 0000x Option Code (x = 0,1,2,4,5)  
 R3 Blank

2. Load R2 with 00001 or 00005

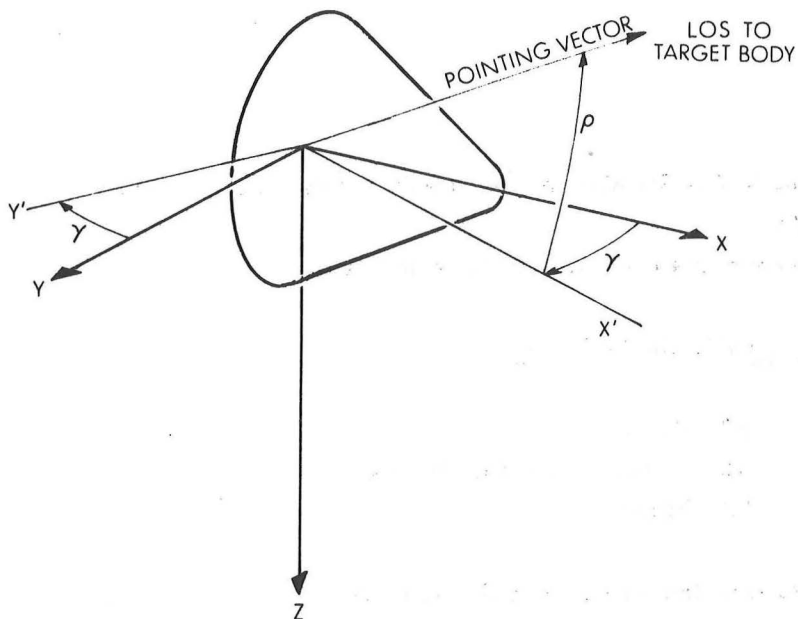
PRO

Observe flashing request for crew to load pointing-vector angles (not preset for these options):

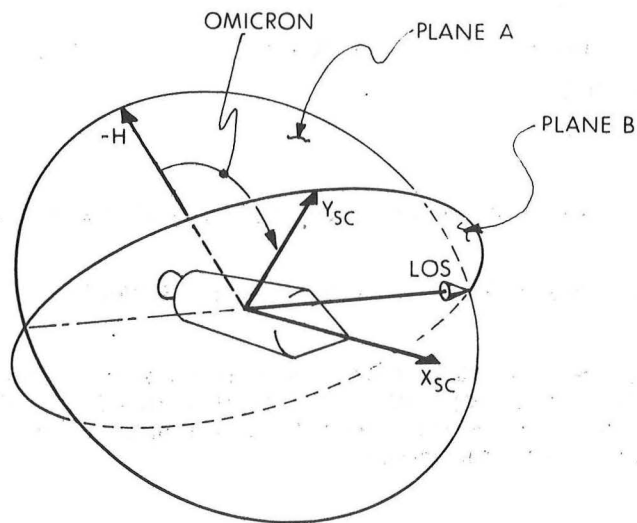
FL VERB 06 NOUN 78

R1 ±xxx.xx deg ( $\nu$ )  
 R2 ±xxx.xx deg ( $\rho$ )  
 R3 ±xxx.xx deg (OMICRON)—not relevant in Option 1

where  $\nu$  is positive rotation from the spacecraft +X-axis about the spacecraft Z-axis ( $0 \leq \nu < 360$  deg);  $\rho$  is positive rotation about the Y'-axis produce in the XY plane by the initial ( $\nu$ ) rotation ( $-90 \leq \nu \leq 90$  deg); and OMICRON is the amount of spacecraft rotation about the LOS.



OMICRON is measured as the positive-sense angle between planes A and B: plane A is defined by the negative momentum vector ( $-H$ ) and the line of sight (LOS); plane B is defined by spacecraft  $+Y$ -axis and the LOS.



OMICRON is relevant only to Options 4 and 5; in these options, alignment of the LOS with either the spacecraft  $Y$ -axis or the momentum vector is proscribed since the necessary two-plane condition for specifying OMICRON would not exist.

3. Load NOUN 78 with the desired pointing-vector angles  
PRO  
Observe flashing display of deadband:

FL VERB 06 NOUN 79

R1 Blank  
R2 +xxx.xx deg (deadband)  
R3 Blank

(R2 preloaded with last R03 deadband)

4. Load NOUN 79 with the desired deadband—minimum deadband (0.5 deg)  
used when register contains zero  
PRO  
Observe flashing display of STARCODE:

FL VERB 01 NOUN 70

R1 00Axx (xx = STARCODE)  
R2 Blank  
R3 Blank

where legal values of xx are  $00 \leq xx \leq 47_8$ . A is ignored by P20.

5. Load R1 of NOUN 70 with the desired STARCODE

NOTE.—If no STARCODE exists for the body selected for tracking, load R1 of NOUN 70 with 00, key PRO, and observe flashing request for the crew to load the desired unit star vector:

FL VERB 06 NOUN 88

(occurs only if R1 of NOUN 70 contains 00000)

R1  $\pm$ ,xxxxx (X)

R2  $\pm$ ,xxxxx (Y)

R3  $\pm$ ,xxxxx (Z)

Load the desired unit star vector.

PRO

Observe flashing request to "Please perform automatic maneuver to tracking attitude" (due to a pointing error greater than 10 deg for option 1 or a gimbal angle error greater than 10 deg for option 5):

FL VERB 50 NOUN 18

R1 +xxx.xx deg OGA

R2 +xxx.xx deg IGA

R3 +xxx.xx deg MGA

NOTE.—If in Option 5, possible Alarm 00401 ("Desired gimbal angles produce gimbal lock"), key VERB 23 NOUN 78 ENTR; change contents of R3 (OMICRON); then key ENTR to deny request for maneuver (reset V50N18FL). When UPLINK ACTY light illuminates (any gimbal-angle error > 10 deg), key VERB 58 ENTR (to set V50N18FL and reset STIKFLAG). Flashing VERB 50 NOUN 18 returns with a request to perform maneuver to attitude reflecting new OMICRON.

6. To execute maneuver, key PRO

Observe nonflashing display of final gimbal angles as automatic maneuver is being performed:

VERB 06 NOUN 18

R1 +xxx.xx deg OGA

R2 +xxx.xx deg IGA

R3 +xxx.xx deg MGA

7. Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually, then key VERB 58 ENTR to set V50N18FL and to reset STIKFLAG.

NOTE 1.—A middle-gimbal angle of  $\pm 75$  deg during the maneuver causes the RCS DAP to terminate the

maneuver and to maintain attitude hold (sets STIKFLAG and zeros HOLDFLAG). Maneuver rate will be as prescribed by R03. When maneuver has completed or is interrupted, the flashing request to perform automatic maneuver (VERB 50 NOUN 18) returns. PRO recycles the maneuver; ENTR causes the Attitude Maneuver Routine (R60) to exit. The Tracking-attitude Routine (R61) continues to track the celestial body. If tracking is interrupted (e.g., by the crew's use of the RHC) or if the pointing vector is changed (NOUN 78) such that a pointing error (Option 1) or any gimbal-angle error (Option 5) >10 deg results, the UPLINK ACTY light will illuminate signaling the need to perform an R60 maneuver. To initiate R60, key VERB 58 ENTR and respond to flashing VERB 50 NOUN 18 as in steps 6 and 7.

NOTE 2.—In Option 1, the pointing error is measured as the angle between the LOS and the center of the DAP deadband.

4.2.1.1.2 Procedures (Option 2).—To have P20 initiate and maintain a constant-rate rotation about a specified spacecraft vector, proceed as follows:

1. Key VERB 37 ENTR 20 ENTR

Observe flashing display of option code (zero preloaded):

FL VERB 04 NOUN 06

R1 00024 Checklist Code

R2 0000x Option Code (x = 0,1,2,4,5)

2. Load R2 with 00002

PRO

Observe flashing request for crew to load pointing-vector angles (in Option 2, the vector—not preset—about which the constant-rate rotation shall be established):

FL VERB 06 NOUN 78

R1 ±xxx.xx deg ( $\lambda$ )

R2 ±xxx.xx deg ( $\rho$ )

R3 ±xxx.xx deg (OMICRON)

3. Load registers R1 and R2 with the desired angles. (OMICRON is not relevant to Option 2.)

PRO

Observe flashing display of rotation rate and deadband:

FL VERB 06 NOUN 79

R1  $\pm$ x.xxxx deg/sec (rate)

R2 +xxx.xx deg (deadband)

R3 Blank

(R2 preloaded with last R03 deadband.)

4. Load NOUN 79 with desired parameters—minimum deadband (0.5 deg) used when register R2 contains zero

PRO

Observe flashing display of the time to begin rotation:

FL VERB 06 NOUN 34

R1 +ooxxx hr GET

R2 +ooxxx min

R3 +xxx.xx sec

5. Load NOUN 34 with the desired time (GET) to initiate rotation

PRO

NOTE.—If the time loaded is in the past, rotation begins immediately. Otherwise, rotation about the vector specified in NOUN 78 begins at the time specified in NOUN 34. (Option-2-compatible program active, with no intervening "permanent" termination of P20. Refer to Figure 4.2.1-1.) Once rotation begins, the program does not look at the contents of NOUNS 78 and 79 again until rotation is interrupted and restarted. Consequently, to change the rotation axis, rate, or deadband, the crew should effect one of the following:

- a. Load new parameters into NOUN 78 and 79; remove the RHC from detent (to stop rotation), then return the RHC to detent and key VERB 58 ENTR to resume rotation using the new parameters.
- b. Key VERB 37 ENTR 20 ENTR (with 20 in the PROG lights) and reinitialize with new parameters.

- c. Load new parameters; call a program that is incompatible with P20 Option 2 (see Table 4.2.1-I) —rotation stops; then recall a compatible program—rotation resumes with new parameters.

#### 4.2.1.2 P20 Rendezvous Navigation

The rendezvous-navigation mode—Options 0 and 4 of the Universal Tracking and Rendezvous Navigation Program (P20)—is an onboard means of updating either of two inertial state vectors (CSM or OWS) carried in the Command Module Computer. If the VHF Range Rate Mark Processing Routine (R27) has been enabled by V76E (see paragraph 4.2.1.3.1), then the range state vector is also updated with this mode. The designated state vector is updated by incorporating measurements of line of sight (optics) and range (VHF) from the CSM to the OWS. Except during the thrusting phases, P20 operates continuously throughout CSM-OWS rendezvous, in conjunction with whichever is appropriate of the following targeting programs:

P30—External  $\Delta V$   
P31—NC1 Targeting  
P32—NC2 Targeting  
P33—NCC Targeting  
P34—NSR Targeting  
P35—Transfer Phase Initiation (TPI)  
P36—Transfer Phase Midcourse (TPM)  
P38—Plane Change (PC)

In addition, P20 performs X-axis tracking when initiated by the Rendezvous Final Program (P37). The rendezvous GNCS functional requirements are Navigation, Targeting, Powered-flight Control and Guidance, and IMU Alignment.

- a. Navigation.—Optical and VHF ranging data are continually incorporated to improve the estimate of the inertial position and velocity of the updated vehicle relative to the inertial state vector of the non updated vehicle. VHF ranging data are also used to update or to optimize the relative position and velocity along the line of sight (range and range-rate) between the two vehicles. These functions are controlled by the rendezvous-navigation mode of P20, which is described in this section (paragraph 4.2.1.2). The rendezvous-navigation mode also controls the spacecraft orientation during the coasting phase of rendezvous.
- b. Targeting.—On the basis of the command-module computer (CMC)



estimates of inertial 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 inertial state vectors 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.

The following discussion—through paragraph 4.2.1.2.5—applies to rendezvous navigation in general, using manual sequencing. Paragraph 4.2.1.2.6 describes rendezvous navigation using minimum-keystroke (MINKEY) sequencing.

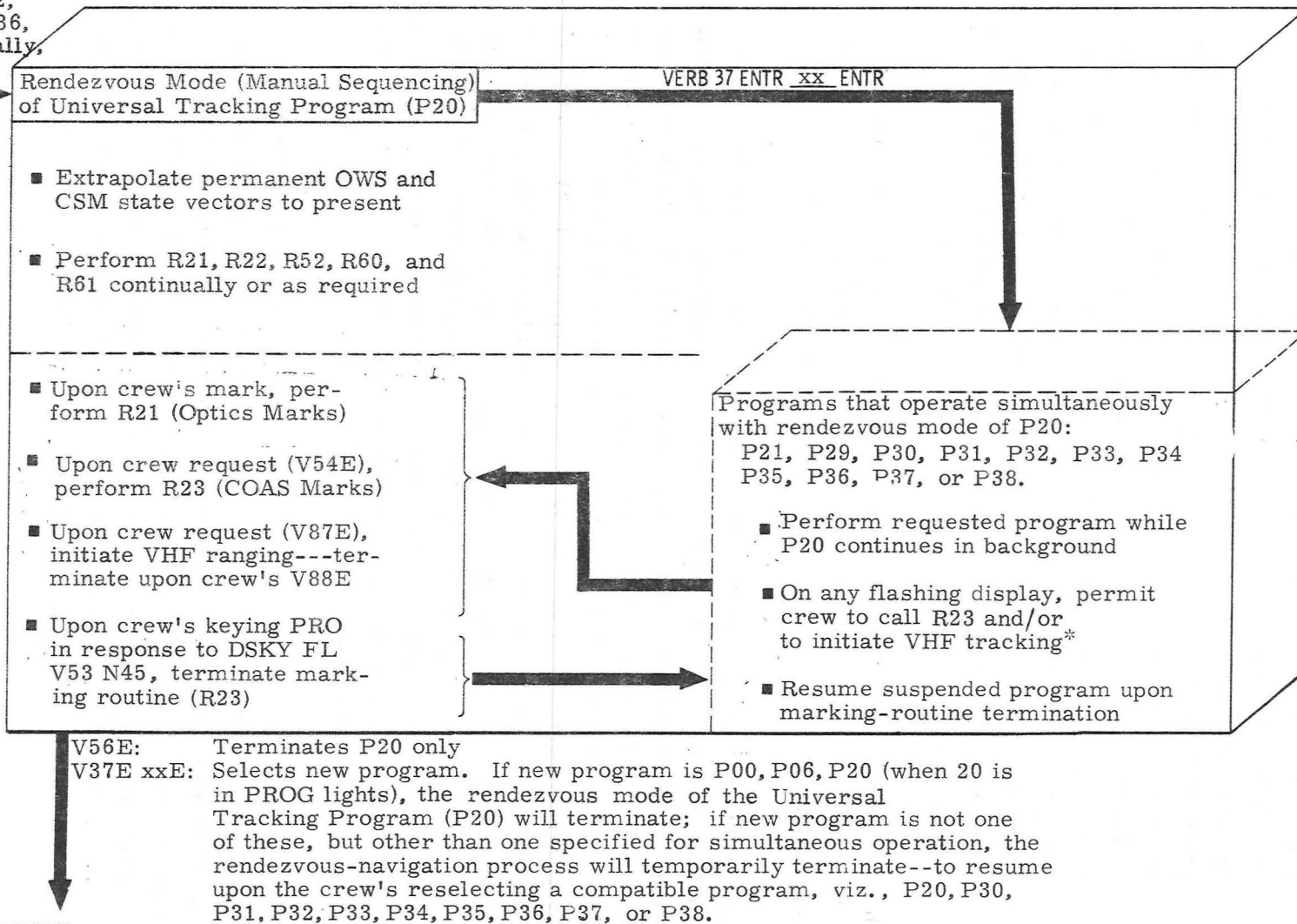
Operating in the background throughout rendezvous, P20 becomes temporarily dormant (attitude tracking continues) upon the crew's requesting a final targeting computation,\* remains dormant (no tracking) during the powered-flight phase, and re-awakens only upon the crew's selecting a compatible targeting program (Figure 4.2.1-2) or P20—VERB 37 ENTR 20 ENTR. Should it become necessary to call any other program except P00 or P06 (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, P31, P32, P33, P34, P35, P36, and P38 or with P37. Once P20 is entered, subsequent selection of a compatible targeting program or of P37 changes the DSKY PROG number to reflect the program selected, but allows navigation to continue.

Accordingly, the crew can, upon a flashing display during a P20-compatible program (normally flashing VERB 16 NOUN 45), take the required optical measurements simply by depressing the mark button. If necessary, the crew can call 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

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\* R27 continues to operate during targeting computations.

Selected automatically, by P31, P32, P33, P34, P35, P36, P37 or P38 manually, by V37E 20E



\* Navigation data are not incorporated, however, during the time that UPDATE flag is reset. See paragraph 4.2.1.2.

Figure 4.2.1-2. Simplified Flow Diagram Showing Relationship of P20 Rendezvous Mode (Manual Sequencing) to Other CMC Programs

range data to be incorporated until the crew resets the VHF RANGE flag by keying VERB 88 ENTR or by VERB 37 ENTR. 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, with the following exceptions, marks can be incorporated during targeting-program displays preceding the request for final targeting computation (PRO response to flashing VERB 16 NOUN 45—temporarily terminates navigation): marks not incorporated during (a) recycle displays preceding the VERB 06 NOUN 81 display in P35, (b) alarm displays, (c) displays after the first two in P30. (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  $\Delta v$  required to effect rendezvous.

Figure 4.2.1-3 is a simplified functional diagram of the logic for updating one of the two CMC state vectors—designated in Figure 4.2.1-3 as "passive vehicle orbit" and "active vehicle orbit."

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  $\delta Q$ . This is multiplied by a statistical weighting vector ( $\omega$ ) comprising an onboard computation of expected state-vector uncertainties, expected sensor performance ( $\bar{\alpha}^2$ ), and the sensor geometry vector ( $b$ ). The resulting  $\delta x$  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 similarly for optics; the selected state vector is automatically updated by the computed deviation  $\delta x$ . If the magnitude of either the position-vector change ( $\delta r$ ) or the velocity-vector change ( $\delta v$ ) of the deviation  $\delta x$  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.

**4.2.1.2.1 Crew Options.**—Before selecting the rendezvous mode of P20, the crew should resolve the following questions:

1. Which attitude option (0 or 4) do I wish to select? (Options listed in Table 4.2.1-I.)
2. If option 4 is to be used, what kind of sequencing do I want—manual or MINKEY?
3. Do I wish to enable R27 for back-up targeting? (See paragraph 4.2.1.3.1).

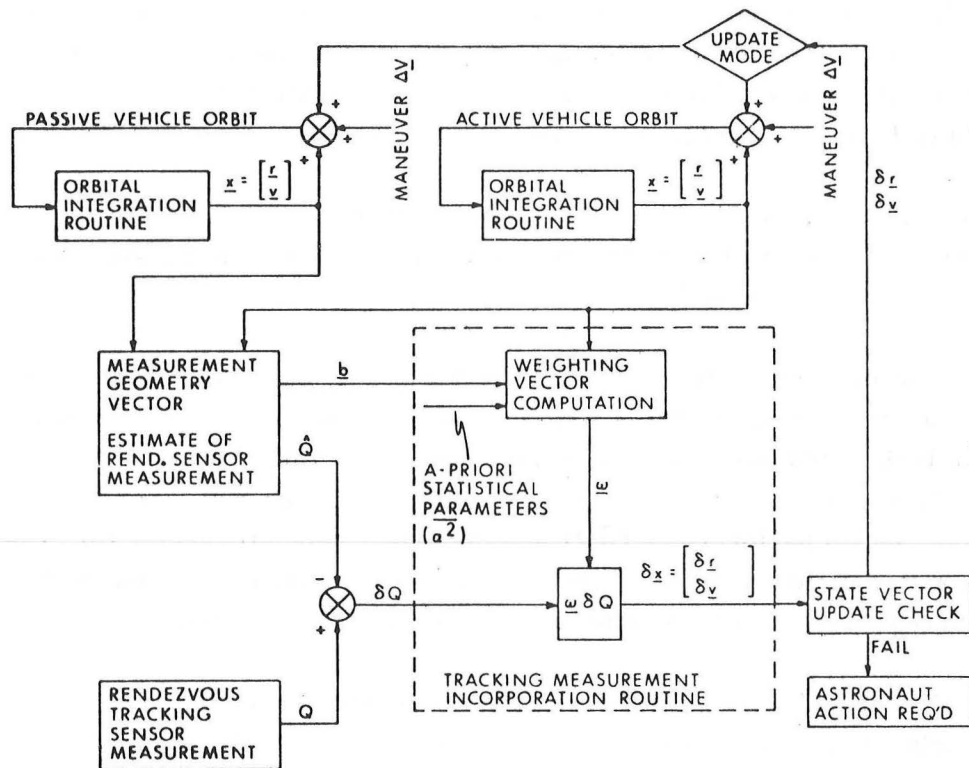


Figure 4.2.1-3. Simplified Rendezvous Navigation Diagram (CSM)

If option 0 is desired (unconstrained attitude about pointing vector), the crew has no choice but to use manual sequencing, since MINKEY can only be performed using option 4 (attitude constrained about pointing vector). If option 4 is desired, however, the crew has the further option of using either manual or MINKEY sequencing. For MINKEY sequencing, the crew would start the rendezvous mode of P20 simply by keying in a MINKEY-compatible targeting program (P31, P32, P33, P34, P35, P36, P37, P38). Program sequencing would then be as described in paragraph 4.2.1.2.6. For manual sequencing under option 0, the rendezvous mode of P20 is also started by calling a compatible targeting program, as described in paragraph 4.2.1.2.2. In either instance, manual or MINKEY, the P20 rendezvous mode can be entered by keying VERB 37 ENTR 20 ENTR and proceeding through the universal-tracking initialization displays. This entry is mandatory, however, when manual-sequencing option 4 is desired. The procedure for selecting this configuration is as follows:

1. Key VERB 37 ENTR 20 ENTR and observe preloaded option display:

FL VERB 04 NOUN 06

R1	00024	Option Code
R2	00000	Preloaded zero option
R3	Blank	

2. Key VERB 22 ENTR 4 ENTR.
3. When satisfied with NOUN 06 option, key PRO and observe preloaded tracking attitude:

FL VERB 06 NOUN 78

R1	+000.00	deg	$\gamma$
R2	-035.00	deg	$\rho$
R3	+000.00	deg	OMICRON

(where  $\gamma$ ,  $\rho$ , and OMICRON are as defined in paragraph 4.2.1.1.)

4. To change NOUN 78 values, key VERB 2x and load the appropriate register(s).
5. When satisfied with NOUN 78 values, key PRO and observe DAP dead-band.

FL VERB 06 NOUN 79

R1 Blank  
R2 +xxx.xx deg Deadband  
R3 Blank

6. To change deadband, key VERB 22 ENTR and load register R2 with the desired value—minimum deadband (0.5 deg) used when register contains zero.
7. When satisfied with NOUN 79 values, key PRO and observe R60 request to perform automatic attitude maneuver to the displayed gimbal angles (if required change to any gimbal angle is >10 deg).

FL VERB 50 NOUN 18

R1 +xxx.xx deg OGA  
R2 +xxx.xx deg IGA  
R3 +xxx.xx deg MGA

8. To perform automatic maneuver, key PRO and observe nonflashing display of final gimbal angles as the maneuver is being performed; monitor FDAI Ball and Attitude Error Needles.
9. When attitude maneuver has completed and the flashing VERB 50 NOUN 18 returns, key PRO to recycle, ENTR to exit R60.
10. Take marks at crew's discretion; when ready for targeting program, key VERB 37 ENTR 3x ENTR and observe request to perform MINKEY Rendezvous.

FL VERB 50 NOUN 25

R1 00017 Checklist Code  
R2 Blank  
R3 Blank

11. To perform manual sequencing, key ENTR and observe first targeting display (assuming no attitude change). All initialization values will be retained.\*

---

\* A PRO response to the VERB 50 NOUN 25 display calls MINKEY. In that instance, the contents of NOUNS 78 and 79 will be conserved. If Option 4 not previously selected, however, that option would now be selected automatically and N78 (R3) would be loaded as determined by HDSUPFLG.

NOTE.—As when P20 is entered from a targeting program, NOUNS 78 and 79 can be called and their contents changed whenever a change is required. Also, as with a targeting-program entry to P20, the crew's changing the contents of NOUN 06 will have no effect once he keys PRO on the initial display.

#### 4.2.1.2.2 Manual Sequencing of Rendezvous Navigation.—

4.2.1.2.2.1. Functional Description. —The following routines are used by P20 in the rendezvous-navigation mode.

R02 — The IMU Status Check Routine is called by programs requiring an aligned IMU. R02 checks the IMU orientation (REFSMMAT) flag and (if not set) checks the IMU operate bit. A PROG alarm is initiated if either is not set. The crew verifies the alarm by keying VERB 05 NOUN 09 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, the crew keys RSET, and the program goes 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 is started by the P20 rendezvous mode and continues to run until the P20 rendezvous mode 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. In addition R22 calls R27 for range, range rate processing when enabled by keying V76 ENTR.

R61 — The Tracking Attitude Routine is called either by P20 or R52. R52 calls R61 on every pass during rendezvous tracking (options 0 and 4). On every fourth pass (only), R61 extrapolates the CSM and OWS state vectors to the present, calculates the LOS from the CSM to the OWS, and computes the IMU gimbal angles required to keep the CSM properly oriented for tracking the OWS. If option 0 has been selected, an appropriate attitude is held for SXT and VHF tracking (as determined by NOUN 78 values—for preferred tracking attitude, Register R1,

000.00 deg; R2, -035.00 deg).<sup>\*</sup> If option 4 has been selected, the attitude will be further constrained by the contents of NOUN 78, Register R3, e.g., 000.00 deg (heads-up) or 180.00 deg (heads-down). Comparing the spacecraft pointing axis (center of DAP deadband) with the LOS (Option 0), or comparing the required and present gimbal angles in each axis (Option 4), R61 determines whether any error exceeds 10 deg. If not, 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, with V50N18FL flag set, the error exceeds 10 deg, R61 calls the Attitude Maneuver Routine (R60). If, on subsequent passes through R61 (V50N18FL flag reset), the pointing error (Option 0) or a gimbal-angle error (Option 4) exceeds 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 V50N18FL flag (and resetting STIKFLAG) 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 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. A middle-gimbal angle of  $\pm 75$  deg during an automatic maneuver causes the RCS DAP to terminate the maneuver and to maintain attitude hold (sets STIKFLAG and zeros HOLDFLAG).

NOTE.—STIKFLAG is also set by the crew's moving the RHC out of detent. To enable subsequent tracking, key VERB 58 ENTR to reset STIKFLAG and set V50N18FL.

R52 — During rendezvous navigation, the Automatic Optics Positioning Routine keeps the CSM optics pointed at the OWS (OPTICS MODE switch in

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<sup>\*</sup>For COAS, or X-axis tracking, NOUN 78 values are as follows: Register R1, 000.00 deg; R2, 000.00 deg; R3, as desired.



CMC). Calculating the LOS to the OWS, with R61 maintaining tracking attitude, R52 drives the optics shaft and trunnion accordingly until the TRACKFLG is reset or the OPTICS MODE switch is set to MAN.

R21 — The Rendezvous Tracking Sighting Mark Routine is called automatically by R22. The crew can take SXT marks anytime during R22 unless R23 has been selected.

R23 — The Backup Rendezvous Tracking Sighting Mark Routine allows the crew to use the crew optical alignment sight (COAS), rather than the sextant (SXT), for rendezvous tracking. R23 is called by the crew's keying VERB 54 ENTR and is terminated by PRO.

4.2.1.2.2.2 Manual-sequencing Procedures.—Table 4.2.1-II is a chronological summary of G&N procedures and displays associated with a manually sequenced rendezvous. Table 4.2.1-III summarizes extended and regular verbs that may be used during rendezvous. An amplified description of the procedures is presented here.

#### I. INITIALIZATION

- A. Perform preliminary set-up of controls, switches, and displays according to mission procedures.
- B. Perform DAP Data Load Routine (R03)—paragraph 9.2.1—and load desired deadband and maneuver rate for rendezvous attitude maneuvers. Load other DAP parameters as required by mission procedures and spacecraft configuration.
- C. Set up GNCS according to Mission Procedures.
- D. If an hour or more has elapsed since the W-matrix was initialized—or if the state vector has not been updated via P27—key VERB 93 ENTR to reinitialize W-matrix.
- E. Initiate rendezvous navigation.
  1. Key VERB 37 ENTR xx ENTR (where xx is 31, 32, 33, 34, 35, 36, 37, 38). Selection of a rendezvous targeting program or P37 causes a check to be made of REFSMMAT. If the IMU is not on and aligned to a known orientation, the program proceeds to the first display (no alarm) in program xx. If there is a valid REFSMMAT, however, P20 is turned on and performs the following:
    - a. Selects the CSM state vector as the one to be updated.

NOTE.—The crew can change the state vector selected for update by keying VERB 80 ENTR, which designates the OWS state vector for update. VERB 81 ENTR is available for reselecting the CSM state vector for update should there be a requirement for doing so. Considerations affecting the decision on which state vector to update are (1) the desire to update the state vector having the largest uncertainties, (2) the desire to update the state vector of the vehicle that is to perform the maneuver.

- b. Sets V50N18FL flag and resets STIKFLAG enabling R60 and the display of required gimbal angles for a maneuver to the desired tracking attitude.
- c. Sets TRACKFLG, enabling automatic attitude maneuver, optics pointing, and state-vector update.
- d. Sets UPDATFLG, enabling state-vector update.
- e. Sets RNDVZFLG, enabling total rendezvous mode of P20.
- f. Resets UTFLAG, terminating nonrendezvous modes of P20.
- g. Extrapolates both CMC-resident state vectors (CSM and OWS) to the present time.
- h. Selects option 0, designating rendezvous-mode tracking with unconstrained rotation about the pointing vector.

NOTE.—It serves no purpose for the crew to change the NOUN 06 option when the rendezvous mode is initiated by a targeting program. See crew options, paragraph 4.2.1.2.1.

- i. Loads NOUN 78 with  $\nu = 000.00$  deg (R1);  $\rho = -035.00$  deg (R2); and OMICRON =  $000.00$  deg (R3, unconstrained).
- j. Loads NOUN 79 with deadband (R2, xxx.xx deg) last designated by Routine R03.

NOTE.—NOUNS 78 and 79 are not displayed when the rendezvous mode is initiated by a targeting program. If the crew wishes to change the contents of either

noun, he can do so by keying (a) VERB 2x, (b) the appropriate noun, (c) ENTR, (d) the desired value(s), (e) ENTR. Subsequent tracking will conform to the new inputs.

- k. Flashes VERB 50 NOUN 25 (R1, 00017), "Please perform MINKEY Rendezvous."
2. To perform manually sequenced rendezvous, key ENTR. (To perform MINKEY-sequenced rendezvous, key PRO and proceed as described in paragraph 4.2.1.2.6.) The crew's ENTR on the flashing VERB 50 NOUN 25 display causes the pre-selected option and all initialized values in NOUNs 78 and 79 to be retained and initiates the required tracking-attitude maneuver (R61/R60). If a maneuver of 10 deg or less is required, it is accomplished by R61. If a maneuver greater than 10 deg is required, R61 calls R60 (V50N18FL flag set), which displays the required gimbal angles and requests the crew to perform an automatic tracking-attitude maneuver:

FL VERB 50 NOUN 18

R1 +xxx.xx deg OGA (Roll)

R2 +xxx.xx deg IGA (Pitch)

R3 +xxx.xx deg MGA (Yaw)

3. To accept the automatic maneuver, set the SC CONT switch to CMC, the CMC MODE switch to AUTO, and key PRO. (To perform the maneuver manually, key VERB 62 ENTR for FDAI display of total attitude error and use the RHC to null the needles.) While the automatic maneuver is in progress, a nonflashing VERB 06 NOUN 18 displays required gimbal angles. The crew monitors the maneuver on the FDAI ball and the attitude-error needles. If the maneuver approaches gimbal lock, the crew uses the RHC to complete the maneuver manually.

NOTE.—A middle-gimbal angle of  $\pm 75$  deg causes the RCS DAP to terminate the automatic maneuver and to maintain attitude hold. The maneuver must be completed with the RHC, referencing the FDAI ball to avoid gimbal lock. After using the RHC to complete the maneuver, the crew must key VERB 58 ENTR to reset STIKFLAG and allow subsequent automatic maneuvers.

When the maneuver has completed, the flashing VERB 50 NOUN 18 returns. To trim out residual errors, the crew can recycle the maneuver by keying PRO again, or he can use the RHC to make final attitude adjustments (rotation about the pointing vector, for example). Again, use of the RHC must be followed by VERB 58 ENTR to reset STIKFLAG.

4. When satisfied with the tracking attitude, key ENTR. This terminates R60, starts the Automatic Optics Positioning Routine (R52), and calls up the first display in targeting program xx. (See Section 5.0 for a discussion of targeting-program procedures.) R61 continues to compute and maintain a tracking attitude appropriate for the designated option and pointing vector.

NOTE.—If on subsequent passes through R61 (V50N18FL flag reset), the difference between the DAP deadband center and the LOS is found to be greater than 10 deg, the program will illuminate the UPLINK ACTY light but will not allow R61 to call R60. If maneuver is desired, the crew must key VERB 58 ENTR. R60 will then be called, and the crew will be presented a request to perform an automatic maneuver to tracking attitude (flashing VERB 50 NOUN 18)—as in step 2.

5. For automatic optics positioning, set the OPTICS ZERO switch to OFF and the OPTICS MODE switch to CMC. The Automatic Optics Positioning Routine (R52) will (a) extrapolate the CSM and OWS state vectors to the present time plus 2.4 seconds, (b) get the CSM attitude from the ICDUs, (c) compute a vector from the CSM to the OWS, (d) calculate the required optics shaft and trunnion angles, and (e) drive the OCDUs to point the sextant line of sight at the OWS.

NOTE.—If the required trunnion angle is greater than 50 deg, R52 will drive the OCDUs to the trunnion upper limit (~50 deg). The crew should verify that the CSM is at the proper tracking attitude. (The desired gimbal angles can be observed by keying VERB 16 NOUN 22 ENTR (or on the FDAI Error Needles—Mode II), the desired optics angles by keying VERB 16 NOUN 92 ENTR.) If an attitude correction is necessary, the crew can do one of the following: (a) use the RHC to manually maneuver the spacecraft to the desired gimbal angles; (b) verify that the SC CONT switch is in CMC, the CMC MODE switch is in AUTO, and that the correct attitude parameters are loaded in NOUN 78—then key

VERB 58 ENTR (sets V50N18FL flag and resets STIKFLAG) to allow R61 to call R60 to perform the required maneuver.

## II. RENDEZVOUS TRACKING, NAVIGATION, AND TARGETING

The initialization phase of the rendezvous-navigation mode ends when the crew is satisfied with the tracking-attitude parameters contained in NOUNs 78 and 79, has the tracking attitude established, and is ready to proceed with navigation and targeting. From this point until the crew requests a final targeting solution, he must coordinate his navigation activities with the targeting program in progress. Tracking and W-matrix-reinitialization schedules are discussed in paragraph 4.2.1.2.5. Targeting programs are described in Section 5.0.

### A. VHF TRACKING

When the tracking attitude has been established, key VERB 87 ENTR to initiate VHF tracking. VHF range data will then continue to accumulate at approximately 1-minute intervals until terminated by the crew's keying VERB 88 ENTR or VERB 37 ENTR xx ENTR. Incorporation of the data will cease, automatically (UPDATFLG reset), when the crew requests a final targeting solution (PRO on flashing VERB 16 NOUN 45). (See Restrictions and Limitations, paragraph 4.2.1.2.4.)

### B. OPTICS TRACKING (SXT OR SCT)

Take optical line-of-sight measurements on the OWS according to a predetermined tracking schedule. (See Tracking and W-Matrix-reinitialization Schedules, paragraph 4.2.1.2.5.):

1. Set OPTICS MODE switch to MAN.
2. Use optics hand controller (OHC) to center OWS in SXT.
3. Depress MARK button.
4. If mark was satisfactory, wait the prescribed time (based on geometry, timeline, etc.), recenter the OWS in the SXT, and repeat the mark (if more marks are desired). If mark was unsatisfactory, depress MARK REJ button, within 7 sec, and repeat mark procedure.

NOTE.—Marks are processed by the Rendezvous Tracking Data Processing Routine (R22). If any mark results in an excessive update (discussed in paragraph 4.2.1.2.5.1), a priority display (flashing VERB 06

NOUN 49) will automatically interrupt any program-initiated display and present the magnitude of the excessive update:

FL VERB 06 NOUN 49

R1 +xxx.xx n. mi.  $\Delta R$   
R2 +xxxx.x ft/sec  $\Delta v$   
R3 ooooo Source Code  
(1 = optics, 2 = VHF ranging)

After 2 seconds (priority display), key PRO to incorporate the data; key VERB 32 ENTR to reject the data.

(See paragraph 4.2.1.3.4 for delays in R27 resulting from the Noun 49 display).

C. BACKUP (COAS) TRACKING

To perform sighting marks using the backup (COAS) optics, proceed as follows:

1. Load NOUN 78 Registers R1 and R2 with +000.00 deg (X-axis tracking).
2. Key VERB 58 ENTR (if necessary) to set V50N18FL flag, reset STIKFLAG, and cause R61 to call R60 to perform maneuver to X-axis tracking attitude. (Refer to initialization procedures for initiating rendezvous navigation.)
3. When satisfied with tracking attitude, key VERB 54 ENTR to call the Backup Rendezvous Tracking Sighting Mark Routine (R23).

FL VERB 06 NOUN 94

R1 xxx.xx deg SA (X-axis nominal = +00000)  
R2 xx.xxx deg TA (X-axis nominal = +57470)

4. Load equivalent shaft angle (SA) and equivalent trunnion angle (TA) for the alternate LOS in NAVBASE coordinates.

NOTE.—In-flight calibration of COAS should be performed (as described in paragraphs 7.2.2 and 7.2.3) before use with rendezvous. If the primary optics (SXT or SCT) are optically functional but unusable in their shaft-and-trunnion drive function, they can be used as the backup optical device by loading NOUN 94 with the frozen shaft and trunnion angles (from the telescope precision angle counter—TPAC—or NOUN 91) and by loading the equivalent LOS values into NOUN 78.

5. When satisfied with NOUN 94 values, key PRO and observe request to perform alternate LOS mark:

FL VERB 53 NOUN 45

R1 +xxBxx VHF-Optics marks  
R2 ±xxBxx min-sec TFI  
R3 -00001 or xxx.xx deg MGA

NOTE.—Registers R2 and R3 are only valid when calculated by a targeting program. Register R1 contains number of marks processed by R22. Left two digits display VHF marks; right two digits display optics marks.

6. When called for by tracking schedule, take COAS marks as follows:
- Use RHC to center OWS in COAS.
  - To mark, key ENTR.
  - To reject mark (within approximately 7 seconds), key VERB 86 ENTR and repeat a and b.
  - To accept mark, wait the prescribed time (based on geometry, time line, etc.), recenter OWS in COAS, and repeat the mark (if more marks are desired).
  - To exit R23 and return to targeting display, key PRO.

NOTE.—Marks are processed by the Rendezvous Tracking Data Processing Routine (R22). If any mark results in an excessive update (discussed in paragraph 4.2.1.2.5.1), a priority display (flashing VERB 06 NOUN 49) will automatically interrupt any program-initiated display and present the magnitude of the excessive update:

FL VERB 06 NOUN 49

R1 +xxx.xx n. mi.  $\Delta R$   
R2 +xxxx.x ft/sec  $\Delta v$   
R3 oooxx Source Code  
(1 = optics, 2 = VHF ranging)

After 2 seconds (Priority display), key PRO to incorporate the data; key VERB 32 ENTR to reject the data.

(See paragraph 4.2.1.3.4 for delays in R27 resulting from the NOUN 49 display.)

#### D. CHANGE W-MATRIX (V67F)

1. To change the preset RMS error values, key VERB 67 ENTR and load the desired values in registers R1 and R2 of NOUN 99:

##### FL VERB 06 NOUN 99

R1 +xxxxxx. ft (position error)  
R2 +xxxxx.x ft/sec (velocity error)  
R3 +00001 Option Code (Rendezvous)

2. When desired values have been loaded (R3 must contain 00001 to change values, if 0 new values will not be loaded), key PRO to exit Extended VERB 67.

NOTE.—VERB 93 ENTR is required for initializing to the new NOUN 99 values.

#### E. W-MATRIX REINITIALIZATION (V93E)

To reinitialize W-matrix to preset RMS position and velocity errors, key VERB 93 ENTR. (W-matrix-reinitialization schedules and strategies are discussed in paragraph 4.2.1.2.5.)

### III. PLANE-CHANGE IMU ALIGNMENT

When a plane-change maneuver is to be performed that requires rotating the CSM's X-axis normal to the orbital plane, the maneuver must be preceded by an IMU realignment. The MINKEY procedure for plane-change IMU realignment is described in paragraph 4.2.1.2.6.

### IV. RENDEZVOUS THRUSTING

During each rendezvous targeting program, navigation ends when the crew requests a final targeting solution (PRO on the flashing VERB 16 NOUN 45). Typically, depending upon mission procedures and the maneuver to be performed, this request is made 10 to 12 minutes before ignition. After the final targeting solution has been displayed and recorded, the crew calls the appropriate powered-flight program (P40/P41) and performs the thrusting maneuver. (Powered-flight programs are described in Section 6.0.)



NOTE.—If the thrusting maneuver involves rotating the spacecraft X-axis normal to the orbital plane, an IMU realignment must be performed before the powered-flight program is called. See Sequence III, above.

After the thrusting maneuver has been completed, the crew calls the next rendezvous-targeting program in the sequence and is again presented with a request to perform MINKEY Rendezvous (flashing VERB 50 NOUN 25, R1 = 00017). If the crew wishes to continue rendezvous with manual sequencing, he keys ENTR and proceeds as in Sequence I,E above. If he wishes to change to MINKEY sequencing, he keys PRO and proceeds as described in paragraph 4.2.1.2.6.

#### V. FINAL PHASE

When the final rendezvous thrusting maneuver has been performed, the crew has the option either of calling the Rendezvous Final Program (P37) or of manually loading +000.00 deg into Register R2 of NOUN 78 and then reselecting P20. If he elects to call P37, the program will display request to perform MINKEY as in the targeting programs. To continue with manual sequencing, the crew keys ENTR. To enable MINKEY, he keys PRO; the program will set TRACKFLG and UPDATFLG and will automatically load R1 and R2 of NOUN 78 with the +X-axis value and then flash a request to perform a maneuver to the X-axis tracking attitude (flashing VERB 50 NOUN 18).

When the attitude maneuver has been completed, P37 proceeds automatically to the Rendezvous Parameter Display Routine (R31). (See MINKEY Rendezvous, paragraph 4.2.1.2.6.)

Should the crew elect to reselect P20 to perform the maneuver to point the CSM +X-axis at the OWS, he would first load Register R2 of NOUN 78 with +000.00 deg (for +X-axis tracking) and then key VERB 37 ENTR 20 ENTR to restart P20.

NOTE.—When P20 has been temporarily terminated (by request for final targeting solution) or is operating in the background (not in PROG lights), a VERB 37 ENTR 20 ENTR causes P20 to restart after the initialization displays, viz., NOUNS 06, 78, and 79. (See Figure 4.2.1-1, Initial-condition B.)

The first display in the restarted P20 program ( $\Delta\theta > 10$  deg) will be a flashing VERB 50 NOUN 18, "Please perform automatic maneuver to tracking attitude." When the maneuver has been completed (as in Sequence I,E, step 3), the crew keys VERB 83 ENTR to start the Rendezvous Parameter Display Routine (R31):

FL VERB 16 NOUN 54

R1	+xxx.xx	n. mi.	Range
R2	±xxxx.x	ft/sec	Range rate
R3	+xxx.xx	deg	theta

The NOUN 54 display is updated every 2 seconds. When the crew is ready to terminate R31, he keys PRO. Typically, he would then key VERB 37 ENTR 48 ENTR to call the Rendezvous Thrust Monitor Program (P48) for monitoring the manually controlled final docking maneuver.

4.2.1.2.3 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 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.
- b. 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.
- c. 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.
- d. Alarm 00210 indicates IMU not operating. It should be turned on and the stable-member orientation determined before entering P20.
- e. Alarm 00220 indicates IMU not aligned. No REFSMMAT is stored. Key RSET and execute P51 (or equivalent; e.g., checklist rapid IMU realign).
- f. Alarm 00401 indicates desired angles yield gimbal lock. Key RSET and either select new gimbal angles or maneuver spacecraft to avoid gimbal lock.
- g. Alarm 00406 indicates that R23 has been called with P20 Rendezvous Mode not operating. Select P20 before calling the mark routine.

TABLE 4.2.1-II  
MANUAL RENDEZVOUS PROCEDURE SUMMARY (SHEET 1 OF 4)

Step	Entry	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
I. INITIALIZATION								
A, B, C, D	---	---	---	---	---	---	Perform preliminary procedures as described in paragraph 4.2.1.2.2.2.	---
E-1	VERB 37 ENTR xx ENTR, where the rendezvous mode of P20 is inactive and xx is 31-38. (Initial-condition C)	---	P20	Initiate Rendezvous Navigation.	---	<ul style="list-style-type: none"> <li>• Check REFSMMAT</li> <li>• Turn on P20</li> <li>• Select CM state vector for update.</li> <li>• Set V50N18FL</li> <li>• Set TRACKFLG</li> <li>• Set UPDATFLG</li> <li>• Set RNDVZFLG</li> <li>• Extrapolate CSM and WS state vectors to present time</li> <li>• Load Option 0 into R2 of Noun 06.</li> <li>• Load Noun 78 with <math>\gamma = 000.00</math> deg (R1); <math>\rho = -035.00</math> deg (R2); and OMICRON = <math>000.00</math> deg (R3).</li> <li>• Load Noun 79 with the last R03 designated deadband.</li> </ul>	---	If no REFSMMAT, the program proceeds to first display in Pxx without turning on P20.
E-2	---	FL V50 N25	P3x	Request permission to perform MINKEY Rendezvous.	R1 00017 Checklist Code R2 Blank R3 Blank	<ul style="list-style-type: none"> <li>• Upon crew's ENTR, proceed with manual (conventional) sequencing.</li> <li>• Upon crew's PRO, proceed with MINKEY sequencing.*</li> </ul>	ENTR	* MINKEY sequencing described in paragraph 4.2.1.2.6.
E-3	---	FL V50 N18**	P3x	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	• Upon crew's PRO, perform maneuver to tracking attitude.	PRO	** Occurs only if $\Delta\theta > 10$ deg. Nonflashing V06 N18 occurs only if crew keys PRO on FL V50 N18.
E-4		V06 N18**	P3x	Display final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually. Key VERB 58E to reset STIKFLAG.	A middle-gimbal angle of $\pm 75$ deg causes the RCS DAP to terminate the automatic maneuver and to maintain attitude hold. Complete maneuver with the RHC, referencing the FDAI Ball to avoid gimbal lock. Key VERB 58 ENTR.
E-5		FL V50 N18**	P3x	Same as E-3	Same as E-3	<ul style="list-style-type: none"> <li>• Upon crew's PRO, recycle maneuver.</li> <li>• Upon crew's ENTR, start R52 and proceed to first ordinary targeting display in P3x.</li> </ul>	• ENTR For automatic optics positioning set OPTICS ZERO switch to OFF, the OPTICS MODE switch to CMC.	Program proceeds automatically to first regular targeting display in P3x.

TABLE 4.2.1-II

## MANUAL RENDEZVOUS PROCEDURE SUMMARY (SHEET 2 OF 4)

Step	Entry	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
II. RENDEZVOUS TRACKING, NAVIGATION, AND TARGETING								
		The initialization phase of the Rendezvous Navigation Mode ends when the crew is satisfied with the tracking-attitude parameters contained in Nouns 78 and 79, has the tracking attitude established, and is ready to proceed with navigation and targeting. From this point until the crew requests a final targeting solution, he must coordinate his navigation activities with the targeting program in progress. Tracking and W-matrix-re-initialization schedules are discussed in paragraph 4.2.1.2.5. Targeting programs are described in Section 5.0.						
A-1	VERB 87 ENTR		P3x	Initiate VHF tracking.		<ul style="list-style-type: none"> <li>Upon crew's VERB 87 ENTR begin accumulating VHF range data at 1-minute intervals.</li> <li>Terminate VHF tracking upon crew's VERB 88 ENTR, VERB 37 ENTR xx ENTR, or upon crew's request for a final targeting solution (PRO on flashing VERB 16 NOUN 45).</li> </ul>	<ul style="list-style-type: none"> <li>To initiate VHF tracking, key VERB 87 ENTR.</li> <li>To terminate VHF tracking, key VERB 88 ENTR.</li> </ul>	
A-2		FL V06 N49 <sup>25</sup>	P3x	Display excessive update.	R1 xxx.xx n.mi. ΔR R2 xxxx.x ft/sec Δv R3 oooxx Source code (1 = optics, 2 = VHF)	<ul style="list-style-type: none"> <li>Process marks (R22).</li> <li>Display magnitude of any excessive update.</li> <li>After two seconds (priority display), accept crew's PRO to incorporate data; accept VERB 32 ENTR to reject data.</li> </ul>	<ul style="list-style-type: none"> <li>PRO to accept update.</li> <li>VERB 32 ENTR to reject update.</li> </ul>	<sup>25</sup> Occurs only if there is an excessive update (discussed in paragraph 4.2.1.2.5.1).
B-1			P3x	Update state vector by incorporating optics LOS measurements on the <b>WS</b> .		<ul style="list-style-type: none"> <li>Accept and process optics LOS measurements.</li> <li>Display magnitude of any excessive update.</li> </ul>	<ul style="list-style-type: none"> <li>Set OPTICS MODE switch to MAN.</li> <li>Use OHC to center <b>WS</b> in SXT.</li> <li>Depress MARK button.</li> <li>Depress MARK REJ to reject mark.</li> </ul>	Tracking and W-matrix-re-initialization schedules are discussed in paragraph 4.2.1.2.5.  Mark must be rejected within ~15 sec.
B-2		FL V06 N49 <sup>27</sup>	P3x	Display excessive update.	Same as A-2	Same as A-2	Same as A-2	<sup>27</sup> Occurs only if there is an excessive update (discussed in paragraph 4.2.1.2.5.1).

TABLE 4.2.1-II

## MANUAL RENDEZVOUS PROCEDURE SUMMARY (SHEET 3 OF 4)

Step	Entry	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
C-1	---	---	P3x	Update state vector by incorporating COAS LOS measurements on the $W\hat{S}$ .	---	<ul style="list-style-type: none"> <li>Accept crew inputs for X-axis tracking.</li> <li>Compute required gimbal angles.</li> <li>Turn on UPLINK ACTY if maneuver <math>&gt; 10</math> deg necessary and it is not the first pass through R61.</li> </ul>	<ul style="list-style-type: none"> <li>Load R1 and R2 of Noun 78 with +000.00 deg (X-axis tracking).</li> <li>If UPLINK ACTY illuminates, key VERB 58 ENTR to set V50N18FL and re-set STIKFLAG.</li> </ul>	---
C-2	---	FL V50 N18***	P3x	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to tracking attitude.	PRO	*** Occurs only if $\Delta \theta > 10$ deg. Nonflashing V06 N18 occurs only if crew keys PRO on FL V50 N18.
C-3	---	V06 N18***	P3x	Display final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually. Then key VERB 58 ENTR to reset STIKFLAG.	A middle-gimbal angle of $\pm 75$ deg causes the RCSDAP to terminate the automatic maneuver and to maintain attitude hold. Complete maneuver with RHC, referencing the FDAI Ball to avoid gimbal lock. Key VERB 58 ENTR.
C-4	---	FL V50 N18***	P3x	Same as C-2	Same as C-2	<ul style="list-style-type: none"> <li>Upon crew's PRO, recycle maneuver.</li> <li>Upon crew's ENTR, exit R60, continue X-axis tracking.</li> </ul>	<ul style="list-style-type: none"> <li>ENTR</li> <li>Key VERB 54 ENTR to call R23.</li> </ul>	---
C-5	VERB 54 ENTR (R23)	FL V06 N94	P3x	Display equivalent shaft and trunnion angles for the alternate LOS.	R1 xxx.xx deg SA (Nominal = 00000) R2 xx.xxx deg TA (Nominal = 57470)	---	<ul style="list-style-type: none"> <li>Verify equivalent shaft and trunnion angles; load new values as determined by in-flight calibration.</li> <li>PRO</li> </ul>	---
C-6	---	FL V53 N45	P3x	Display number of marks accumulated. Display TFI computed by targeting program operating. Display code indicating final target solution has not been requested.	R1 xxBxx VHF-Optics Marks R2 $\pm$ xxBxx min-sec TFI R3 -00001 preliminary cycle (R2 and R3 valid only if at NOUN 45 display in P3x.)	<ul style="list-style-type: none"> <li>Process marks (R22).</li> <li>Display magnitude of any excessive update.</li> </ul>	<ul style="list-style-type: none"> <li>Use RHC to center <math>W\hat{S}</math> in COAS.</li> <li>To mark, key ENTR.</li> <li>To reject mark, key VERB 86 ENTR.</li> <li>When finished marking, wait 15 sec after last mark and then key PRO.</li> </ul>	Maximum in R2 is 59 min 59 sec. "-" denotes before t <sub>IG</sub> ; "+" denotes after t <sub>IG</sub> .  Mark must be rejected within about 15 sec.

TABLE 4.2.1-II

## MANUAL RENDEZVOUS PROCEDURE SUMMARY (SHEET 4 OF 4)

Step	Entry	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
C-7	---	FL V06 N49	P3x	Display excessive update.	R1 xxx.xx n.mi. $\Delta R$ R2 xxxx.x ft/sec $\Delta v$ R3 oooxx Source Code (1 = optics, 2 = VHF).	• After two seconds (priority display), accept crew's PRO to incorporate data; accept VERB 32 ENTR to reject data.	• PRO to accept update. • VERB 32 ENTR to reject update.	*Occurs only if there is an excessive update (discussed in paragraph 4.2.1.2.5.1).
D-1	VERB 67 ENTR	Other than a marking or priority display.	P3x	Change W-matrix preset RMS values.	---	• Upon crew's VERB 67 ENTR, calculate and display RSS position and velocity errors.	• VERB 67 ENTR	W-matrix-reinitialization schedules and preset values are discussed in paragraph 4.2.1.2.5.
D-2	---	FL V06 N99	P3x	Display RSS position and velocity errors.	R1 xxxxx. ft(pos err) R2 xxxx.x ft/sec (vel err) R3 00001 Option Code	• Accept crew-loaded values. • Upon crew's PRO, exit V67E.	Load new values if desired (R3 must contain 00001). • PRO	---
E	VERB 93 ENTR	---	P3x	Reinitialize W-matrix to preset RMS values.	---	---	To reinitialize W-matrix to preset values, key VERB 93 ENTR.	W-matrix-reinitialization schedules and preset values are discussed in paragraph 4.2.1.2.5.
IV. RENDEZVOUS THRUSTING								
A	VERB 37 ENTR 40/41 ENTR (P40/P41)	Ten to twelve minutes before ignition, the crew requests a final targeting solution (PRO on the flashing VERB 16 NOUN 45). When the final solution has been displayed and recorded, the crew calls the appropriate powered-flight program, to perform the thrusting maneuver (Refer to Section 6.0 for a description of powered-flight programs.)						

TABLE 4.2.1-III

## REGULAR AND EXTENDED VERBS USED WITH RENDEZVOUS: SUMMARY

(SHEET 1 OF 6)

Astronaut	Purpose	DSKY	CMC Operation	Remarks
V16 N20E	Display present gimbal angles.	R1 + xxx.xx deg Roll R2 + xxx.xx deg Pitch R3 + xxx.xx deg Yaw	---	Noun 20 displays the existing ICDU angles.
V16 N22E	Display CMC-desired gimbal angles.	R1 + xxx.xx deg OGA R2 + xxx.xx deg IGA R3 + xxx.xx deg MGA	---	Noun 22 displays the R61-computed desired ICDU angles—not necessarily the center of the DAP deadband.
V16 N92E	Display desired optics angles.	R1 + xxx.xx deg (SA) R2 + xx.xxx deg (TA) R3 Blank	---	---
V54E Load equivalent SA and TA for backup tracking PRO	Call Backup Rendezvous Tracking Sighting Mark Routine (R23)	<u>FL V06 N94</u> R1 + xxx.xx deg (SA) R2 + xx.xxx deg (TA) R3 Blank	Request crew to load the equivalent shaft and trunnion angles for the backup pointing axis. (Nominal for COAS is SA = 000.00 deg, and TA = 57.470 deg.)	R23 can be used for backup tracking with a frozen SXT/SCT (optically operational) by loading the existing shaft and trunnion angles in NOUN 94, and manually tracking the OWS with the RHC. The COAS must be in-flight calibrated before used for rendezvous navigation.

TABLE 4.2.1-III

## REGULAR AND EXTENDED VERBS USED WITH RENDEZVOUS: SUMMARY

(SHEET 2 OF 6)

Astronaut	Purpose	DSKY	CMC Operation	Remarks
V54E (cont.) ENTR to mark V86E to reject mark PRO (15 sec after last mark) to exit R23	---	<u>FL V53 N45</u> R1 +xxBxx VHF, op- tics R2 ±xxBxx min, sec TFI R3 xxx.xx deg MGA	Request crew to perform alternate LOS sighting mark; display mark counters, time from ig- nition (TFI), and middle- gimbal angle at $t_{IG}$ .	R1 contains the number of marks processed by the Rendezvous Data Processing Routine (R22) R2 contains time from $t_{IG}$ — maximum reading, 59B59 ("-" before $t_{IG}$ , "+" after $t_{IG}$ ; R3 is always "+" for the last pass thro- ugh P31-P36,38 with the IMU aligned. (For preliminary pas- ses through P31-P36,38, R3 con- tains -00001; during P30 or dur- ing final passes through P31— P36,38 with the IMU not aligned, R3 contains -00002.)
V56E	Terminate ren- dezvous naviga- tion without ter- minating other major programs.	---	Reset RNDVZFLG,* TRACKFLG, UPDATFLG, UTFLAG.	*Resetting this flag terminates the entire rendezvous-navi- gation process. Also reset by V37E 00E. Set by selection of P20 Options 0 or 4.
V57E	Call display of flag bit governing post-TPI pro- cessing of sensor data (single sen- sor or dual sen- sor).	<u>FL V04 N12</u> R1 = 00004 R2 = 0000x R3 = Blank	When R2 = 0, FULTKFLG indicates that post-TPI navigation will be per- formed using data from both sensors (VHF and optics). When R2 ≠ 0, FULTKFLG indicates that post-TPI navigation will be performed using data from only one sensor (VHF or optics).	V57E is only used with auto- matic W-matrix reinitializa- tion during MINKEY rendezvous. Its function is entirely descrip- tional, i. e., to inform the Data-processing Routine (R22) whether it is receiving post- TPI data from one or both sensors (should be performed before the first mark post-TPI).



TABLE 4.2.1-III

REGULAR AND EXTENDED VERBS USED WITH RENDEZVOUS: SUMMARY  
(SHEET 3 OF 6)

Astronaut	Purpose	DSKY	CMC Operation	Remarks
V58E	Allow RCS DAP to resume automatic attitude control and allow R61 to call R60.	---	Reset STIKFLAG and set V50N18FL flag.	STIKFLAG is set whenever the RHC is removed from detent, with the CMC CONT switch in the CMC position. Once set, the flag can only be reset by the selection of a new program or by V58E. The V50 N18FL flag is initially set by any V37E xxE (xx $\neq$ 00) and then reset during each pass through R61. Consequently, after the initial pass, V58E is required if the crew wishes R61 to call R60 to perform an automatic attitude maneuver.
V60E	Load present gimbal angles (Noun 20) into astronaut-specified-gimbal angle registers (Noun 17).	---	---	Noun 17 provides reference for Mode 3 FDAI Needles (V63E).
V61E	Display discrepancy between existing CDU angles and current DAP command.	---	Start Mode-1 error display. Reset NEEDLFLG. Display in-progress attitude error (difference between Noun 20 and current DAP command) on the FDAI error needles.	Proper operation is when error is within DAP deadband limits.

TABLE 4.2.1-III

REGULAR AND EXTENDED VERBS USED WITH RENDEZVOUS: SUMMARY  
(SHEET 4 OF 6)

Astronaut	Purpose	DSKY	CMC Operation	Remarks
V62E	Provide FDAI reference for manual attitude maneuver.	---	Start Mode-2 error display. Set NEEDLFLG and N22ORN17 flag. Display total attitude error (difference of contents N22 and contents N20) on the FDAI error needles.	---
V63E	Provide FDAI reference for manual attitude maneuver to astronaut-specified attitude (Noun 17).	---	Start Mode-3 error display. Set NEEDLFLG and reset N22ORN17 flag. Display total attitude error (difference of contents N17 and contents N20) on the FDAI error needles.	---
V67E	Display, and permit crew to change, W-matrix.	<u>FL V06 N99</u> R1 xxxxx. ft (pos err) R2 xxxx. x ft/ (vel err) R3 00001 option code (rendezvous)	Accept crew-loaded values.	To reinitialize W-matrix to preset values, the crew must key V93E. (See Below.) W-matrix is maintained automatically during MINKEY.
V80E	Select the CMC-resident OWS state vector for rendezvous-navigation update.	---	Clear VEHUPFLG to designate the OWS state vector for update.	Once set, VEHUPFLG is cleared by V80E only.

TABLE 4. 2. 1-III

REGULAR AND EXTENDED VERBS USED WITH RENDEZVOUS: SUMMARY  
(SHEET 5 OF 6)

Astronaut	Purpose	DSKY	CMC Operation	Remarks
V81E	Select the CMC-resident CSM state vector for rendezvous-navigation update.	---	Set VEHUPFLG to designate the CSM state vector for update.	Automatically set by initial entry to P20. If the crew wishes to designate OWS state vector for update he should key V80E.
V82E	Call Orbit Parameter Display Routine (R30).	See paragraph 9. 2. 3.		Display apogee, perigee and time of free fall to 300, 000 ft.
V83E	Call Rendezvous Parameter Display Routine No. 1 (R31).	<u>FL V16 N54</u> R1 xxx.xx n.mi. range R2 xxxx.x ft/sec range rate R3 xxx.xx deg theta	Calculate and display (two-second updates) range and range rate between CSM and OWS. Calculate and display angle (theta) between CSM +X-axis and the local-horizontal plane.	Negative sign in R2 denotes closing. When finished with display, key PRO. Called automatically by P37.
V85E	Call Rendezvous Parameter Display Routine No. 2 (R34).	<u>FL V16 N53</u> R1 xxx.xx n.mi. range R2 xxxx.x ft/sec range rate R3 xxx.xx deg phi	Calculate and display (two-second update) range and range rate between CSM and OWS. Calculate and display angle (phi) between optics SLOS and the local-horizontal plane.	Negative sign in R2 denotes closing. When finished with display, key PRO.
V86E	Reject last R23 mark taken.	---	Erase last sighting mark taken during the Backup Rendezvous Tracking Sighting Mark Routine.	Must be performed within approximately 15 seconds of mark.

TABLE 4.2.1-III

REGULAR AND EXTENDED VERBS USED WITH RENDEZVOUS: SUMMARY  
(SHEET 6 OF 6)

Astronaut	Purpose	DSKY	CMC Operation	Remarks
V87E	Allow R22 to accept VHF range data.	---	Set VHFRFLAG.	VHFRFLAG is cleared whenever V37 is selected. It will remain in its current state during MINKEY major mode changes. VHF ranging will continue automatically until the crew keys V88E or V37E.
V88E	Stop R22 from accepting range data.	---	Reset VHFRFLAG.	See V87E.
V89E	Call Rendezvous Final Attitude Routine (R63).	See paragraph 2.2.1.		R63 can only be called from P00.
V90E	Call Rendezvous Out-of-Plane Display (R36).	See paragraph 9.2.4.		Displays CSM out-of-plane distance (Y) and rate (Y) and OWS out-of-plane rate (Y).
V93E	Reinitialize W-matrix.	---	Reset RENDWFLG.	V93E reinitializes W-matrix to preset values. (See V67E) W-matrix is automatically maintained during MINKEY.

4.2.1.2.4 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, where the data are automatically incorporated into the state vector. Should marks be taken faster than about one every 20 seconds, however, there is a chance that the data will be lost. Also, after the last mark, about 15 sec should be allowed for processing the 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 4.2.1.2.5 and in the "Introduction to Coasting Flight Navigation," subsection 4.1.)

A limiting factor regarding VHF range data is that the input counter to the CMC is modulo 327,68. At 327.67 n.mi., the counter begins again at zero, such that at a range of 350 n.mi., for example, the counter will contain the value, 22.32. Consequently, the CMC will modulo the VHF range data when the onboard range estimate and the VHF data differ by 300 n.mi.

Also, depending upon scaling, there is a minimum range at which P20 is effective. Although it is difficult to establish definite limits, operation with current scaling is not recommended for ranges less than about 3 nmi.

4.2.1.2.5 Tracking and W-Matrix-reinitialization Schedules.—The Rendezvous Mode of P20 uses measurements of the relative state of the two vehicles to update the inertial state of one vehicle. 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. 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. The initial W-matrix values are 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 reinitialized (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 4.2.1-4 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 40 minutes, but allowing 10–15 minutes of tracking before a final targeting solution, (b) take several marks immediately before, immediately after, and halfway between each reinitialization, and (c) reinitialize before taking marks after a maneuver if more than 60 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, corresponding to the RMS values of probable position and velocity errors respectively. An initiation of rendezvous navigation, however, when relative state-vector uncertainties are largest, typical WRI values are 10,000 ft, and 10 ft/sec.
2. The larger the WRI values, for a given a priori sensor variance, the more sensor data required to smooth the WRI transient. Even for the larger initial values of WRI at the start of rendezvous navigation, 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 nominal sensor operation is to incorporate SXT marks prior to TPI and SXT plus VHF marks post TPI. This procedure for W matrix operation following transfer-phase initiation (TPI) in this case is to reinitialize before taking any marks following a maneuver. The single sensor post-TPI procedure is to take marks with no WRI between TPI

and the first midcourse correction (MCC1) and after MCC1, reinitialize before the first mark. Tracking then continues in the normal pattern.

Paragraphs 4.2.1.2.5.1-4.2.1.2.5.4 present some general recommendations for mark-reject and accept procedures.

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., 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.

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

- a. Initial period of tracking
- b. After maneuvers
- c. Beginning of tracking after long period with no tracking
- d. Bringing a new sensor on line.

Typically reasonable values for updates in phases a through d above are a  $\delta R$  of 6000 ft and a  $\delta v$  of 6 ft/sec or less. Should the update value exceed reasonableness values, the crew should reject the first mark, ensure that the sextant is actually tracking the OWS, 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, either sensor is not tracking target or has failed. Then follow "Bad Mark" procedure (paragraph 4.2.1.2.5.2 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 crew 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 "Bad Mark" procedure (paragraph 4.2.1.2.5.2).

4.2.1.2.5.2 Accepting A Known "Bad Mark". Unreasonably large update is accepted; and is known to have been incorrect (system malfunction discovered; bad ground uplink, etc.) Procedure. (a) Fix malfunction;

(b) get new ground uplink, if possible, and start again; (c) if uplink not possible, reinitialize W-matrix.

4.2.1.2.6 MINKEY Rendezvous (See also paragraph 5.2.5). —Minimum-key-stroke (MINKEY) rendezvous differs from conventionally sequenced rendezvous as follows:

- a. Instead of selecting each program as it is required in the rendezvous sequence, the crew simply keys in the appropriate targeting program for a given point in the sequence; this causes an immediate display of FL VERB 50 NOUN 25 (R1 = 00017), "Please perform MINKEY Rendezvous." A PRO response initiates automatic sequencing of the rendezvous programs. (An ENTR response inhibits MINKEY and allows manual sequencing. See paragraph 4.2.1.2.2.)
- b. Instead of the crew's manually establishing a wings-level attitude, an erasable quantity will be preloaded, designating the desired attitude for performing the rendezvous. The CMC will then compute and execute the appropriate attitude maneuvers.
- c. In the MINKEY sequence, the CMC reinitializes the W-matrix according to predetermined criteria requiring no consideration by the crew.
- d. Alignment procedures for plane-change maneuvers simplified.

4.2.1.2.6.1 MINKEY Sequence Initiation.—The crew can begin the MINKEY sequence at any one of the seven points: (1) Pre-NC1 Maneuver, (2) Pre-NC2 Maneuver, (3) Pre-NCC Maneuver, (4) Pre-NSR Maneuver, (5) Pre-Transfer-phase Initiation (TPI), (6) Pre-Transfer-phase Midcourse Correction 1 (MCC1), (7) Final phase, (8) Pre-Plane Change Maneuver. At which reset point the sequence begins is determined by the program selected. If the crew wishes to enter the sequence before the NC1 maneuver, he selects major mode P31; if he wishes to enter the sequence before NC2, he selects major mode P32; etc. The MINKEY sequence, including reset points, is as follows:

P31 (VERB 37 ENTR 31 ENTR)

1. Start Rendezvous Navigation Program (P20)
2. Display request to perform MINKEY.



3. Execute maneuver to track attitude and perform NC1 targeting program (P31).
4. Perform Powered-flight Program (P40/P41).<sup>\*</sup> Continue to step 7.

P32 (VERB 37 ENTR 32 ENTR)

5. Start Rendezvous Navigation Program (P20).
6. Display request to perform MINKEY.
7. Execute maneuver to track attitude and perform NC2 targeting program (P32).
8. Perform Powered-flight Program (P40/41). Continue to step 11.

P33 (VERB 37 ENTR 33 ENTR)

9. Start Rendezvous Navigation Program (P20).
10. Display request to perform MINKEY.
11. Execute maneuver to track attitude and perform NCC targeting program (P33).
12. Perform Powered-flight Program (P40/41). Continue to step 15.

P34 (VERB 37 ENTR 34 ENTR)

13. Start Rendezvous Navigation Program (P20).
14. Display request to perform MINKEY.
15. Execute maneuver to track attitude and perform NSR targeting program (P34).
16. Perform Powered-flight Program (P40/41). Continue to step 19.

P35 (VERB 37 ENTR 35 ENTR)

17. Start Rendezvous Navigation Program (P20).
18. Display request to perform MINKEY.
19. Execute maneuver to track attitude and perform TPI targeting program (P35).
20. Perform Powered-flight Program (P40/41). Continue to step 23.

---

<sup>\*</sup> Whenever MINKEY calls a powered-flight program, the criterion for P40/P41 is whether the required  $v_G \geq 10$  ft/sec (call P40) or  $< 10$  ft/sec (call P41). The one exception is when PC pulse torquing is bypassed in P38. In that instance, the program calls P41 regardless of  $v_G$ .

TRACKING SCHEDULE FOR CSM-SWS  
M=5 RENDEZVOUS SEQUENCE

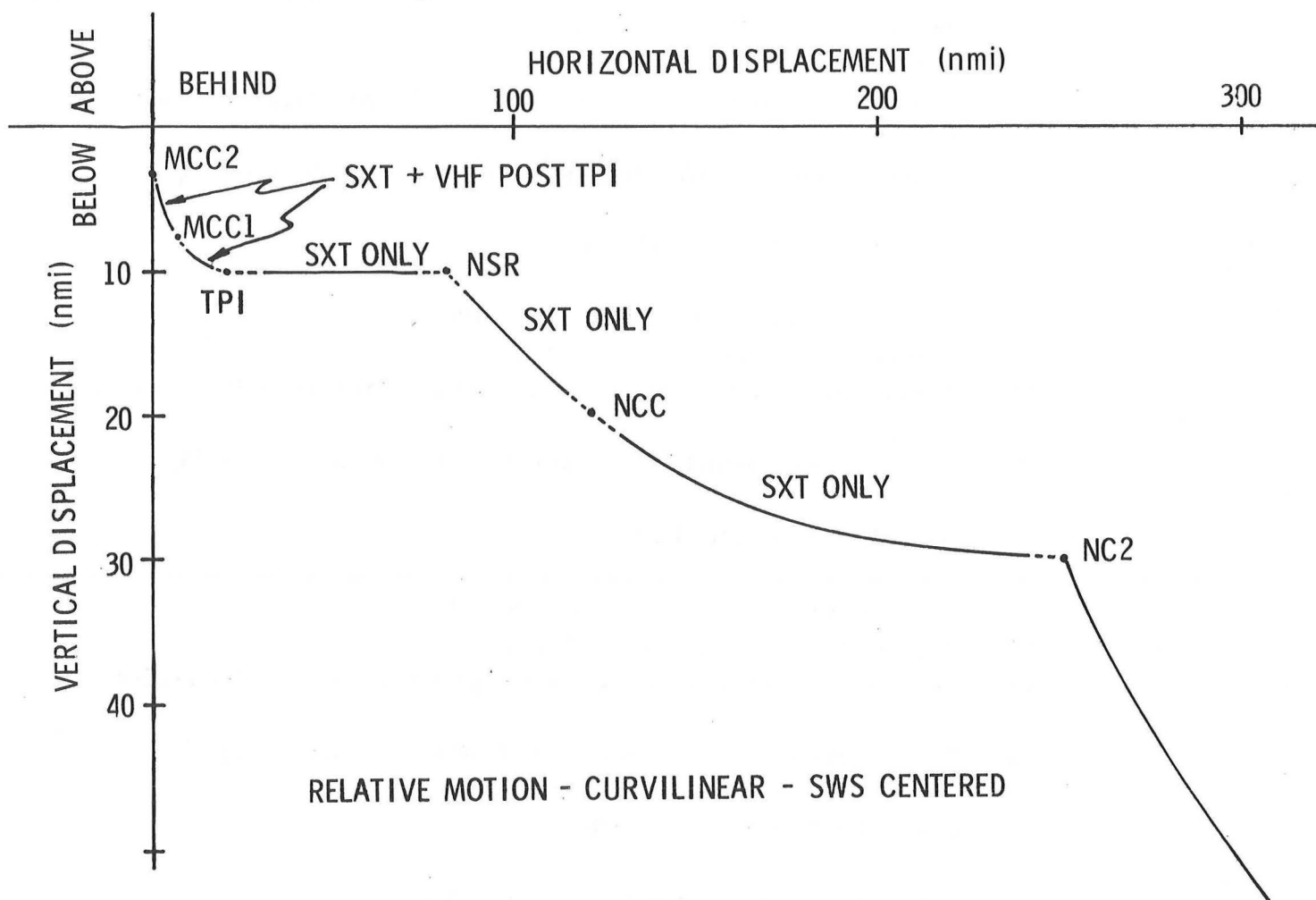


Figure 4.2.1-4. Typical Tracking Schedule for CSM-SWS Rendezvous

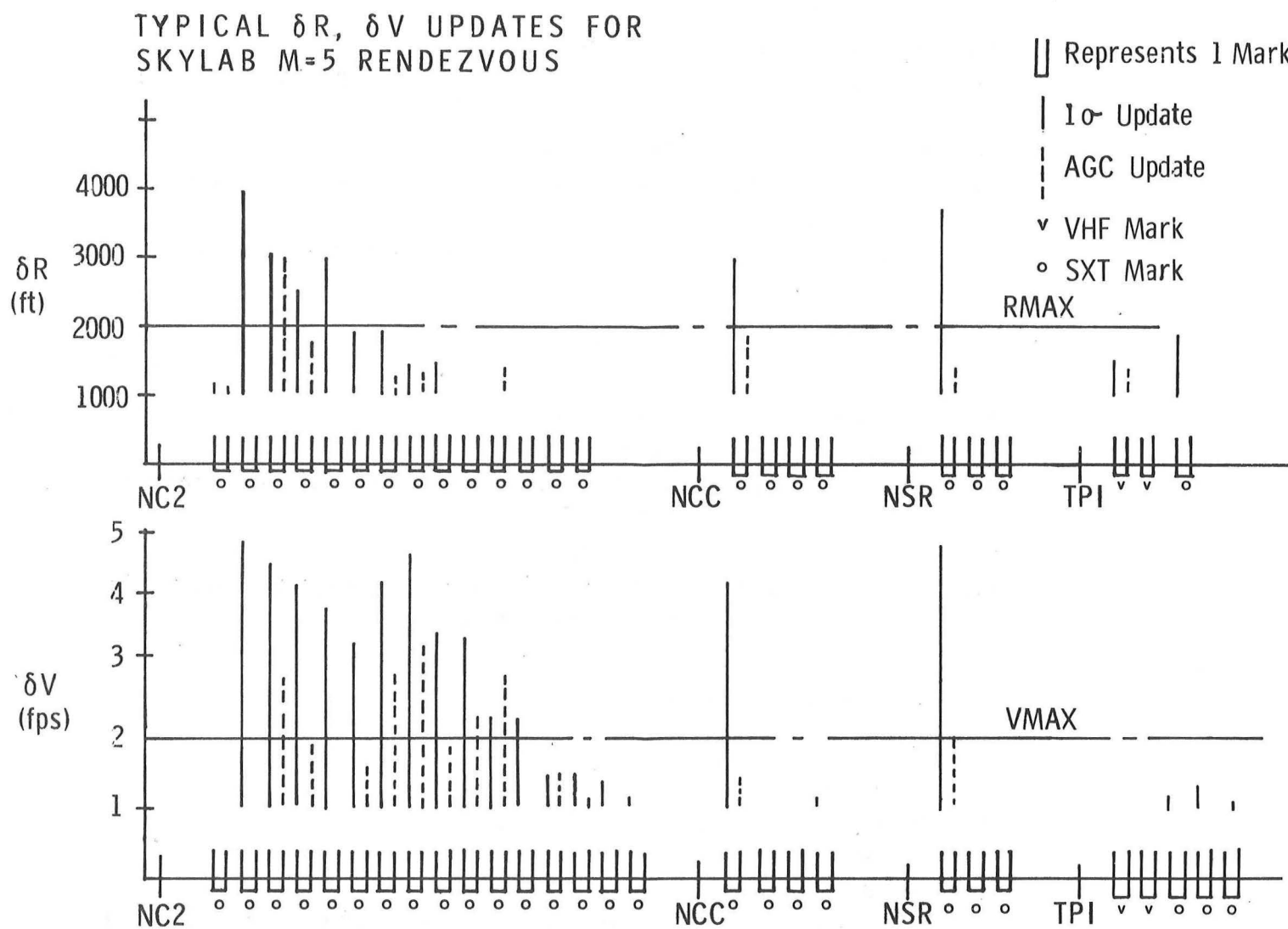


Figure 4.2.1-5. Typical VHF and SXT  $\delta R$ ,  $\delta v$  Updates

P36 (VERB 37 ENTR 36 ENTR)

21. Start Rendezvous Navigation Program (P20).
22. Display request to perform MINKEY.
23. Execute maneuver to track attitude and perform TPM (MCC1) targeting program (P36).
24. Perform Powered-flight Program (P40/41).
25. Execute maneuver to track altitude and perform TPM (MCC2) targeting program (P36).
26. Perform Powered-flight Program (P40/P41). Continue to step 29.

P37 (VERB 37 ENTR 37 ENTR)

27. Start Rendezvous Navigation Program (P20).
28. Display request to perform MINKEY.
29. Execute maneuver to x-axis tracking attitude and perform rendezvous final phase program (P37).
30. Perform Rendezvous Thrust Monitor Program (P48).
31. Upon crew's exit from P48, flash VERB 37 to request selection of new program. END OF MINKEY SEQUENCE.

P38 (VERB 37 ENTR 38 ENTR)

1. Start Rendezvous Navigation Program (P20).
2. Display request to perform MINKEY.
3. Execute maneuver to track attitude and perform PC program (P38).
- 4a. Sequence I-(NPC<sub>VG</sub>  $\neq$  0 ft/sec)
  - . Perform modified P52 IMU alignment-PRO on FL V50 N25 (R1=00020).
  - . Perform Powered-flight Program (P40/P41).
  - . Call P20 to return spacecraft to tracking attitude.
  - . Re-establish IMU alignment (Modified P52).Continue to step 5.
- 4b. Sequence II-(NPC<sub>VG</sub>  $\neq$  0 ft/sec)
  - . Omit IMU alignment - ENTR on FL VERB 50 NOUN 25 (R1=00020).
  - . Perform RCS Powered-flight Program (P41).Continue to step 5.

4c. Sequence III-(NPC<sub>VG</sub> = 0 ft/sec)

. . . Omit PC maneuver.

5. Terminate Plane Change Sequence flash VERB 37 to request selection of new program.

END OF MINKEY PLANE CHANGE SEQUENCE

4.2.1.2.6.2 Heads-up/Heads-down Option.—A heads-up rendezvous is defined as a rendezvous with the spacecraft oriented such that its Y-axis lies approximately along the negative of the angular momentum vector; a heads-down rendezvous is defined as a rendezvous with the spacecraft oriented such that its Y-axis lies approximately along the positive of the angular momentum vector. Whether the rendezvous orientation is heads-up or heads-down is determined by the value loaded in NOUN 78, Register R3. (+000.00 deg designates heads-up; +180.00 deg designates heads-down.) When the rendezvous sequence is first initiated, NOUN 78 (R3) is automatically loaded to +000.00 deg if HDSUPFLG is set; automatically loaded to +180.00 deg if HDSUPFLG is reset.

NOTE.—HDSUPFLG configuration can be changed by the Channel and Erasable Modification Routine (R01). The flag is only looked at, however, when MINKEY is first selected —by PRO to FL VERB 50 NOUN 25 (R1 = 00017) and Option 4 of P20 has not been previously selected (RNDVZFLG and AZIMFLAG set). Once the MINKEY sequence has begun, therefore, changing the configuration of HDSUPFLG will have no consequence (unless P20 is "permanently" terminated —see Figure 4.2.1-1—and MINKEY re-selected).

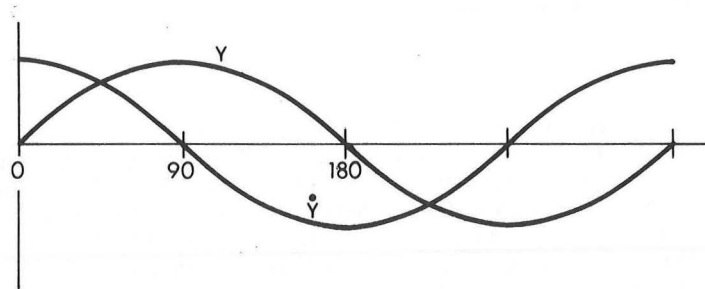
The contents of NOUN 78 (R3) can be manually changed, however, without interrupting the MINKEY sequence, by keying VERB 23 NOUN 78 ENTR and loading the desired OMICRON. The CMC will then compute and execute a maneuver to the newly designated orientation.—NOUN 78 is interrogated on every pass through the Tracking-attitude Routine (R61), or once about every 8 seconds—unless delayed by R22 mark processing.

Temporary interruption of the MINKEY sequence—by manual selection of P40 for example—can be effected without concern that the last-designated heads-up/heads-down option will be affected when the MINKEY sequence is reinitiated at one of the reset points, e.g., VERB 37 ENTR 35 ENTR.

When the rendezvous sequence is first initiated (at any reset point), NOUN 78 Registers R1 and R2 are automatically loaded with the preset values +000.00 and -035.00 deg respectively (preferred tracking attitude). If the crew wishes, he can subsequently change the preset values by keying VERB 2x NOUN 78 ENTR. As with R3, the last-loaded values will be unaffected by subsequent reset-point entries

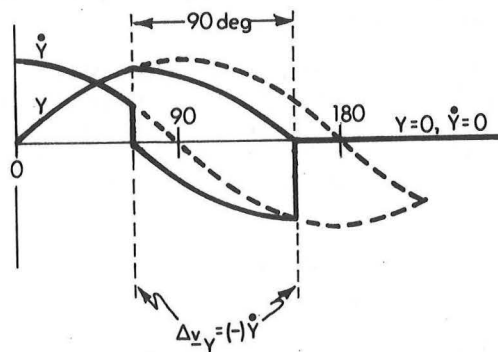
to the rendezvous sequence, so long as RNDVZFLG remains set. When the Rendezvous-final Program (P37) is initiated, however, whether manually or in the MINKEY sequence, Register R1 and R2 is changed automatically to +000.00 deg (X-axis tracking attitude). Subsequent entry at a MINKEY reset point would then result in X-axis tracking.

4.2.1.2.6.3 Plane Changes. —The essential points of plane-change targeting are that the paths of two bodies in noncoplanar orbits about the same center of mass will cross every 180 deg, that the maximum displacement between the orbits occurs 90 deg out of phase with the crossings, and that the rate of displacement change is greatest at the crossings and is zero at the points of maximum displacement. Thus, the rate ( $\dot{Y}$ ) that the lateral distance ( $Y$ ) between the two bodies changes is greatest at the crossings, or nodes ( $Y = 0$ ), and is least ( $\dot{Y} = 0$ ) at the points of maximum displacement (antinodes).



This allows the following scheme for establishing coplanar orbits during rendezvous:

1. At any given time, the active vehicle performs a thrusting maneuver resulting in  $\dot{Y} = 0$ , thus establishing an antinode and, 90-deg later, a node ( $Y = 0$ ,  $\dot{Y} = \text{maximum}$ ).



2. A second thrusting maneuver is performed at the node in order to null  $\dot{Y}$  and, thereby, establish the coplanar condition ( $Y = 0, \dot{Y} = 0$ ).

4.2.1.2.6.4 W-Matrix Reinitializing.—A salient feature of MINKEY rendezvous sequencing is the elimination of the crew's task of periodically reinitializing the error-transition (W-) matrix. Crew responsibilities regarding the W-matrix during manually sequenced rendezvous are discussed in Users' Guide subsection 4.1 and paragraph 4.2.1.2.5. As a result of mission experience, the behavior of the W-matrix during rendezvous can be predicted with sufficient confidence to incorporate a MINKEY reinitialization scheme that totally relieves the crew of W-matrix consideration.

The reinitialization (WRI) scheme shown in Figure 4.2.1-6 is essentially a mechanization of the ground rules provided to the crews for improvising a manually sequenced, contingency WRI schedule. The basic considerations are (1) to avoid premature reinitializations, which would degrade the W-matrix's error-correction and correlation performance; (2) to avoid late reinitializations, which would allow the W-matrix to become superannuated. Specifically, a superannuated W-matrix is one that has either (a) shrunk to the point that incoming measurements are downweighted excessively (loss of filter gain) or (b) disintegrated in accuracy to the point that it is no longer reliable. Loss of filter gain is a function of the measurement geometry and the number of marks taken since the last WRI and is the result of incomplete error modeling; loss of reliability is a function of time since the last WRI and is the result of incorrect error modeling due to computer storage limitations. Since geometry is a factor in the loss of gain, determining when the loss will occur requires a bit-by-bit analysis of simulated computer operations for a particular mission; determining how long the W-matrix can be extrapolated before it becomes unreliable is more difficult, since a major factor is the accuracy of the vehicle state vector not being updated. A generalized scheme that can be mechanized for all contingencies is possible, however, by following a minmax concept of reinitializing more often than may be necessary but less often than would significantly degrade performance.

Accordingly (Figure 4.2.1-6), the principal criterion for allowing a WRI after other than a first mark following a maneuver is whether a specified minimum time (WRDTIME) has elapsed since the last WRI. Typically, WRDTIME is about 40 minutes—long enough for effective correlation and smoothing, short enough to occur well before superannuation. The second criterion is whether no more than a specified maximum time (MINBLKTM, typically 5 minutes) has elapsed since the last mark.



- 
- The diagram illustrates three types of flow, each represented by a different arrow style:
- Nominal Flow**: Represented by a solid black arrow.
  - Single-sensor contingency, Post-TPI**: Represented by a hollow arrow with a black outline.
  - Nominal-flow criteria not satisfied**: Represented by a solid black arrow.

(This figure is intended to illustrate the general strategy for automatic W-matrix reinitialization. It is not intended to rigorously define program coding. For specific details of coding, therefore, refer to Figure 2.5.3 in GSOP Section 5.)



If more than MINBLKTM has elapsed since the last mark (VHF or SXT),\* WRI will be INHIBITED (A) for three marks in order to allow W-matrix correlation to reduce error buildup during the no-mark period. The third criterion for allowing WRI is whether more than a specified minimum time (TBEFCOMP) remains before the final targeting computation. For example, TBEFCOMP will have a preset value of about 10-15 minutes, allowing a sufficient period of post-WRI tracking to provide a correlated W-matrix and a best state-vector estimate for the targeting computation. If the other criteria have been satisfied and more than TBEFCOMP remains before final targeting, WRI is allowed and the mark is incorporated.

Before transfer-phase initiation (TPI), the nominal flow for a first mark following a maneuver is to INHIBIT (A) WRI until three marks have been accumulated. The exception to this is when, as a result of the TBEFCOMP restriction preceding a maneuver, the W-matrix age would exceed MAXWTIME (~1 hour) should WRI be INHIBITED. For this contingency, WRI is specified (D) to occur before (D') the first mark is incorporated.

The other condition when WRI occurs before the first mark is incorporated is in the nominal-flow situation following TPI. The post-TPI geometry is such that filter gain deteriorates more rapidly than in the pre-TPI phase. Consequently, with both VHF and SXT operating, the nominal post-TPI procedure gives higher priority to restoring filter gain than to correlation: WRI occurs on the first mark, and is prohibited (C) on subsequent marks.

Correlation in the unmeasured dimension becomes obligatory, however, when data are being incorporated from only one sensor (as signaled by the crew's VERB 57 ENTR, to load R2 of N12 with 00001—FUL TKFLG set). The post-TPI, single-sensor strategy, therefore, is to reinitialize the W-matrix only once between TPI and the second midcourse correction (MCC2). The strategy is mechanized as follows. The first mark following TPI is incorporated without WRI; since subsequent marks between TPI and the first midcourse correction (MCC1) will not pass the TBEFCOMP criterion, no WRI can occur during the TPI-MCC1 phase. Following MCC1 (or any midcourse correction), however, a WRI is specified (B) to occur after the first three marks have been incorporated (B')—regardless of the single WRI, occurring three marks after an MCC, ensures the best post-TPI trade-off between the requirements of one-sensor correlation and filter gain.

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\* Throughout the MINKEY section of the Users' Guide, reference to "SXT" reflects nominal conditions. Unless specified otherwise, however, the COAS optics can be used as back-up.

4.2.1.2.6.5 Plane-change IMU Alignment.—Unless the change-plane component was quite small, a plane-change maneuver would require rotating the X-axis normal to the orbital plane.

The MINKEY procedure for avoiding plane-change gimbal lock is to perform the following sequence, incorporating a modified P52:

1. A new REFSMMAT is computed for a Z-gyro torqued 45 deg.
2. Resulting gimbal angles are computed and displayed (VERB 06 NOUN 22) for a Z-gyro torqued 45 deg. Crew keys PRO.
3. VERB 50 NOUN 25 (R1 = 00020) request crew to, "Please perform MINKEY PC pulse torquing."
4. Crew keys PRO, and the Z-gyro is pulse-torqued 45 deg. (An ENTR response bypasses pulse torquing and calls P41, then proceeds to a Flashing V37).

NOTE.—Once PRO is keyed on the VERB 50 NOUN 25 display, the plane-change sequence must not be interrupted. Sequence must be allowed to complete in order to reestablish original IMU alignment.

5. During torquing, present gimbal angles are displayed by VERB 16 NOUN 20. At completion of torquing, the display blanks and P40/P41 is called.
6. After regular P40/P41, the CMC calls P20 to perform automatic maneuver to tracking attitude.

NOTE.—Should it become necessary to manually avoid gimbal lock during the maneuver back to the tracking attitude, the program will proceed to step 7, and the crew will have no display available (NOUN 18) for viewing the desired gimbal angles. Unless the original maneuver to burn attitude attempted to go through gimbal lock, however, the return maneuver to tracking attitude is not likely to require manual intervention. Should manual maneuvering be required, the crew can fly the spacecraft back into plane (referencing the FDAI Ball), then respond to the pulse-torquing request. When pulse torquing has completed, the program will proceed to the next reset point, and, if further maneuvering is necessary, the crew will be requested (FL VERB 50 NOUN 18) to perform a maneuver to tracking attitude.

7. When tracking attitude obtains, the program returns to the P52 subroutines and completes the first three of the above steps in order to reestablish the original alignment.
8. Crew keys PRO, and the Z-gyro is pulse torqued to original alignment.

NOTE.—An ENTR response here produces an Alarm 00402. Crew must perform pulse torquing.

9. During torquing, the present gimbal angles are displayed by VERB 16 NOUN 20. At completion of torquing, the display blanks, and program proceeds to a Flashing V37.

#### 4.2.1.3 R27, VHF Range Rate Mark Processing Routine

The VHF Range Rate Mark Processing Routine (R27) maintains, during rendezvous, an estimate of the relative position and velocity along the line of sight—the range and range rate—between the two spacecraft. This range state vector is independent of the inertial state vectors carried in the CMC. In R27, one-dimensional recursive navigation\* is used to provide a least-mean-squares fit of VHF-ranging data to a second-order polynomial in time. This polynomial is then expanded about either the current time or some mission time specified by the crew.

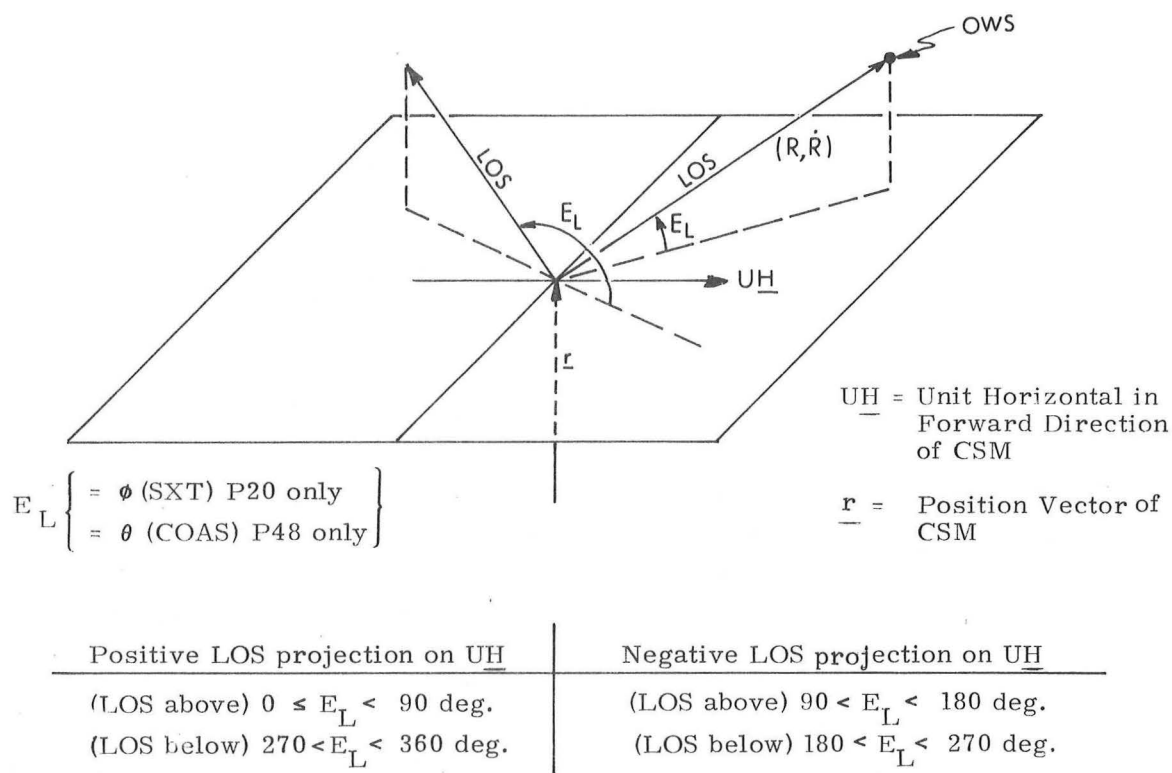


Figure 4.2.1.3-1 R27 Relative-motion Parameters:  
Range, Range Rate, Elevation Angle

Depending on its calling program, R27 also updates the elevation angle from the local-horizontal plane of the CSM to the OWS line of sight. This angle is computed from the CSM inertial state vector and is referred to either as phi, when measured with the SXT during prethrust targeting, or as theta, when measured with the COAS during TPF. Figure 4.2.1.3-1 illustrates these R27 output parameters.

\* See paragraph 4.1.2.

R27 is called automatically by P25 and by P48 and is called at the option of the crew by P20. As used in these three programs, R27 serves two distinct rendezvous functions of the CMC. It provides to the crew (1) relative-motion parameters for specific mission times—the so-called optimized range and range rate—to be used with charts in obtaining back-up targeting solutions, and (2) continual relative-motion parameters for use in monitoring the braking phase (TPF). Accordingly, the crew can operate R27 in either of two modes corresponding to these functions—the fixed mode and the current mode, respectively. A summary of R27 follows:

<u>Calling Program</u>	<u>R27 Selection</u>	<u>Primary Function</u>	<u>Purpose</u>
P20	Crew option	(R, R-dot, phi) for specific GETs	Nominal back-up targeting
P25	Automatic	(R, R-dot) for specific GETs	Contingency back-up targeting
P48	Automatic	Continual (R, R-dot, theta)	Monitor TPF

The remainder of paragraph 4.2.1.3 is both a general discussion of R27 and a functional comparison of its differing applications to programs P20, P25, and P48. Paragraph 4.2.1.3.1 is an overview of all R27 use. Paragraph 4.2.1.3.2 serves as the principal explanation of the purpose of R27 with P20, although this material is also relevant to P25. For an explanation of P25, see paragraph 4.2.5. For P48, see paragraph 6.2.4.

4.2.1.3.1 Programs Using R27.—P20 calls R27 from the Rendezvous Tracking Data Processing Routine (R22)—that is, only during the rendezvous-navigation mode of P20. The P20 options therefore associated with R27 are 0 and 4 only. (See paragraph 4.2.1.2.) With P20, the associated displays of R27 must be called manually by the crew.

R27 can be enabled or disabled in R22 by the crew's performing Verb 76 or Verb 77, respectively. (See Figure 4.2.1.3-2a.) Since R27 significantly increases the cycle time of prethrust programs running in the foreground (except P36, with zero target offsets), the crew should perform Verb 77 prior to keying PRO for a final computation. Other reasons for disabling R27 include the possibility of continuously bad VHF data and, as well, the fact that R27 may not be needed during such programs as P30, P37, and P38.

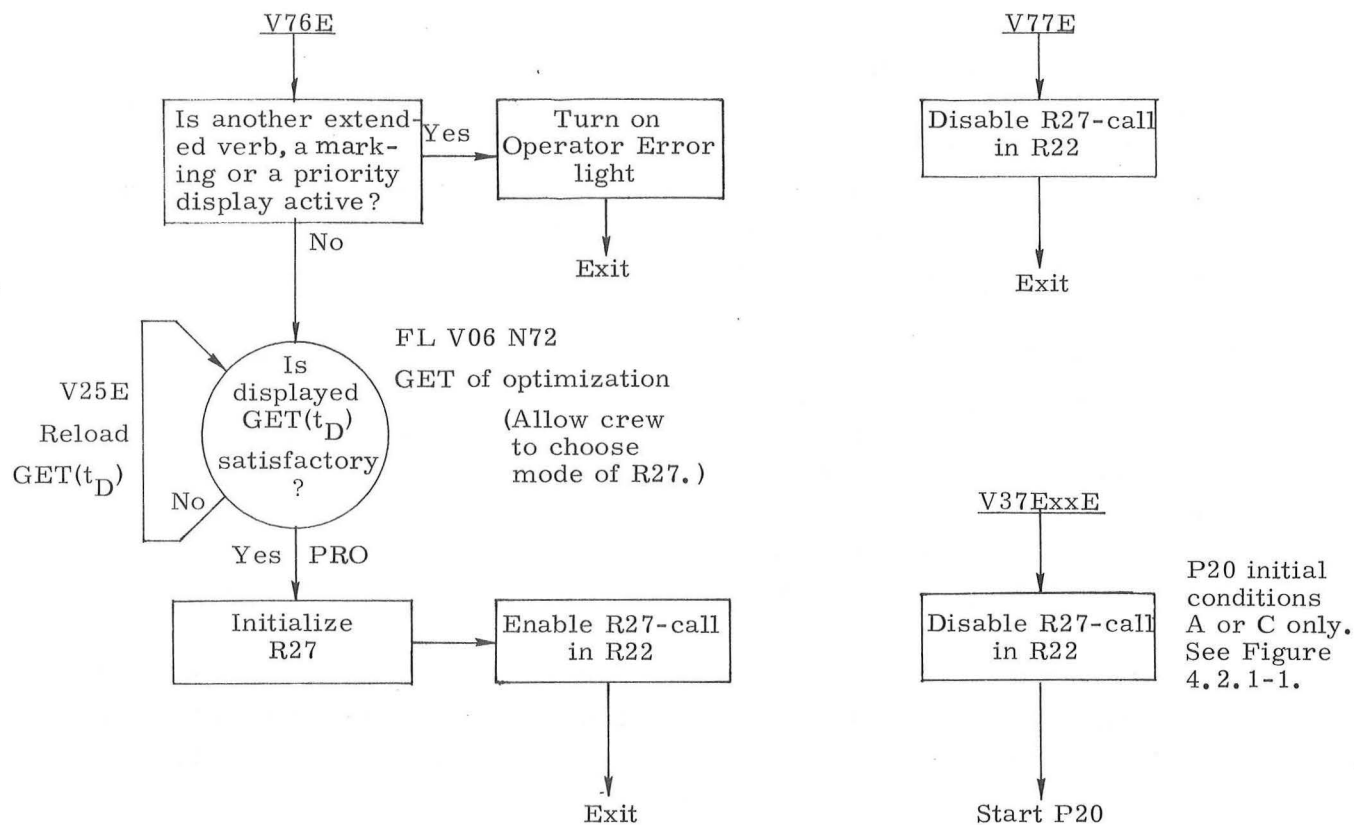


Figure 4.2.1.3-2a. Enabling/Disabling R27 in P20

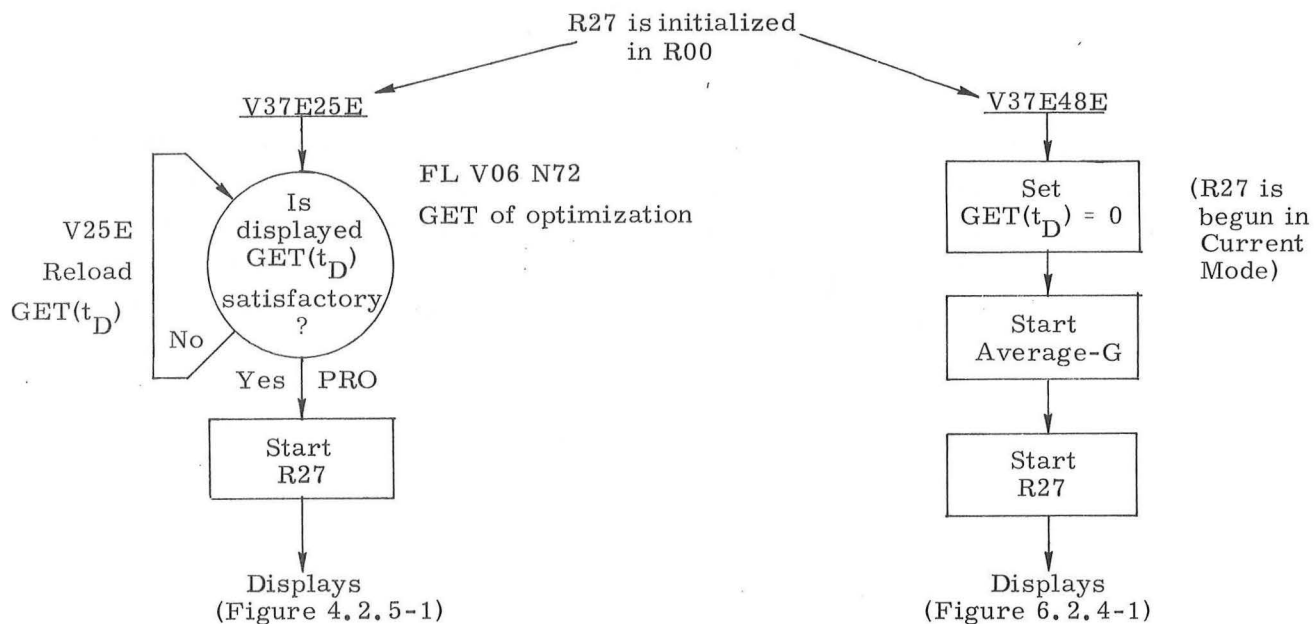


Figure 4.2.1.3-2b. Starting R27 in P25/P48

R27 is also disabled in R22 if the crew starts P20 by Verb 37 under certain of the initial conditions of paragraph 4.2.1. (See Figure 4.2.1-1.) Therefore, if the crew terminates P20 by Verb 56 (or by any other means)—or if Verb 77 is performed—then Verb 76 must be performed subsequent to re-establishing P20 in order that R27 be enabled. The recommended procedure for Verb 76 is that it be performed over the first  $t_{IG}$  display of a given prethrust program.

P25 (paragraph 4.2.5) is a contingency program which provides for chart solutions when the primary targeting programs cannot be used. It consists only of R27 and its related displays. P48 (paragraph 6.2.4) is a rendezvous braking phase (TPF) program in which R27 is coupled with the Average-G routine to monitor both the relative motion of the spacecraft and any CSM thrusting. The displays of these two programs are automatic and follow directly upon the crew's keying V37E25E or V37E48E.\* (See Figure 4.2.1.3-2b.)

Initialization. R27 is said to be "initialized" when the two flags R27UP1 and R27UP2 have been reset. This causes the initial values of both the range state vector and the R27 W-matrix to be recomputed and the mode-switching logic (Figure 4.2.1.3-5) to be entered. As Figures 4.2.1.3-2 indicate, the crew can initialize R27 at any time by keying—

- 1) V37ExxE,\*\* where xx is any program,

or

- 2) V76E and PRO on the flashing display.

R27 Marks. With good VHF data, the filter processes a mark each time it is called by its user program. This R27 mark is unrelated to the VHF marks incorporated by R22 once per minute. With P20, calls to R27 are regularly made at intervals of 5 seconds, but if R22 must process a VHF or an optics mark, then the succeeding call to R27 can be delayed by as much as 15 seconds. On an average, the frequency of R27 marks is:

in P20—every 7 sec (with VHF and optics marks)  
—every 5 sec (no VHF or optics marks)

---

\*P48 is also selected by MINKEY following P37.

\*\*This also applies to the implicit Verb 37 in a MINKEY transition between major modes.

in P25—every 3 sec  
in P48—every 2 sec

R27 Displays. The three displays associated with R27 are as follows. Their significance with respect to the two modes of R27 is discussed in paragraph 4.2.1.3.3.2:

FL VERB 06 NOUN 72

Flashing display of the time  $t_D$  for which the range state vector is optimized and an elevation angle computed:

R1 +00xxx. hr GET  
R2 +000xx. min  
R3 +0xx.xx sec

To accept data, key PRO.

To change data, key VERB 25 ENTR, load GET ( $t_D$ ), and key PRO.

NOTE.—NOUN 72 loaded to zero indicates R27 is operating in the current mode.

FL VERB 16 NOUN 76

Flashing monitor of (R1, R2) the range state vector being carried in R27 and (R3) the difference between the present time and the time in NOUN 72:

R1 +xxx.xx n.mi. Range  
R2 ±xxxx.x fps Range rate  
R3 ±xxBxx. min, sec Time-from- $t_D$

NOTE.—R3 of NOUN 76 is elsewhere referred to as "TFO".

FL VERB 16 NOUN 77

Flashing monitor of (R1, R2) either the current or the partly-optimized range state vector and (R3) either an elevation angle or the code -00001:

R1	+xxx.xx n.mi.	Range
R2	±xxxx.x fps	Range rate
R3 (P20)	+xxx.xx deg	Phi
R3 (P25)	-00001	Code
R3 (P48)	+xxx.xx deg	Theta

NOTE.—The code -00001 also appears in R3 at certain times during P20 and P48 if an optimization is performed. (See paragraph 4.2.1.3.3.2.)

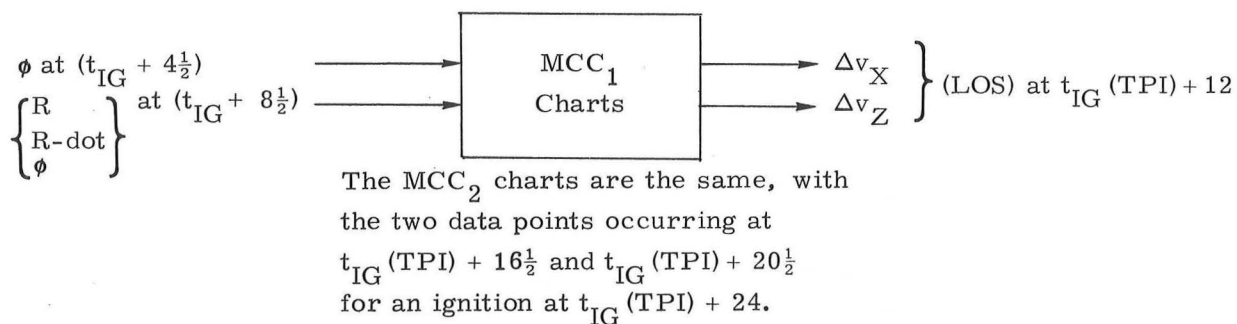
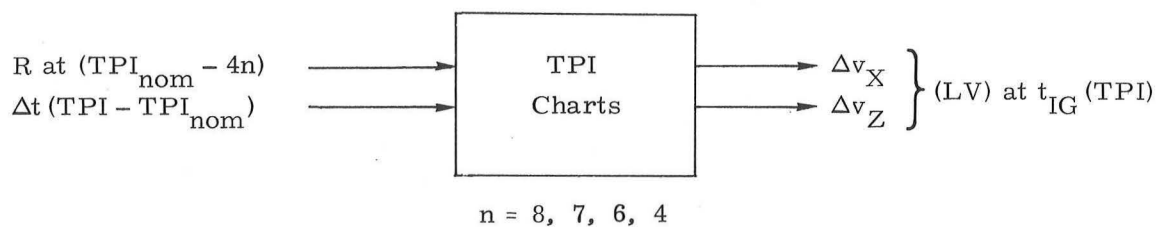
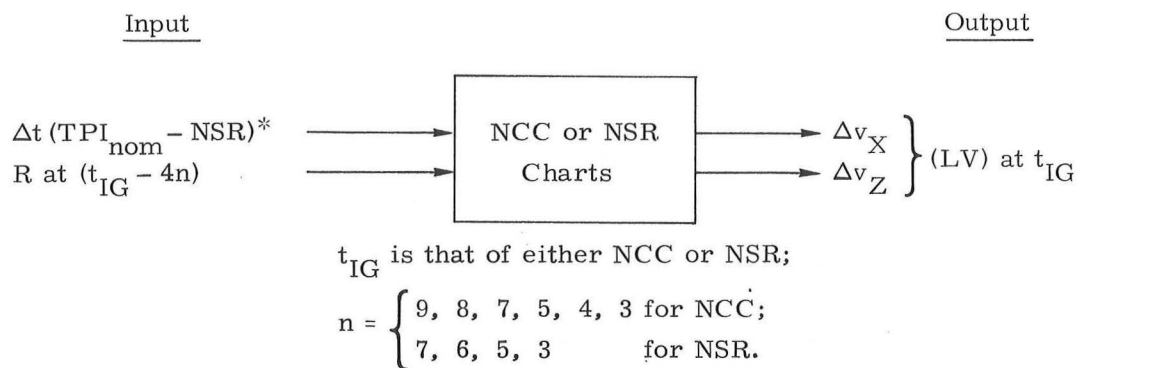
4.2.1.3.2 Back-up Targeting, Chart Solutions.—Beginning with NCC, the maneuvers necessary to effect rendezvous can be targeted onboard by an alternative scheme to the prethrust programs P33 through P36 (see Section 5.0). This back-up scheme may be needed in the event of a failed IMU, bad inertial state vectors, or some other contingency rendering the primary scheme unusable. To maintain this capability, the crew performs back-up targeting concurrently with each of the post-NC2 prethrust programs. The back-up solutions can be utilized if necessary, but in a nominal rendezvous they are used as an independent, onboard means of verifying the primary solutions. Finally, ground solutions provide for another independent comparison, thus completing the "no-fail rendezvous" capability.

To obtain back-up solutions through TPI, the crew basically needs to know only the line-of-sight range between the two spacecraft at selected points in time. These data are automatically provided by R27. But, since raw VHF-ranging measurements can be read "on-the-fly" in the Entry Monitoring System (EMS), even a failure of the CMC would not in itself prevent a solution. Thus, the only "hard" requirement for rendezvous by this means is that VHF lock-on be established.

Back-up targeting involves a relationship between the changing range state vector and the velocity to be gained at ignition. This relationship is determined by preflight simulations of a large number of trajectories, and it is contained onboard in the form of charts unique to each maneuver. Output parameters from R27 become input data to the charts, and the crew must, therefore, specify in R27 the times, in Ground-Elapsed Time (GET), for which these data are desired. With each prethrust program, the crew initiates a sequence of chart data points by loading Noun 72 with a GET which is some multiple of four minutes before the displayed  $t_{IG}$  of that program. All succeeding data points are then scheduled automatically by R27—each, four minutes from the last. (A single data point is elsewhere referred to as  $t_D$ .)

A back-up solution differs in two ways from a primary solution. First, the  $t_{IG}$  for any maneuver, or for a succeeding maneuver, is never determined by the charts





\*All  $\Delta t$ 's and references to  $t_{IG}$  are in minutes.

R = Range in n. mi.

R-dot = Range rate in fps.

$\phi$  = SXT Elevation angle in deg.

Figure 4.2.1.3-3. Back-up Charts Input/Output for Skylab 2 and 3.

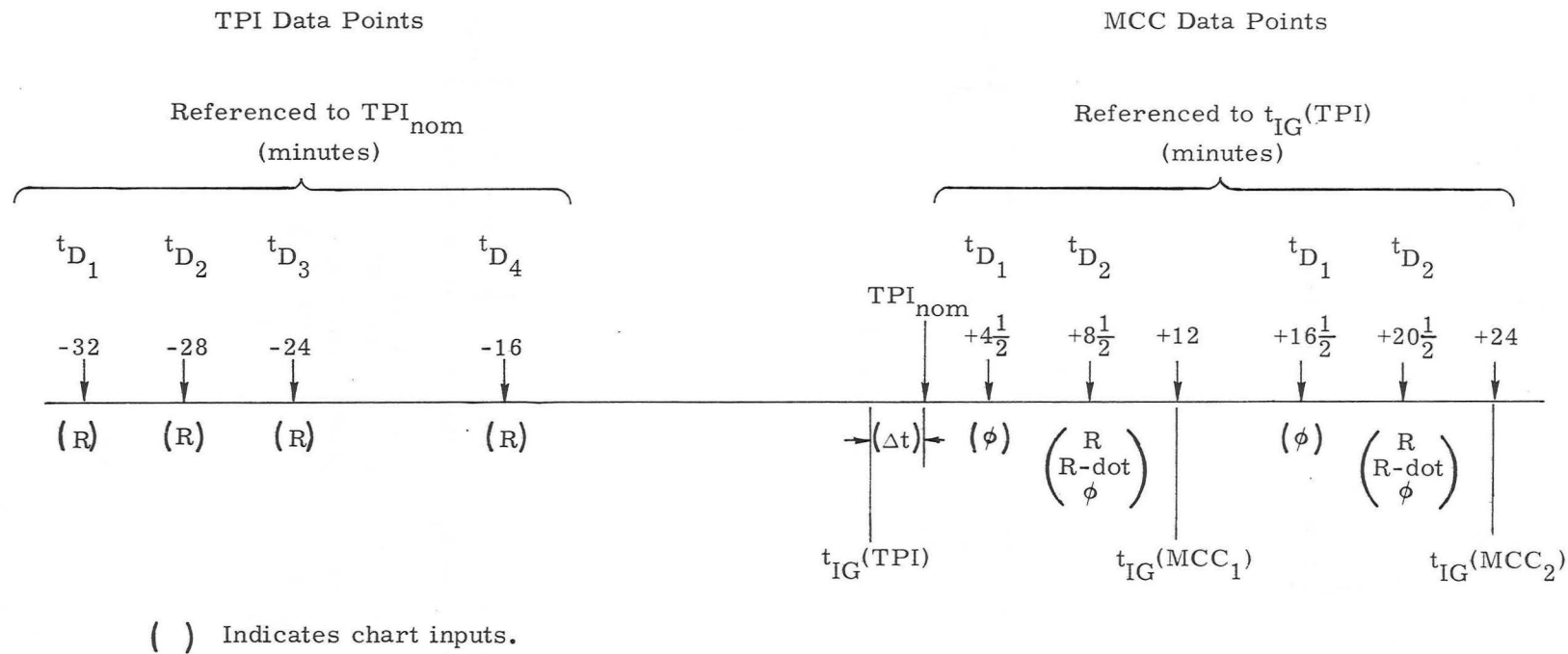


Figure 4.2.1.3-4. Nominal TPI-MCC Back-up Charts Timeline

but is strictly an input to them, either from the corresponding prethrust program or from the ground. In particular, P35 may recompute  $t_{IG}(TPI)$ —or the ground may do so—and the difference ( $\Delta t$ ) between this and the nominal time of TPI then becomes an input to the TPI charts. (See Figure 4.2.1.3-4 and paragraph 5.2.5.) Second, the output  $\Delta v$  components are in X and Z (LV) only, for back-up targeting assumes the orbits of the two spacecraft to be coplanar. A fully back-up-targeted rendezvous is accomplished by the crew's leaving any accumulated rate in Y (LV) to be nulled manually during TPF. (See paragraph 6.2.4.) It is estimated that up to 50 fps of Y-dot can be thus accommodated.

As Figure 4.2.1.3-3 illustrates, the NCC, NSR, and TPI charts each involve essentially the same input/output parameters—the range states referenced to some future  $t_{IG}$ , a  $\Delta t$  between  $t_{IG}$ s, and the output  $\Delta v$ 's in local-vertical coordinates. The MCC charts, however, require range states and elevation angles referenced to a  $t_{IG}$  in the past (TPI), and their output  $\Delta v$ 's are in line-of-sight coordinates. In the MCC charts, the elevation angle  $\phi$  is defined as the angle between the local-horizontal plane and the sextant line of sight to the OWS. Figure 4.2.1.3-4 shows a complete timeline for back-up targeting from TPI through MCC2. Except for the constraint of four-minute intervals on data points, the parameters and times specified in these figures are subject to mission plans and can be changed. Their inclusion here is intended to represent typical chart data. The output from R27, however—when used with P20—is always range, range rate, and  $\phi$  for every data point.

**4.2.1.3.3 R27 Modes.**—The fixed mode of R27 is used in back-up targeting and involves the processing of VHF marks over a time interval of 190 seconds, at the end of which the range state vector is said to be "optimized" for the time  $t_D$ , where  $t_D$  is a GET which lies at the center of this interval.

The current mode, primarily used during TPF, provides a fresh estimate of the range state with each successive mark. The time for which R and R-dot are valid, therefore, is approximately the time at which their display is updated.

The difference between the two modes refers to the two ways in which the range state vector is related to time. One is precise; the other, immediate. The fixed mode attains its accuracy by focusing over the entire 190-second interval on the range state for the time  $t_D$ , and, within this interval, the range state for no other time is available in R27. On the other hand, the range state of the current mode is no older than the last-accepted R27 mark. Indeed, the rate at which R27-mark processing takes place largely determines the need in back-up targeting for the fixed, instead of the current, mode. In TPF, this rate is about one mark every two

seconds, but, during prethrust targeting, the time between marks can be as great as 20 seconds. In this instance, the current mode would yield an uncertainty of at least 10 seconds in the range state—an error unacceptable for chart solutions. The fixed mode not only precludes such an uncertainty but refines the estimate of R and R-dot at precisely  $t_D$  to an accuracy of  $\pm 0.00$  n.mi. in range and  $\pm 0.1$  fps in range rate. Current mode accuracy is  $\pm 0.00$  n.mi. and  $\pm 0.4$  fps for the time of each R27 update. (These values are for a nominal marking schedule during post-NC2 targeting, in which the frequency of R27-mark processing averages once every 7 seconds.)

The elevation angles phi and theta are each computed to correspond to the time of the range state of each of the two modes. The crew, therefore, will most likely use these angles as follows:

Phi (P20) — Fixed mode:  $\phi$  computed for a SXT sighting at  $t_D$ .

Theta (P48) — Current mode:  $\theta$  computed for a COAS sighting at the current time.

But the time for which either angle is computed depends upon the R27 mode used. That is, the crew can select the current mode with P20 (and phi would then be continually updated to the present time), or it can select the fixed mode with P48 (and theta would be computed for  $t_D$ .)

4.2.1.3.3.1 Mode Selection.—The crew controls the selection of R27 modes only by appropriate loading of Noun 72. If, when R27 is initialized, this noun contains a GET in the past, the current mode will be established and will continue until the crew loads Noun 72 with a time in the future. When this is done, a sequence of optimizations will be established in which R27 alternates from one mode to the other automatically, with the first of these optimizations for that time loaded in Noun 72. It is important to note that, once a particular  $t_D$  sequence is established, the crew should then change Noun 72 only when R27 is operating in the current mode, i.e., between optimization intervals of that sequence. This restriction is further amplified in paragraph 4.2.1.3.4. The remainder of this paragraph presents in some detail the content of the above. (Refer to Figure 4.2.1.3-5.)

Selection of the current mode is made automatically whenever one of the following is true:

1. Noun 72 contains a GET of zero,
2. Noun 72 contains a GET in the past,\*
3. Noun 72 contains a GET in the future by at least 95 seconds.

Condition 1 is the prime means for the crew's continuing R27 in the current mode. This condition causes P25 and P48 to bypass the Noun 76 display—which is redundant, but still valid, with this mode—and to go automatically to the Noun 77 display.

Condition 2 keeps R27 operating when lacking a  $t_D$  in the future. For example, when P20 is re-established after a thrusting maneuver and the GET in Noun 72 represents the last  $t_D$  before the maneuver—then, by Condition 2, R27 will be on and converging to the steady state while "waiting" for the crew to load the next  $t_D$ .

Condition 3 is true during the approach to an optimization interval, either the first or the nth of the  $t_D$  sequence.

Upon initialization, the time required for the filter to converge to its current-mode accuracy of  $\pm 0.4$  fps is, typically, 250 seconds with P20.\*\* (See the RMS errors of Figure 4.2.1.3-6.)

Selection of the fixed mode is made automatically whenever Noun 72 contains a GET in the future by not more than 95 seconds—that is, if the time of at least one processed mark,  $t_M$ , falls within the first half of an optimization interval:

$$(t_D - 95) < t_M < t_D .$$

Once established, the fixed mode remains operative until R27 accepts a mark such that  $t_M > (t_D + 95)$ . At this point, with the present optimization complete, the erasable registers containing  $t_D$  (Noun 72) are automatically incremented by four minutes, thereby continuing the sequence. Condition 3, above, is now true, and R27 reverts to the current mode. For all R27 use, regardless of whether the filter has had time previously to converge, the full 190 seconds is required for convergence to the fixed-mode accuracy of  $\pm 0.1$  fps.

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\* This does not refer to the second half of the optimization interval. (See "Selection of the fixed mode.")

\*\* This time delay is considerably less with P25 and P48 because the frequency of their mark processing is about three times faster. (See paragraphs 4.2.5.1 and 6.2.4.1.)

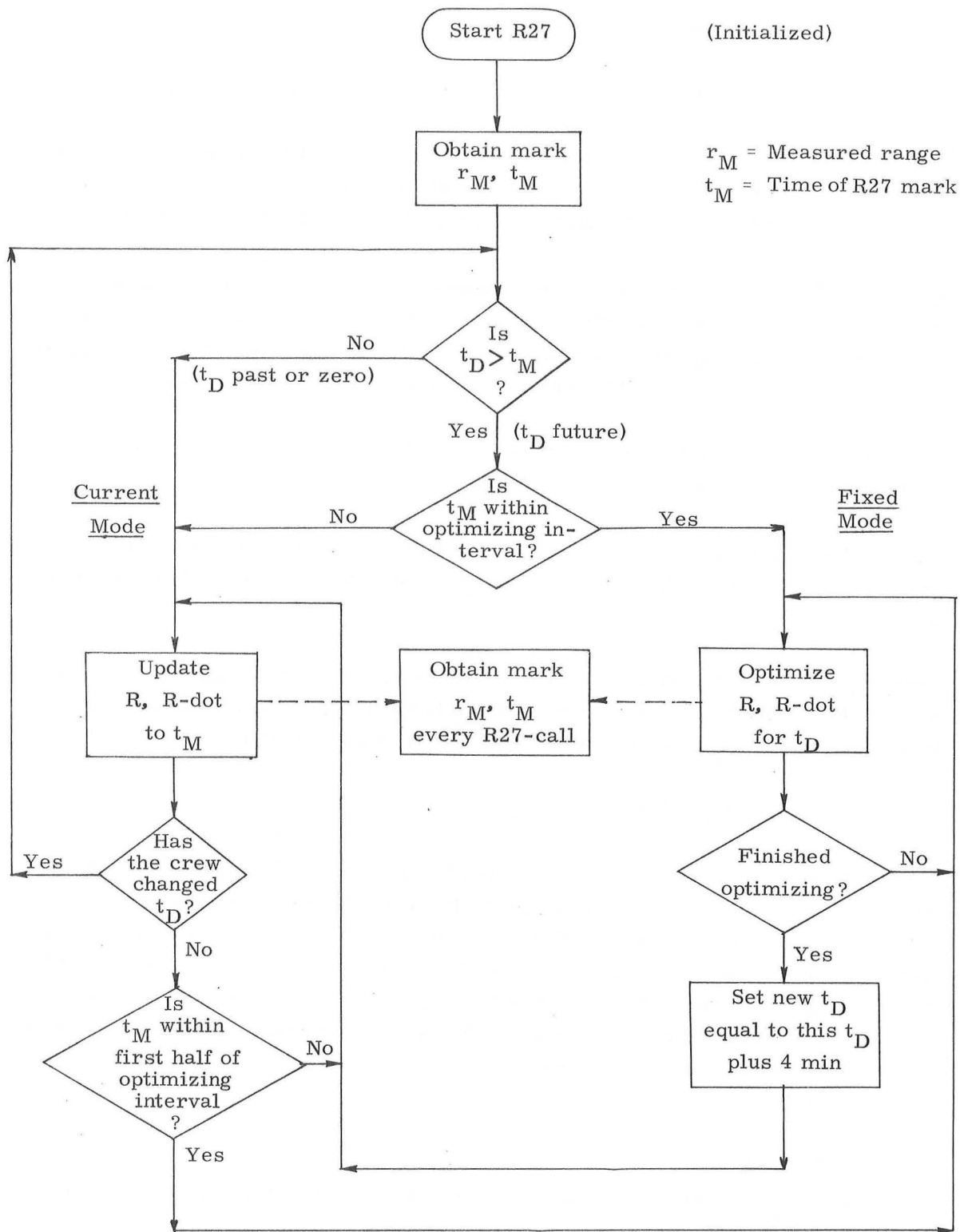


Figure 4.2.1.3-5. R27 Mode Switching

In order to ensure that a complete optimization is performed for  $t_D$ , the crew should load Noun 72 no later than 95 seconds in advance of  $t_D$ . To ensure only that a particular  $t_D$  sequence is established—that is, should the first optimization of the sequence be of no importance—the crew must still load Noun 72 enough in advance of  $t_D$  (at least 20 seconds with P20<sup>\*</sup>) to cause the fixed mode to be entered.

4.2.1.3.3.2 Mode Displays, Procedures.—Noun 76 and Noun 77 each contain a range and range rate associated with a particular time. With either mode, Noun 77 can be considered primary, and Noun 76 secondary. That is, Noun 77 provides the available R27 output parameters, and Noun 76 provides information about the time(s) for which these parameters are valid. The remainder of this paragraph presents the significance of these nouns as they might be used together during each of the two modes. (Refer to Figure 4.2.1.3-6.)

#### Displays with the current mode.

The range and range-rate displays (R1, R2) of both Noun 76 and Noun 77 are always identical and updated simultaneously.

R3 of Noun 76 (TFO) is static at +59B59 if Condition 1 is true (paragraph 4.2.1.3.3.1) and is counting if either of the other conditions is true. TFO is static in any case, however, if NOUN 72 contains a time which is more than an hour in the past or future.

R3 of Noun 77 (elevation angle) contains:

- with P20 —the current  $\phi$ , provided a computation cycle is not at the same time being performed by any of the prethrust programs<sup>\*\*</sup>;
- with P25 —the code -00001;
- with P48 —the current  $\theta$ .

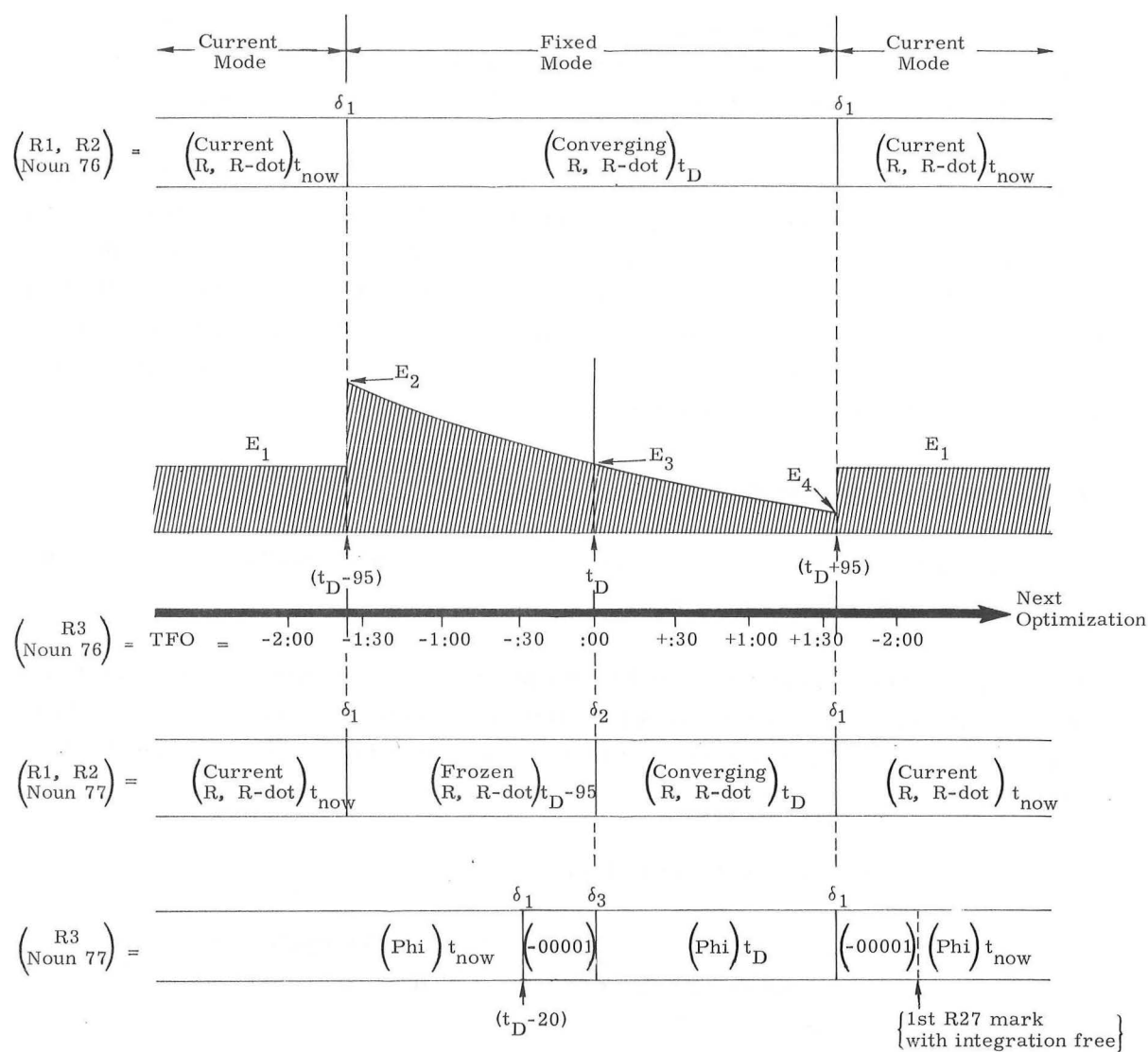
#### Displays with the fixed mode.

Noun 76 always displays whatever range state is being carried in the filter. The extrapolation of the range state from the current time to the time  $t_D$  can, therefore,

---

\* This allows for possible R22-mark processing.

\*\* The current  $\phi$  is updated only if the integration routines are not in use.



RMS Errors (E)  
(Post-NC2)

Update Delays ( $\delta$ )  
(until appearance of indicated value)  
(Seconds)

	<u>R(n, mi.)</u>	<u>R-dot(fps)</u>		<u>Ave.</u>	<u>Max.</u>
$E_1$	.00	0.4	$\delta_1$	3.5	15
$E_2$	.02	1.6	$\delta_2$	2.5	5
$E_3$	.00	0.5	$\delta_3$	5.0	10
$E_4$	.00	0.1			

Figure 4.2.1.3-6. Contents of Noun 76 and Noun 77 During Optimization in P20



be monitored in Noun 76 as R27 enters the optimization interval. Throughout the interval, Noun 76 is continually updated with the improving estimate of the range state for  $t_D$ . Finally, at the end of the interval, the fully-optimized range state is seen to be extrapolated from  $t_D$  up to the current time, and the process is ready to begin again for the next data point of the sequence.

R3 of Noun 76, during the optimization, counts down to +00B00 and up to at least +01B35. With the next-accepted R27 mark, occurring in  $\delta_1$  seconds (Figure 4.2.1.3-6), the counter becomes negative and begins counting down to the next  $t_D$ .

Noun 77 yields the results of the optimization. During the first half of the interval, R1 and R2 are frozen with the values of range and range rate just prior to the initial extrapolation. In other words, the last-computed "current" range state is displayed in Noun 77 until the arrival of  $t_D$  itself. By this time, the range state for  $t_D$  has converged approximately to the steady-state accuracy (Figure 4.2.1.3-6), and, at  $t_D + \delta_2$ , it first appears in Noun 77 as a partially-optimized range state. R1 and R2 of both nouns are now identical and being updated simultaneously. The extrapolation from  $t_D$  to the current time appears in Noun 77 at the time of the first mark after  $t_D + 95$ —that is, at  $t_D + 95 + \delta_1$ .

Note.—The crew must record all optimization data before the arrival of  $t_D + 95$  (TFO = +01B35), after which time these data are replaced by current values.

If using the range-only charts (pre-TPI), the crew can consider the optimization complete at  $t_D + \delta_2$ , since further improvements in the optimized range estimate are generally too small for DSKY resolution.

If using the MCC charts, the crew should wait until nearly the end of the interval in order to obtain the most accurate value of the optimized range rate (see Figure 4.2.1.3-6). Assuming the Digital Event Timer (DET) to be counting up from  $t_{IG}$  (TPI), the recommended procedure is that the crew read the fully-optimized range rate at DET = +10:00 for MCC1, and at DET = +22:00 for MCC2. (See Figures 4.2.1.3-3 and -4.) These times each correspond to TFO (Noun 76) equal to +01:30—that is, just before the end of the interval. This procedure also assumes that the crew reads the optimized range and the elevation angle  $\phi$  in Noun 77 just before keying PRO at DET = +9:00 and at DET = +21:00 to obtain the primary MCC final solutions.

R3 of Noun 77 displays the current elevation angle—exactly as it does with the current mode—until R27 accepts a mark within 20 seconds of  $t_D$ . At this point ( $t_D - 20 + \delta_1$ ), the code -00001 appears, indicating (1) that any R22-mark processing

is inhibited, (2) that the CDU "snapshot" at  $t_D$  is imminent, and (3) that the next-displayed elevation angle will be for  $t_D$ .

The crew should have the SXT boresighted over a period of time from one second before  $t_D$  to one second after. This ensures that the CDU angles are correct when the snapshot occurs.\*

The elevation angle  $\phi$  at  $t_D$  is computed by precision integration and appears in Noun 77 in  $\delta_3$  seconds after  $t_D$  (Figure 4.2.1.3-6). R22 is now free to process marks. If a prethrust computation cycle should have been entered before  $t_D$ ,  $\phi$  will be further delayed. A maximum delay would occur during a computation cycle in P33 and would be approximately 30 seconds beyond  $\delta_3$ .

With the first mark after  $t_D + 95$ , the code -00001 once again appears. Here, the code indicates (1) that the optimization is completed and Noun 72 has been updated, and (2) that the next-displayed elevation angle will be for the current time.

Because of an anomaly\*\* in R27, there exists a 4-percent probability that the computed  $\phi$  at  $t_D$  will not be displayed—i.e., that R3 of Noun 77 will still contain the code -00001 after  $t_D + 10$  sec. If this should occur, the crew can use Erasable Memory Program SL1 to recover the desired value. With this EMP, the crew loads Noun 26 with the priority and the address of the job which computes  $\phi$  at  $t_D$ , then performs Verb 30 to cause the job to be executed. The crew procedure is as follows:

1. Key:  
VERB 25 NOUN 26 ENTR  
27001 ENTR  
02410 ENTR  
60002 ENTR.

If, following the CDU snapshot,  $\phi$  is not displayed within 10 seconds, then—

2. Before  $t_D + 85$  seconds, key:  
VERB 30 ENTR.

---

\*The window extends over the interval  $(-0.64 \text{ sec} < t_D < +0.64 \text{ sec})$ , within which the snapshot can occur anywhere.

\*\*Skylark Anomaly SKY-001.

4.2.1.3.4 Restrictions and Limitations.—Once the fixed mode has been entered, R27 automatically performs a sequence of optimizations, one every four minutes, with 50 seconds of current-mode operation between optimizing intervals. Nominally, the crew would not wish to change a sequence after it has begun, but, should this become necessary, the following procedure is recommended:

To alter the  $t_D$  sequence, change Noun 72 via V25N72E, but only during intervals of the current mode. Changing this noun during a fixed-mode interval will invalidate the range state, and the filter will require initialization. Verb 76 can, of course, be used to change Noun 72 at any time, but this method has the attendant disadvantage of the delay in accuracy of the range state because of the time required for the filter to attain the steady state.

R27 is prevented from processing marks whenever a Noun 49 is being displayed (indicating an excessive state vector update), or for as long as the VHF data-good discrete is absent. The effect on R27 is the same in either case: the range state is not updated for the duration of the delay. Such a delay can significantly affect R27 performance only if it continues for more than 45 seconds—at which point, the RMS errors on the fully-optimized range and range rate begin to be larger than the nominal values (see Figure 4.2.1.3-6). The "worst-case" delay is that which begins before  $t_D - 95$  seconds and continues past  $t_D$ : this will cause both a less-accurate computation of  $\phi$  at  $t_D^*$  and the termination of the  $t_D$  sequence itself. Should this occur, the sequence can be re-established only by the crew's loading Noun 72.

4.2.1.3.5 Restarts.—R27 maintains a permanent range state vector. A restart occurring during the processing of a mark, in effect, means that R27 will ignore the mark. The TFO counter in Noun 76 and the CDU snapshot at  $t_D$  are both restart-protected.

An anomaly exists in the restart protection of the computation of  $\phi$  after the snapshot at  $t_D^{**}$ . A restart that occurs between  $t_D$  and the time of the display of  $\phi$  will result in a new CDU-shapshot at the time of the restart.  $\phi$  will then be recomputed and will be in error. If the SXT were boresighted at the instant of the restart, the error would be equivalent to the change in the LOS direction since  $t_D$ .

---

\* In this case, as part of the computation of  $\phi$ , the CSM state vector would be conically integrated to the time in the AGC clock (near  $t_D$ ) instead of precision-integrated to  $t_D$ .

\*\* Skylark Anomaly SKY-002.

#### 4.2.2 P21, Ground-track Determination

P21 is used to provide the astronaut with details (latitude, longitude and altitude) of his ground track without the need for ground communication. The astronaut specifies a time (GET) and vehicle (CSM or OWS). The program integrates the appropriate vehicle state vector to that time, converts it into latitude, longitude, and altitude, and displays the result.

An optional trajectory parameter display, 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.

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 Advanced Ground-track Determination

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 T LAT LONG corresponding to the original GET plus ten minutes, or reject it by keying VERB 25 ENTR and overwrite any desired T LAT LONG.

##### 4.2.2.2 Limitations

To predict the future orbital position of a vehicle (OWS 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. 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 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. Subsequent computations via the VERB 32 ENTR option use the previous state vector to start the next iteration without, however, ensuring that subsequent integrations are precision. Use of the VERB 32 ENTR option depends on the closeness of the desired times. If the times are reasonably close, the option should be used. If not, it is quicker to reselect P21.

TABLE 4. 2. 2-I

## P21 (CSM) GROUND-TRACK DETERMINATION PROCEDURES

DSKY	Register	Comments
Key V37 E21E	DSKY P21	Only requirement for P21 is a valid 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 ooxxxx. hr R2 oooxxx. 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 xxx. x n. mi.	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).
V06 N73E	R1 xxxxxxB n. mi. R2 xxxxxx. fps R3 xxx. xx deg	V32E will increment GET (T LAT LONG) initially specified by 10 minutes; recycle to V06N34 display. T LAT LONG may then be overwritten via V25E to any desired time.  Keying PRO or V34E will terminate P21.  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.
FL V37		

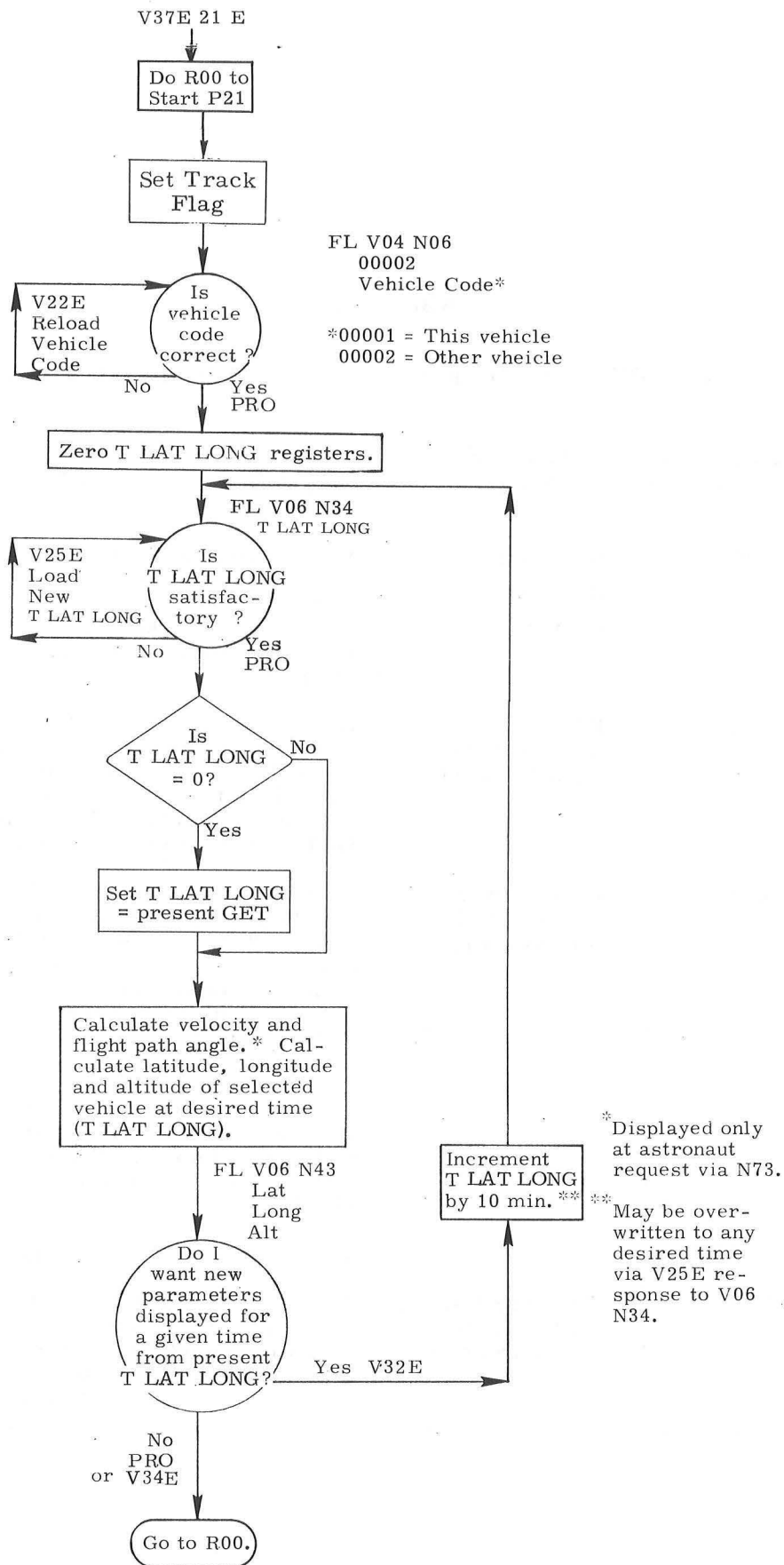


Figure 4.2.2-1. Ground-track Determination Program (CSM P21)

#### 4.2.3 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 4.2.3-I and -II show the P27 DSKY displays and extended verbs, respectively.

##### 4.2.3.1 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.

4.2.3.1.1 VERB 70 ENTR.—VERB 70 allows the ground or crew to update the time of liftoff. The crew loads the time as xxxxx ENTR xxxxx ENTR, i.e., two pieces of data appear successively in R1 of the DSKY. After ENTR has been keyed—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 = Blank

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

TABLE 4.2.3 -I  
DSKY DISPLAYS ASSOCIATED WITH P27 (CSM)

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 xxxxxx
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 xxxxxx
FL V21 N02	P27	Request load of octal identifier	R3 contains address where identifier is to be loaded	R1 Blank R2 Unchanged R3 xxxxxx

\*ECADR is an erasable memory constant.



TABLE 4.2. 3-II  
EXTENDED VERBS USED WITH P27 (CSM)

VERB	Identification	Purpose	Remarks
70 ENTR	Liftoff time update	Select P27 for liftoff time update	Refer to paragraph 4.2.3.1.1
71 ENTR	Contiguous block update	Select P27 to update from 1 <sub>8</sub> to 22 <sub>8</sub> consecutive erasable memory locations in the same EBANK*.	Refer to paragraph 4.2.3.1.2
72 ENTR	Scatter update	Select P27 to update from 1 <sub>8</sub> to 11 <sub>8</sub> not necessarily consecutive erasable memory locations.	Refer to paragraph 4.2.3.1.3
73 ENTR	Octal clock increment	Select P27 to increment or decrement the CMC clock	Refer to paragraph 4.2.3.1.4

\* EBANK is an erasable memory bank.

To correct some of the update data, the crew 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 OWS state vector time.\*

4.2.3.1.2 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/OWS state vector update
- b. CMC desired REFSMMAT update
- c. CMC REFSMMAT update
- d. CMC External  $\Delta v$  update
- e. CMC retrofire External  $\Delta v$  update
- f. CMC entry update

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

```
II ENTR
AAAA ENTR
xxxxxx ENTR
xxxxxx ENTR
.
.
.
xxxxxx ENTR
```

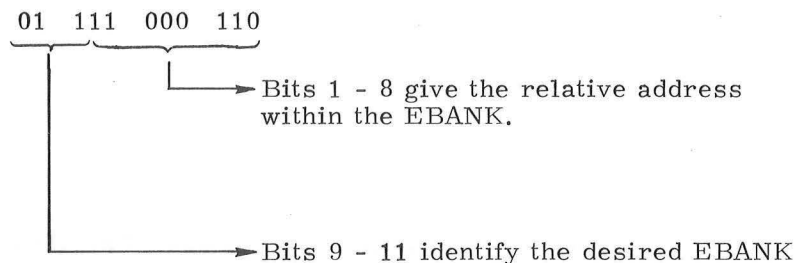
where:

II is a 2-digit octal number between  $3_8$  and  $24_8$ —the index value representing the total octal number of numeric quantities to be loaded.

---

\* TEPHEM is ephemeris time.

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



xxxxxx is octal data to be loaded.

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

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modification, of the data. Keying in VERB 33 ENTR (data accepted) causes P27 to transfer the data to the specified block.

4.2.3.1.3 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
xxxxxx ENTR
AAAA ENTR
xxxxxx ENTR
.
.
.
AAAA ENTR
xxxxxx 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 xxxxxx). 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 xxxxxx immediately following.

xxxxxx is octal data to be loaded.

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

4.2.3.1.4 VERB 73 ENTR.—The crew keys 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 4.2.3.1.1. 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.

#### 4.2.3.2 P27 Procedure

Figure 4.2.3-1 gives the logical flow of P27. Figure 4.2.3-2 gives two examples of manual data loads.

Before entering P27, the CMC major mode must be P00, P02, or P20 (options 1, 2, or 5) 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, a marking display, or a priority display 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, P02 or P20 (options 1, 2, or 5), 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.

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

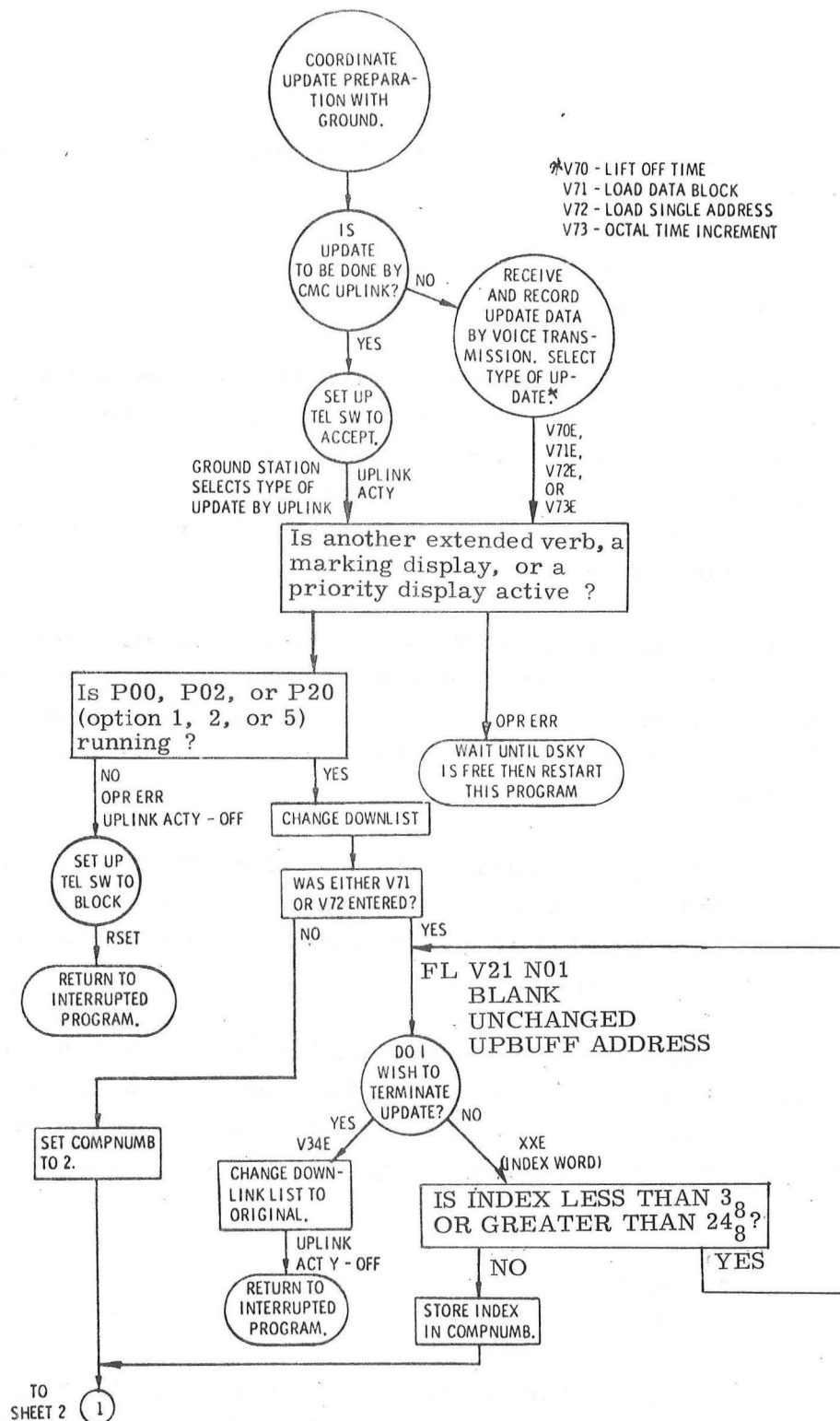


Figure 4.2.3 -1. CMC Update Program (P27) (Sheet 1 of 3)

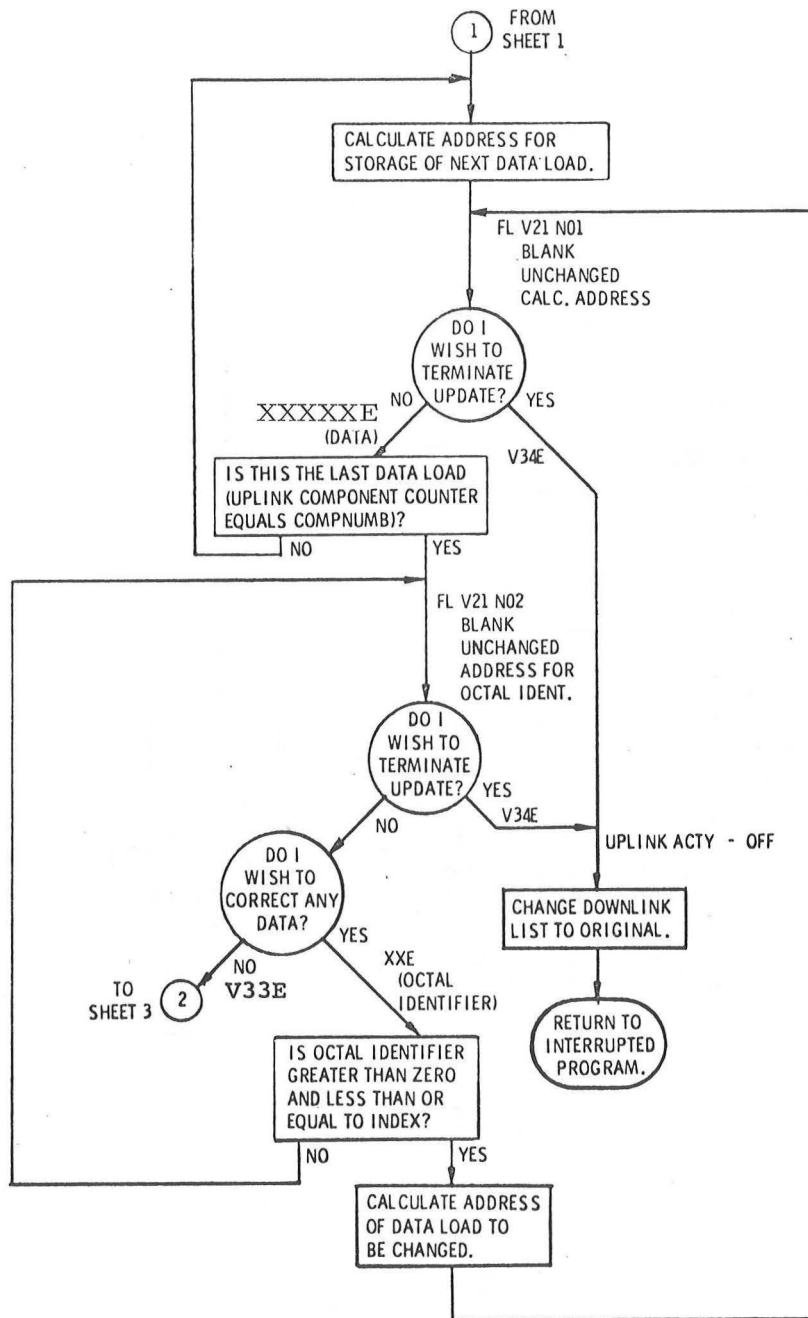


Figure 4.2.3 -1. CMC Update Program (P27) (Sheet 2 of 3)

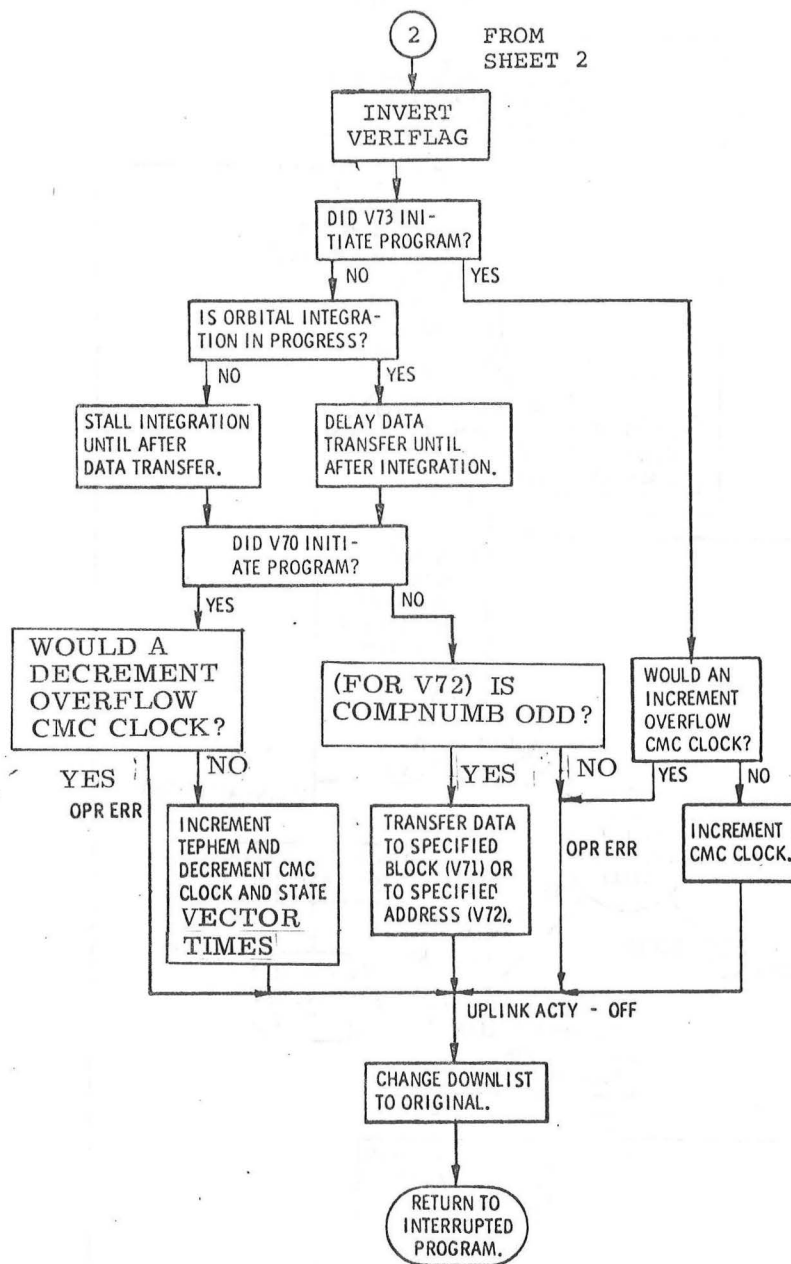


Figure 4.2.3 -1. CMC Update Program (P27) (Sheet 3 of 3)



EXAMPLE 1: Load REFSMMAT (CM)

<u>ENTRY</u>	<u>CMC RESPONSE</u>	<u>EXPLANATION</u>
VERB 71 ENTR →	FL VERB 21 NOUN 01	
24 ENTR		Octal number of numeric values to be loaded (including this one)
1717 ENTR		First erasable location
xxxxxx ENTR		Data
⋮		
xxxxxx ENTR →	FL VERB 21 NOUN 02	Last data point
VERB 33 ENTR →	P00 or P20	

EXAMPLE 2: Load CSM state vector in earth orbit

<u>ENTRY</u>	<u>CMC RESPONSE</u>	<u>EXPLANATION</u>
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
xxxxxx ENTR		Data
⋮		
xxxxxx ENTR →	FL VERB 21 NOUN 02	Last data point
VERB 33 ENTR →	P00 or P20	

Figure 4.2.3-2. Examples of Manual Data Loads

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 has 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 loads 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 has three possible responses:

- a. To accept all the data by keying in VERB 33 ENTR<sup>\*</sup>
- 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.

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,

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\* 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.

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 71) 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.

#### 4.2.3.3 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, marking display, or priority display is active; if the CMC is not in P00, P02 or P20 (options 1, 2, or 5), 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.

#### 4.2.3.4 Restrictions and Limitations

P27 is allowed to be entered only when the CMC is in P00, P02, or P20 (options 1, 2, or 5) and no other extended verbs, a marking display, or a priority display are active.

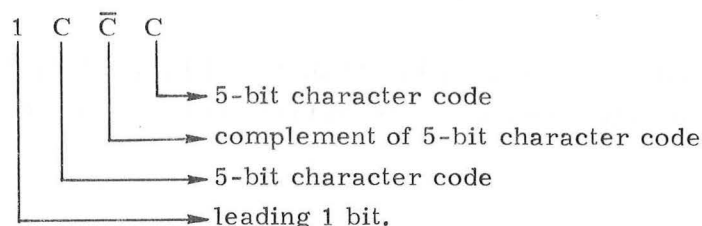
The number of numeric quantities which can be loaded is restricted as follows:

- 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.

#### 4.2.3.5 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  $\bar{C}$  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 4.2.3-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 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,

TABLE 4.2.3 -III

LEGAL INPUT CHARACTERS AND ASSOCIATED UPLINK WORDS (CSM P27)

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

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.

#### 4.2.3.6 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.

#### 4.2.4 P29, Time of Longitude

The Time of Longitude Program is used to compute and display the ground-elapsed time at which the OWS or CSM will pass over a crew-specified longitude. The crew can choose to have the CMC compute time of longitude for either the OWS or the CSM. Program calculations are then made based on the assumption that the chosen vehicle remains in free fall from the selected start time (base time) until the time of crossing.

In addition to displaying the time of crossing over the specified longitude, P29 computes and displays the latitude and vehicle altitude at the point of crossing. Significantly, the time (and related data) displayed by P29 is the time of the first crossing of the vehicle over the crew-specified longitude after the crew-selected base time. Generally, the crew selects present time (all zeros in the VERB 06 NOUN 34 display) as base time, but can also select any past or future time. In all cases of P29 use, the base time should be carefully selected to allow optimum sequencing and performance of desired tasks.

##### 4.2.4.1 Program Use

Because the information displayed by P29 is nominally uplinked from ground, the program is most useful in case of communication loss with ground. It can also prove useful to the crew for sighting either scheduled or unscheduled landmarks for tracking and photography, and for obtaining ground-track information.\*

##### 4.2.4.2 Program Summary

Upon keying VERB 37 ENTR 29 ENTR, the crew observes flashing VERB 04 NOUN 06 with R2 containing the CMC-assumed option code, 00001. If the crew desires the time of longitude and related P29-displayed data for the OWS, he keys VERB 22 ENTR and loads R2 with option code 00002. Otherwise, he keys PRO and observes flashing VERB 06 NOUN 34, displaying the ground-elapsed base time in hours, minutes, and seconds. This display is the base time from which the next crossing

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\* P29 can be used with options 0, 1, 2, 4, and 5 of P20 running in the background for tracking only—no navigation.

of the desired longitude is computed. The choice of base time, is, therefore, crucial to the effective use of P29. The registers initially contain all zeros indicating present time. To select another base time, the crew keys VERB 25 ENTR, loads the desired time, and upon its display, keys PRO. If the present time is satisfactory, he merely keys PRO and observes the flashing VERB 06 NOUN 43 requesting entry of the desired longitude. To load the longitude for which GET is computed, the crew keys VERB 22 ENTR and loads longitude. The CMC then computes GET for the next crossing of this longitude and displays it in flashing VERB 06 NOUN 34. To respecify the longitude using the base time originally entered, the crew keys VERB 32 ENTR. The CMC recycles the program to the flashing VERB 06 NOUN 43 display allowing the crew to change desired longitude. If the GET displayed is satisfactory, the crew keys PRO and observes flashing VERB 06 NOUN 43, the latitude, longitude, and vehicle altitude at the point of crossing. If the data in NOUN 43 is satisfactory, the crew keys PRO, which terminates P29 and allows selection of a new program via VERB 37. The crew can also respecify all the input data by keying VERB 32 ENTR and causing the program to recycle to the flashing VERB 04 NOUN 06 display.

#### 4.2.4.3 Procedures

##### 1. Key VERB 37 ENTR 29 ENTR

Observe display of option code:

FL VERB 04 NOUN 06

R1 00002 specify vehicle  
R2 0000x option code  
R3 Blank

NOTE.—The CMC assumes option code 00001 indicating the CSM. To specify OWS use option code 00002.

Key VERB 22 ENTR to load desired option code in R2.

PRO

##### 2. Observe flashing display of ground-elapsed base time from which next crossing of desired longitude is computed:



FL VERB 06 NOUN 34

R1 00xxx. hr  
R2 000xx. min.  
R3 0xx.xx sec

NOTE.—Initial display contains all zeros indicating present time. Unless crew changes this display, P29 will base its calculations on the present time.

. Key VERB 25 ENTR to load desired base time.

. PRO

NOTE.—The CMC integrates the state vector forward or backward to the desired base time specified by the crew.

3. Observe flashing display of desired longitude:

FL VERB 06 NOUN 43

R1 Blank  
R2 xxx.xx deg Long  
R3 Blank

NOTE.—The desired longitude is specified positive eastward and negative westward.

. Key VERB 22 ENTR to load desired longitude.

. PRO.

NOTE.—Upon a PRO the CMC computes the time of the first crossing over the longitude specified in Step 3 after the base time specified in Step 2.

4. Observe the flashing display of the CMC-computed time of longitude crossing:

FL VERB 06 NOUN 34

R1 00xxx. hr  
R2 000xx. min  
R3 0xx.xx sec

Key VERB 32 ENTR to respecify longitude using base time already specified in Step 2.

PRO

NOTE.—A recycle (VERB 32 ENTR) returns the program to Step 3.

5. Observe flashing display of latitude, longitude, and altitude at crossing:

FL VERB 06 NOUN 43

R1 xxx.xx deg Lat (+North)  
R2 xxx.xx deg Long (+east)  
R3 xxxxx.x n.mi. Alt

Key VERB 32 ENTR (recycle) to respecify input data by returning to FL V04 N06.

PRO

NOTE.—A PRO response terminates P29.

6. Observe flashing display of request for new program:

FL VERB 37

Key xx ENTR.

#### 4.2.5 P25, Contingency VHF Range Rate

P25 provides for rendezvous back-up targeting solutions\* under those conditions when the primary targeting programs (P33-P36) cannot be used—either because of a failed IMU or bad state vectors. The crew operates the VHF Range Rate Mark Processing Routine, R27, through this program. The input to P25 is VHF-ranging data and a crew-specified GET of optimization; the output is either the current or the optimized LOS range and range rate between the CSM and the OWS. Since P25 assumes neither inertial state vectors nor an IMU, no elevation angle to the OWS is computed. (Refer to paragraph 4.2.1.3 for an explanation of R27 use.)

##### 4.2.5.1 P25 Procedures

Figure 4.2.5-1 presents the program flowchart of P25. See also paragraph 4.2.1.3.3 for a discussion of R27 modes.

If the crew wishes to use P25 to provide a back-up chart solution, it should load Noun 72 with a GET that is based upon some time of ignition to be loaded in Noun 33. When Noun 72 is loaded with a time in the future, a sequence of optimizations will occur automatically at 4-minute intervals. As explained in paragraph 4.2.1.3.4, the Noun-72 sequence must not be altered by any means other than Verb 76 as long as R27 is within an optimization interval.

With P25—unlike other programs that use R27—Noun 76 can be used exclusively with a sequence of optimizations, and Noun 77 used exclusively with the current mode. The contents of Noun 76 and Noun 77 are as indicated in Figure 4.2.1.3-6, where "-00001" everywhere replaces "phi." The R27-mark frequency in P25 is about once every three seconds. The time required for the filter to converge to current-mode accuracy is, typically, 150 seconds.

##### 4.2.5.2 Limitations and Restrictions

The crew can use P25 prior to NC2 to obtain accurate range state vector estimates. Although back-up charts for maneuvers scheduled before NCC are not implemented in the SKYLAB flight plan, the existing software can accommodate them should the need for them arise. Subject to the restrictions of the following two paragraphs,

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\* See paragraph 4.2.1.3.2.

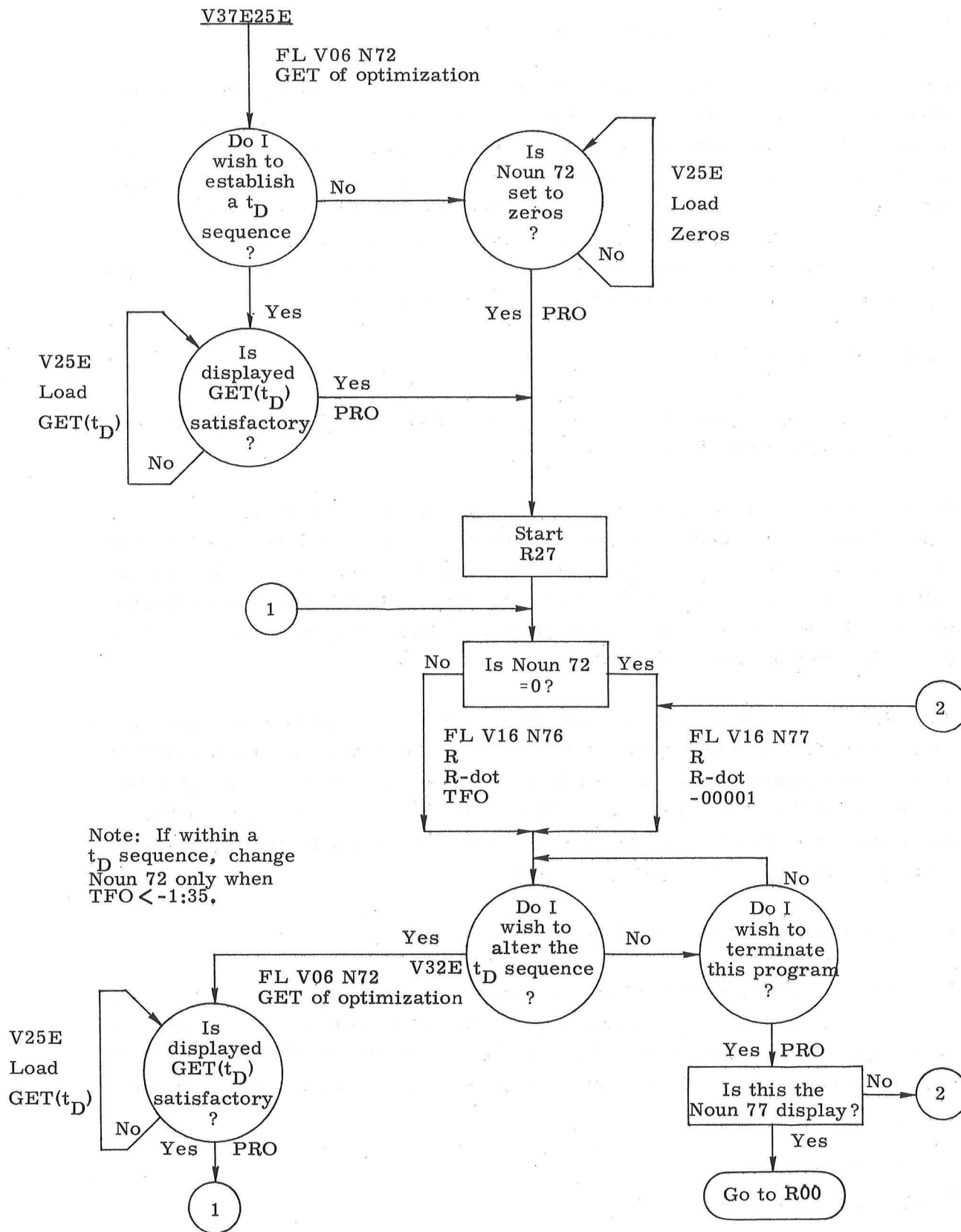


Figure 4.2.5-1. Contingency VHF Range Rate Program(P25)

the crew can operate P25 in either mode of R27 within the limits imposed by the AGC erasable scaling. These limits are:

Range—565 n.mi.\*  
Range-rate— $\pm 1950$  fps  
Range-acceleration— $\pm 6$  fps<sup>2</sup>

4.2.5.2.1 Higher-order Range Derivatives.—The double-precision parameter RTRIDOT is pad-loaded with a value for the third-order range derivative which is valid for all nominal (post-NC2) use of the range-rate filter. RTRIDOT is actually an approximation of all of the higher-order derivatives, and, if R27 is to be used prior to NC2, RTRIDOT must be correspondingly changed, either by uplink or by the crew. The crew procedure is as follows:

To load RTRIDOT (double precision), key:

VERB 24 NOUN 1 ENTR  
2334 ENTR, then—

Nominal: ( $2.4 \times 10^{-4}$  ft/sec<sup>3</sup>, pad-loaded)  
05017 ENTR  
17677 ENTR

Pre-NC2: ( $1.0 \times 10^{-3}$  ft/sec<sup>3</sup>)  
24753 ENTR  
07361 ENTR

This value of RTRIDOT for pre-NC2 is the minimum for which the filter's range-rate error will not diverge. On the other hand, it is the maximum value for which RMS errors in the estimated current range state will be less than  $\pm 0.1$  n.mi. and  $\pm 1.0$  fps, respectively. The RMS errors of the optimized range state are the same as in the nominal case.

4.2.5.2.2 VHF Range Modulus.—Because of the scaling limit of the VHF-read counter, P25 can receive range measurements that are modulo 327.68 nautical miles. This would be the case if the true range were greater than this value and if R08,

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\* See paragraph 4.2.5.2.2.

the VHF Range Read Routine, could not test for range modulus by comparing its measurement with the computed state-vector range of the Tracking Attitude Routine, R61. P25, therefore, makes its own test for range modulus. By this means, the R27 range-rate estimate is maintained correctly, but, under the above conditions in R08, the range estimate remains modulo 327.68 n.mi. In P25, the crew adds multiples of this value to the displayed range according to its knowledge of the true range.

A range modulus can occur within an optimization interval without affecting the results. In either R27 mode, the correct range value is always displayed with the first R27 mark for which the measured range is less than 327.68 n.mi.

#### 4.2.5.3 Restarts

All displays in P25 are restart-protected. R27 restart protection is presented in paragraph 4.2.1.3.5.



SECTION 5.0

PRETHRUSTING

## 5.0 PRETHRUSTING

This section describes selected design considerations and functional and procedural techniques necessary to give the reader an understanding of the SKYLARK GNCS onboard targeting programs. The programs function as prethrusting routines that determine the input target parameters and set the control modes needed by the thrusting programs to execute maneuvers.

To put onboard targeting in context, the overall targeting functions of the SKYLARK Mission have been briefly described and divided into two main categories, ground targeting (subsection 5.1) and onboard targeting (subsection 5.2). The ground targeting subsection essentially deals with those maneuvers for which a ground targeted solution is used, and describes the onboard program (P30) that transforms ground-computed data for onboard computer use. The onboard targeting subsection describes the rendezvous targeting programs.

A summary of the rationale used to apportion functions is that the ground targets all the maneuvers within its capabilities. (See the categories described below.) For rendezvous, when the onboard system has a more accurate relative state through onboard navigation, the onboard solution is prime, and the ground performs a systems-monitoring function to appraise onboard-system performance; when the ground has more accurate state-vector data, its targeting solution is prime.

The ground and onboard targeting capabilities include the maneuvers described below.

1. Ground Targeting—includes all non-rendezvous-orbit-shaping maneuvers and all maneuvers necessary to effect rendezvous with the orbital workshop (OWS), except the midcourse corrections in the terminal phase.
2. Onboard Targeting—includes the rendezvous-maneuver sequence using programs P31-P36 and P38, and comprises the following:\*

Corrective maneuver no. 1 (P31)	NC1
Corrective maneuver no. 2 (P32)	NC2
Corrective combination maneuver (P33)	NCC
Coelliptic maneuver (slow rate) (P34)	NSR

---

\* The braking phase of rendezvous (TPF) is accomplished by a series of manual braking maneuvers that do not require targeting.



Terminal-phase initiation maneuver (P35)	TPI
Terminal-phase midcourse maneuver (P36)	TPM
Plane-change maneuver (P38)	NPC

A basic difference between the targeting performed by the ground and by the onboard system is that the ground-targeting programs may need position and velocity estimates of one or both vehicles as basic input—depending upon the maneuver being targeted. The onboard targeting programs, however, always need estimates of both vehicles. The more current and accurate these state-vector estimates are, the more effective will be the maneuver targeted. Navigation normally precedes onboard targeting, therefore, to improve onboard estimates of position and velocity. By measuring the relative state parameters between the two vehicles, the CSM inertial state is updated so that the estimated relative state closely approximates the true relative state.

It is also evident from the description of the two categories that some overlap exists in the targeting capabilities of the ground and of the onboard computer in the area of rendezvous-maneuver targeting. Since the ground targets all maneuvers, determination of which targeting solution—ground or onboard—is to be nominally used for a given mission phase is based on (1) the type of maneuver being performed; (2) targeting solution accuracy.

#### 5.0.1 Orbit-shaping Maneuvers

To perform orbit-shaping maneuvers, it is necessary to have not only the required equations to target the maneuver, but also an accurate estimate of the inertial state of the vehicle that will perform the maneuver. Because of a NASA/MSFC decision, the onboard system does not include the capability to meet either of these requirements. That is, it has neither targeting equations for various orbit-shaping maneuvers, nor the capability to gather and process the necessary data to perform orbit navigation and, hence, to accurately determine the vehicle's inertial state.\*

The ground system, however, meets both of these requirements. The necessary targeting equations are in the ground computers, and the ground maintains accurate inertial state-vector estimates of the vehicle by processing radar data gathered by the MSFN network. Thus, orbit-shaping maneuvers are, by necessity, ground targeted.

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\*The onboard inertial state is most accurate at last ground-uplink time. That is, it is as accurate as the ground's estimate at uplink time, since errors exist in the ground's knowledge of the state vector [due to incomplete modeling (drag/venting) and imprecise constants].

### 5.0.2 Rendezvous Maneuvers

Accurate targeting of rendezvous maneuvers requires an accurate estimate of the relative state vector between the two rendezvousing vehicles. The ground-targeting programs use as their inputs the inertial state estimates of the two vehicles obtained from ground-based radars. The onboard targeting programs, however, use inertial state estimates derived by updating the inertial state vector of one vehicle relative to the other. The onboard navigation system calculates this estimate by processing optics and VHF ranging measurements of the relative state vector between the two vehicles. During this rendezvous navigation process, as the inertial state error of the updated vehicle approaches the inertial state error of the non-updated vehicle (which has increased since the last state-vector uplink) the relative state error between the two vehicles is being reduced.

For those phases of the rendezvous mission, therefore, where the onboard navigation system can improve the onboard estimates of the state vectors based on relative tracking (nominally at ranges of less than 300 n.mi.), the onboard maneuver solution will be more accurate than that obtained by the ground, using its inertial state estimates. Thus, the onboard solution is prime for maneuvers that occur in this region, as long as the onboard, ground, and chart solutions are within a certain tolerance.

If onboard rendezvous navigation cannot take place, or if it is performed where it does not improve the onboard state estimates (for example, optics-only tracking at ranges greater than 300 n.mi.), ground targeting solutions are considered prime for the maneuver.

### 5.0.3 Maneuver Pads

For SKYLAB, as noted, the ground performs targeting for all the maneuvers in a given mission—except for P36—whether or not the ground solution is prime. For those rendezvous maneuvers that are nominally performed using the onboard solution, however, the crew also uses the ground and the R27 backup chart solutions (see paragraph 4.2.1.3) for comparison. Should it be necessary (see subsection 5.1) the crew can overwrite the onboard-computed values with those of ground or the chart solutions. Values from any of the three sources are interpreted correctly by the thrusting programs.

Thus, at planned intervals throughout the mission—but always well before the expected maneuver—the ground voice-links its targeting data to the crew. Upon receipt, the crew records the voice-linked data in the designated spaces on appropriate

pads to use as an onboard check of all maneuvers. Figure 5.0.3-1 illustrates typical SKYLAB maneuver pads for the NC1, NC2, and NPC maneuvers. As shown in the figure, the maneuver pad provides for all the data necessary to effect the maneuver. For example, the NC1 pad contains the Noun-95 display of time of ignition in hours, minutes, and seconds, and the Noun-81 display of the three components of the required velocity change, in local-vertical coordinates. (Both these calculations are also made by the NC1 onboard targeting program, P31.) In addition, the pad contains the spacecraft attitude at time of ignition in the Noun-22 display of the new ICDU angles for roll, pitch, and yaw. The crew can check these values against the Noun-18 values displayed in the thrusting program to determine the correctness of pre-ignition attitude. The pad also contains the magnitude of the velocity change ( $\Delta V_C$  to be used as backup for the EMS) and the duration of the burn (BT, to be used as backup for the crew watches or DET monitoring).

## 5.1 GROUND TARGETING

Basically, then, ground solutions are used for (1) those maneuvers that the CMC has no capability to target, (2) those maneuvers for which the onboard solution may not be as good as the ground solution, and (3) comparison with the onboard solution.

### Maneuvers For Which CMC Has No Capability

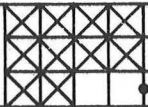
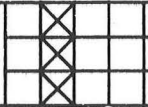
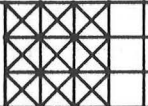

The non-rendezvous-orbit-shaping maneuvers are principally of two types: out-of-plane maneuvers to change orbit inclination, and in-plane maneuvers to change eccentricity, apogee altitude, perigee altitude, and the period of the orbit. For example, the deorbit maneuver—required to remove the CSM from parking orbit in preparation for entry—is essentially a maneuver to change perigee altitude with the added constraint of ensuring the proper entry angle.

The ground targets these orbit-shaping maneuvers; the onboard program P30 is then used to transform the ground-computed data into parameters that can be used by the onboard thrusting programs. These data are nominally uplinked into P30 registers via P27.

### Maneuvers For Which Ground Solution Is Prime

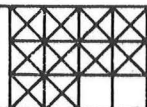
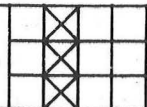
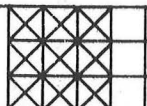

Although the CMC has the capability to target all other maneuvers in the mission, ground solutions are preferred for the rendezvous plane-change maneuver (NPC) and for corrective maneuvers 1 and 2 (NC1 and NC2), for the reasons given in Section 5.0.

NC1

N95 Tig	HRS					
	MIN					
	SEC					
N81	V <sub>X</sub>					
	V <sub>Y</sub>					
	V <sub>Z</sub>					
N22	R <sub>o</sub>					
	P <sub>i</sub>					
	Y <sub>m</sub>					
	$\Delta V_C$					
	BT					

COMMENTS: PLANE CHANGE Tig AND V<sub>GY</sub>  
GDC ALIGNS R P Y  
GET 300 NM

NC2

N28 Tig	HRS					
	MIN					
	SEC					
N81	V <sub>X</sub>					
	V <sub>Y</sub>					
	V <sub>Z</sub>					
N22	R <sub>o</sub>					
	P <sub>i</sub>					
	Y <sub>m</sub>					
	$\Delta V_C$					
	BT					

PLANE CHANGE

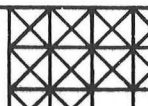
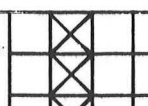
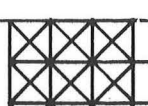

N33 Tig	HRS					
	MIN					
	SEC					
N81	V <sub>X</sub>					
	V <sub>Y</sub>					
	V <sub>Z</sub>					
N22	R <sub>o</sub>					
	P <sub>i</sub>					
	Y <sub>m</sub>					
	$\Delta V_C$					
	BT					

Figure 5.0.3-1. Typical Rendezvous Maneuver Pads

For these maneuvers, two methods are available for loading ground-computed targeting data into the CMC. The method used depends upon mission planning.

1. Nominally, during rendezvous, the appropriate onboard targeting program is called and allowed to compute a final targeting solution (see subsection 5.2); the crew then compares this solution with the ground solution on the maneuver pad and with the backup chart solutions. If the onboard solution is not within a planned tolerance, the crew overwrites the onboard solution with that of ground.
2. Otherwise, using P27, ground uplinks the solution directly into P30 registers. The crew then calls P30 to prepare for thrusting. (The crew can also load P30 registers directly from the maneuver pad if necessary.)

#### 5.1.1 P30, External $\Delta v$ Program

P30 is the onboard prethrusting program that sets up ground-computed targeting parameters in the CMC in preparation for P40 or P41 thrusting. In so doing, the program performs two important internal functions not immediately visible to the crew.

1. Ensures a constant thrust attitude during execution of the ground-targeted maneuver by setting the External  $\Delta v$  flag.
2. Calculates the matrix to transform the ground-targeted velocity change, expressed in local-vertical coordinates, into basic reference coordinates for use by P40 or P41.

##### 5.1.1.1 Program Summary

P30 accepts a ground-targeted maneuver time of ignition (Noun 33) and velocity change (Noun 81)—nominally via P27 uplink—and computes the burn-related parameters of apogee altitude, perigee altitude, and the impulsive velocity change magnitude at  $t_{IG}$  for display in Noun 42. In addition, like all the prethrusting programs, P30 displays Noun 45 containing the number of VHF and optics marks taken, the time from ignition, and the approximate value of the middle gimbal angle after the maneuver to the thrusting attitude. The display of VHF and optics marks is meaningful, however, only if P30 is used during the rendezvous sequence. The display of the middle gimbal angle value informs the crew if an IMU realignment will be needed before thrusting.

If P27 uplink capability is not present (for example, if a ground telemetry site is not transmitting, or if the S-band Antenna is not working), the crew can use the time of ignition and velocity change values on the maneuver pad for input to P30. (See paragraph 5.0.3.)

#### 5.1.1.2 Program Use

P30 is used in the SKYLAB Mission for all non-rendezvous-orbit-shaping maneuvers and can be used for rendezvous maneuvers for which the ground solution is prime.

As discussed in the introduction to ground targeting, orbit-shaping maneuvers can be either out-of-plane maneuvers to change the inclination of the orbit, or in-plane maneuvers to change the eccentricity, apogee altitude, perigee altitude, or period of the orbit. Orbit-shaping maneuvers can be performed while the CSM is alone or while it is docked with the workshop.

Although maneuvers to change orbital inclination will not nominally be needed during the SKYLAB Mission they can be performed if necessary. In the docked state, only x-translation maneuvers with the RCS jets can be used to change apogee or perigee altitude, to circularize the orbit, or to change orbital inclination. The docked maneuvers actually planned are those using the +x RCS jets for EREP shaping to maintain the nominal ground track.

When docked x-translation maneuvers are necessary, they can be performed (1) by the crew's using the translational hand controller (THC) monitored by P47 (refer to the SKYLARK Digital Autopilot Users' Guide), or (2) by calling P30 and then P41.

5.1.1.2.1 Docked P30-P41 x-translation Maneuvers—If the P30-P41 sequence is used to perform docked x-translation maneuvers, a special consideration arises involving the computation of the burn central angle of transfer  $\theta$  in P41.

Figure 5.1.1-1 diagrams the events occurring during the P30-P41 sequence and indicates the initial calculations P41 performs and the sources of mass (Noun 46),  $t_{IG}$  (Noun 33), and velocity-change vector (Noun 81) used by P41.

The computation of  $\theta$  is a function of the thrust, mass of the vehicle, and the in-plane velocity to be gained. The CMC cannot store the value of the OWS mass in erasable memory. For its calculations, the CMC uses either the CSM mass or the CSM plus LM mass depending on the configuration information entered in R03. (See Figure 5.1.1-1.) Because the CMC uses a value for mass that is much smaller than the actual CSM-OWS mass, the central angle computed in P41 is smaller than the true angle to be traveled by the docked vehicle. While performing the External  $\Delta v$  computations specified by P30 (refer to subsection 6.1), P41 then rotates the velocity-to-be-gained vector

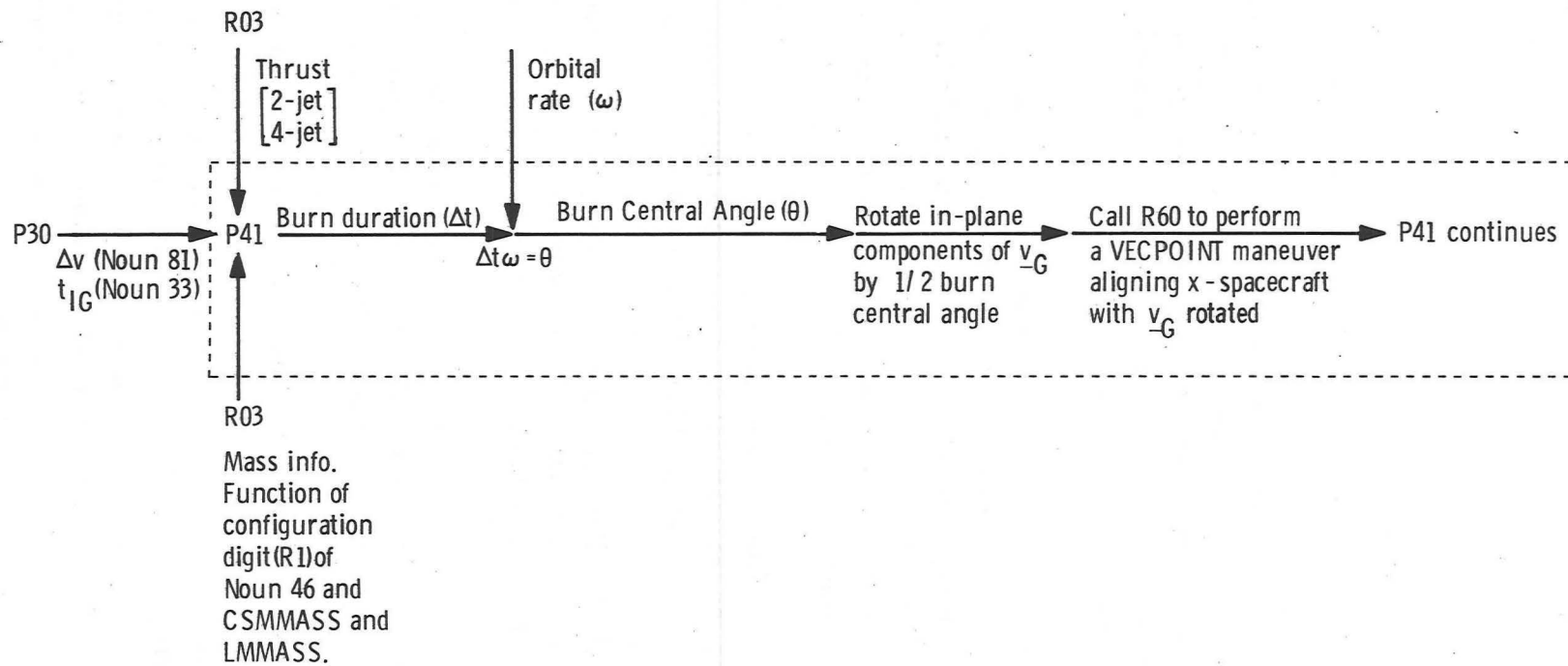
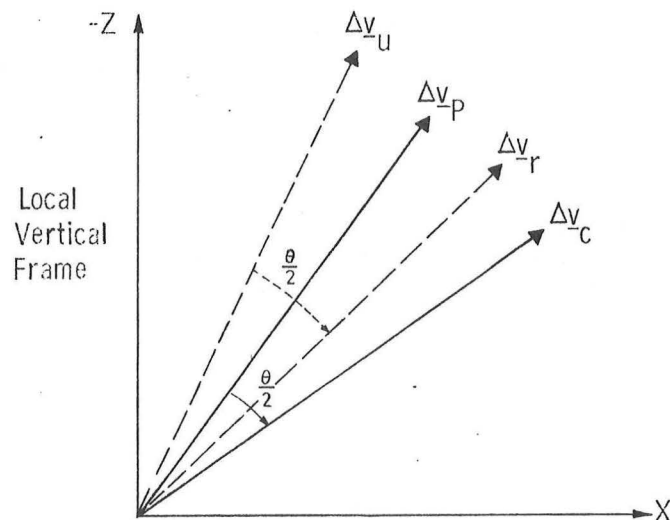


Figure 5.1.1-1. P41 Simplified Diagram: Source of Inputs and Central Angle Calculations

by one half the computed burn central angle. Since the  $\theta$  value entered into this computation is small compared to the actual angle to be traveled, the final onboard computations would yield erroneous values for the components of the velocity-to-be-gained vector.

For this reason, ground also performs the onboard calculations, using the same algorithms as the onboard computer. Since the ground computers contain actual CSM-OWS mass, however, the ground calculations are correct. The ground then compensates for the erroneous P41 rotation by uplinking a biased velocity-change vector into Noun 81 of P30. The continuous lines in Figure 5.1.1-2 show the desired External  $\Delta v$  maneuver central-angle compensation ( $\Delta v_c$ ) occurring with the biased input  $\Delta v_p$ ; the dotted lines show the erroneous compensation ( $\Delta v_r$ ) that would result from CMC calculations using a wrong value for mass if the input velocity-change vector (Noun 81) were not biased ( $\Delta v_u$ ) by ground.



- where  $\Delta v_p$  - biased input inplane-velocity components of  $\Delta v$  (LV) (Noun 81) in reference coordinates.
- $\Delta v_c$  - desired compensated inplane velocity-to-be-gained vector.
- $\Delta v_u$  - unbiased input inplane-velocity components of  $\Delta v$  (LV) (Noun 81) in reference coordinates.
- $\Delta v_r$  - resultant (incorrect) compensated inplane velocity-to-be-gained vector.

Figure 5.1.1-2. Inplane External  $\Delta v$  Maneuver Central Angle Compensation



### 5.1.1.3 P30 Crew Procedures

Although it is unlikely that P30 will be used in conjunction with P20, the procedures for such use are as follows:

- . Key VERB 37 ENTR 20 ENTR
- . Choose desired P20 option (as described in paragraph 4.2.1)
- . Go through P20 displays
- . Proceed to step 1.

NOTE.—If P30 is used during the rendezvous sequence, (option 0 or 4), VHF and optics marks can be taken during the first two flashing displays of P30 (Noun 33 and Noun 81).

#### 1. Key VERB 37 ENTR 30 ENTR

Upon initiation, P30 sets the TRACKFLG and UPDATFLG allowing P20 tracking and state-vector updating by marks. Observe flashing display of stored time of ignition ( $t_{IG}$ ).

NOTE.— $t_{IG}$  and  $\Delta v(LV)$  may have been uplinked during previous execution of P27. If so, registers contain uplinked values. If values have not been uplinked, crew can use the  $t_{IG}$  and  $\Delta v(LV)$  values on the maneuver pad for input to Nouns 33 and 81.

#### 1a. FL V06 N33

R1	+ooxxx.	hr(GET)
R2	+oo0xx.	min
R3	+0xx.xx	sec

VERB 25 ENTR—If not satisfied with displayed value, key VERB 25 ENTR and load new value.

PRO—When satisfied with  $t_{IG}$ , record, key PRO, and observe flashing display of the stored components of the velocity-change vector  $\Delta v(LV)$  at  $t_{IG}$ .

1b. FL V06 N81

R1	xxxx.x	$\Delta v_x$	fps
R2	xxxx.x	$\Delta v_y$	fps
R3	xxxx.x	$\Delta v_z$	fps

where  $\Delta v_x$  is the x-component, in local-vertical coordinates, of the impulsive change in velocity at  $t_{IG}$ ;  $\Delta v_y$  is the y-component; and  $\Delta v_z$  is the z-component.

NOTE.—P30 converts the Noun 81 local-vertical coordinates to reference coordinates for use by P40 or P41. These thrusting programs receive the reference coordinates, convert them back to local vertical, rotate the in-plane components (x and z), and write the rotated values into R1 and R3 of the Noun-81 registers. The x and z components of Noun 81 are, therefore, changed by the thrusting programs and must be re-initialized either by uplink or by DSKY entry if P30 is called again to re-establish parameters after a thrusting program has been entered.

VERB 25 ENTR—To change components key VERB 25 ENTR, and load desired values.

PRO—When satisfied with displayed Noun 81 values, key PRO. Observe flashing display of CMC-calculated post-thrust orbital parameters and burn magnitude.

NOTE.—Upon receipt of a PRO response to FL V06 N81, P30 sets XDELVFLG requiring the CMC thrusting program to perform the velocity-to-be-gained computations in the External  $\Delta v$  mode (see SKYLARK GSOP, Section 5, subsection 5.3), and resets UPDATFLG prohibiting further state-vector updating from marks.

1c. FL V06 N42

R1	xxxx.x	Ha n.mi.
R2	xxxx.x	Hp n.mi.
R3	xxxx.x	$\Delta v$ fps

where Ha is the post-thrust apogee altitude above the launch-pad radius; Hp is the post-thrust perigee altitude above launch-pad radius; and  $\Delta v$  is the magnitude of the required impulsive change in the velocity vector at  $t_{IG}$ .

NOTE.—The display of Ha and Hp is limited to 9999.9 n.mi. (If values for either are greater, display is set equal to 9999.9.) In addition, because P30 assumes an impulsive  $\Delta v$  at  $t_{IG}$  when calculating post-thrust Ha and Hp, the validity of R1 and R2 displays decreases as burn time increases. For long burns (approximately 50 sec and over), therefore, R1 and R2 will be inaccurate.

Coordinate NOUN 42 Parameters With MSFN. If a ground station is not available to confirm Noun 42 values, either use available criteria to judge reasonableness of Noun 42 values and then perform one of the choices below, or wait until a ground station is available to confirm Noun 42 contents. Upon ground confirmation, PRO.

Reselect P30/Select P27, the P30/PRO.

Reselect P30.—If Noun 42 parameters are not satisfactory, reselect P30 via VERB 37 ENTR 30 ENTR; obtain (via voice link) and load new aim parameters in Nouns 33 and 81. When CMC-calculated-post-thrust parameters satisfactory, key PRO to FL V06 N42 and observe FL V16 N45 below.

Select P27.—If Noun 42 parameters are not satisfactory, and desire to directly uplink new aim parameters into P30 registers, select P27 as follows:

- . Key VERB 37 ENTR 00 ENTR. When 00 appears in mode lights,
- . Key VERB 71 ENTR.\* Follow P27 procedures for CMC External Delta V Update (Noun 33 and Noun 81). When P27 transfers data to desired addresses, program returns to P00,
- . Key VERB 37 ENTR 30 ENTR. Continue at step 1.

PRO—If parameters are reasonable, key PRO and observe flashing display of (1) the number of marks processed by R22, (2) TFI, time from  $t_{IG}$ , and (3) MGA, middle gimbal angle at  $t_{IG}$ .

---

\*The crew does not normally call P27, although this capability exists. The ground usually performs this function.

1d. FL V16 N45

R1	xxBxx	VHF, Optics marks
R2	xxBxx	min, sec TFI
R3	xxx,xx	deg

where R1 contains the number of VHF ranging marks in the two most significant digits and optics marks in two least significant digits.

NOTE.—R1 of FL V16 N45 is meaningful only if P30 is used during the rendezvous sequence.

NOTE.—Optics mark counter does not distinguish between SXT (primary) and COAS (backup) marks.

R2 contains time from  $t_{IG}$ . Maximum reading is  $\pm 59B59$ . If TFI is greater than  $\pm 59$  min, 59 sec, display reads  $\pm 59B59$ . Minus sign indicates present time is before  $t_{IG}$  (i.e., the display counts down).

NOTE.—To obtain a full display of TFI in hr, min, and sec, key NOUN 35 ENTR.

R3 contains approximate MGA at  $t_{IG}$  if IMU is on and orientation is known and vehicle is aligned such that the CSM +x-axis is along the thrust direction at  $t_{IG}$ . If IMU not on or orientation not known, R2 contains -00002.

PRO—Upon receipt of PRO response, P30 exits to R00. Observe request for new program.

FL V37

Key xx ENTR where xx is desired program.

NOTE.—If R3 indicates inappropriate MGA for the burn, use P52 to realign IMU. Otherwise, choose P40 or P41 in accordance with mission planning.

## 5.2 ONBOARD TARGETING

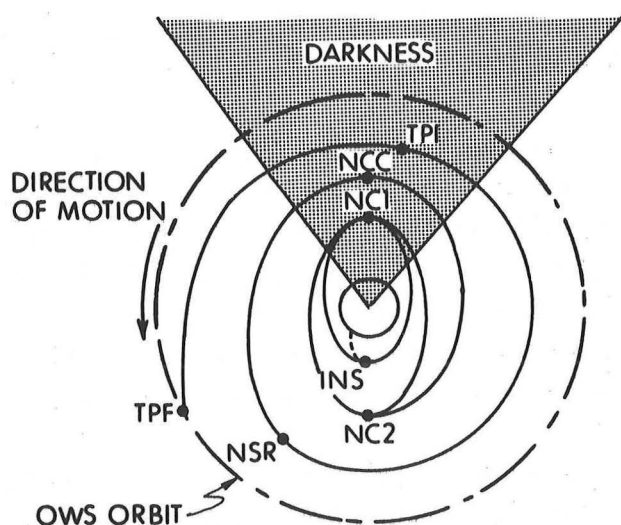
The rendezvous of the CSM with the target vehicle, the OWS, is accomplished by a series of CSM maneuvers resulting in a trajectory that intercepts the OWS orbit at a time that results in the rendezvous of the two vehicles. The function of the targeting programs, within the rendezvous scheme, is to determine the targeting parameters to be used by the thrusting programs for each maneuver the CSM makes during the rendezvous sequence. Because vehicle state vectors are continually updated—either by onboard navigation or by ground uplink—each targeting program is called before its corresponding maneuver to take advantage of the updates in computing the maneuver.

### 5.2.1 Rendezvous-maneuver Sequence

The sequence of maneuvers leading to the rendezvous and docking of the CSM with the OWS is listed and briefly explained below, and illustrated in Figure 5.2.1-1, which shows the orbital geometry of rendezvous. The text following the figure then presents the geometric considerations involved in the design of the rendezvous sequence. The figure should be referenced while reading the maneuver-sequence material in order to gain a clearer understanding of the rendezvous scheme.

- . Phasing maneuver (NC1) performed at apogee.
- . Plane-change maneuver (NPC).
- . Second phasing maneuver (NC2) performed on the opposite end of the orbit from the first phasing maneuver (i.e., NC2 occurs odd multiples of half revolutions from NC1, for example,  $3/2$ ,  $5/2$ ).
- . Corrective combination maneuver (NCC) performed one-half revolution after the second phasing maneuver.
- . Coelliptic maneuver (NSR) performed nominally 37 minutes after the corrective combination maneuver.
- . Terminal phase maneuvers (TPI/TPM/TPF).

This rendezvous sequence is designed to allow accurate onboard targeting of a maximum number of maneuvers. Accurate onboard targeting solutions are particularly important for NCC, NSR, and the terminal-phase maneuvers because of their function within the sequence. Using onboard rendezvous navigation allows these post-NC2 maneuvers to be computed more accurately than using CSM states based on MSFN tracking. Possible trajectory dispersions introduced by maneuvers performed before NCC can be corrected by accurate ground or onboard targeting of NCC.



INS	INSERTION
NC1	PHASING 1
NPC	PLANE CHANGE, IF NECESSARY
NC2	PHASING 2
NCC	CORRECTIVE COMBINATION
NSR	COELLIPTIC
TPI	TERMINAL PHASE INITIATION
TPF	TERMINAL PHASE FINALIZATION

Figure 5.2.1-1. Rendezvous-maneuver Sequence and Orbital Geometry.

To provide adequate rendezvous navigation for onboard computation of post-NC2 maneuvers, therefore, before NCC, the range approximately thirty minutes before NCC-maneuver execution is designed to be 300 n.mi. or less. (For some SKYLAB rendezvous sequences, depending upon phasing at CSM launch, the 300-n.mi. range may be reached much earlier than NCC minus 30 min.)

The purpose of the first phasing maneuver (NC1) within this scheme is to ensure that the range between the OWS and CSM 30 min before NCC is 300 n.mi. or less. The maneuver, which is horizontal, occurs at an apogee of the CSM insertion orbit—at least one and one-half revolutions after insertion to allow for sufficient MSFN tracking to provide updated state vectors for a good maneuver solution. The CSM to OWS range at maneuver calculation time is usually too large to allow onboard rendezvous navigation, and, therefore, the ground solution is prime.

The plane-change maneuver (NPC) is performed between the first and second phasing maneuvers when the CSM is at the intersection of the CSM and OWS planes, that is, at a node. Again, the ground solution is prime. If the velocity change required to align the CSM orbit with that of the OWS is small enough to be handled at the NCC and NSR maneuver points, however, the plane-change maneuver is not performed.

The second phasing maneuver, NC2, is also horizontal and is essentially a height-adjustment maneuver. As shown in the figure, NC2 occurs at the opposite end of the apsidal line from the first phasing maneuver. The ground solution continues to be prime through NC2 since the CSM-to-OWS tracking distance may still exceed 300 n.mi.

The corrective combination maneuver, NCC, provides final phasing as well as height and out-of-plane corrections. For approximately 30 min before execution of NCC, the CSM-to-OWS range is within the 300-n.mi. limit considered acceptable for updating the onboard state vector. Optical (SXT) tracking is performed, therefore, permitting use of onboard targeting solutions from NCC through the terminal phase. In addition, onboard display of raw VHF range data is also available for input to crew backup targeting charts.

The coelliptic maneuver, NSR, puts the CSM in an orbit nominally 10 n.mi. below the OWS orbit and coelliptic to it. When the elevation angle along the line of sight to the OWS from the CSM local horizontal is approximately 27 deg, the TPI maneuver is performed. The TPI velocity change is, therefore, essentially along the CSM-OWS line of sight. The use of coelliptic orbits from NSR to TPI with an elevation angle of approximately 27 deg allows accurate crew determination of the TPI maneuver

using the backup targeting charts. A good TPI maneuver can, therefore, be executed, even if the primary system fails, by thrusting in the direction of the LOS between the CSM and the OWS.

The TPI time and the maneuver points (i.e., the apsidal crossings where NC1, NC2, and NCC occur, and the time of NSR from NCC) are determined before CSM launch, and based on MSFN tracking of the OWS and the phasing between the OWS and CSM at CSM launch. The TPI time is chosen to occur near the midpoint of darkness, several revolutions after the CSM launch, such that when the rendezvous-maneuver sequence is computed (i.e., when NC1, NC2, and NCC are performed at specified apsidal crossings, and NSR is performed at a specified time from NCC), the velocity increment at each maneuver through TPI is large enough to be accomplished using the SPS engine, to conserve RCS fuel, yet small enough so that the total maneuver velocity requirement for the rendezvous sequence is within the CSM fuel budget for rendezvous.

The desired TPI time, the elevation angle, the maneuver points, and the desired altitude differences between the OWS and CSM orbits at NCC and NSR are loaded into the onboard computer so that the onboard system can then compute the maneuver solutions using the targeting program, and based on state vectors obtained from the onboard rendezvous navigation program. Trajectory dispersions during maneuvers in the beginning of the sequence can be corrected by subsequent maneuvers so that the TPI maneuver occurs near the desired TPI time and with the proper phasing conditions. When the CSM is approximately one n.mi. from the OWS, TPF begins and rendezvous is accomplished by a series of braking maneuvers manually executed. Final intercept of the OWS by the CSM is designed to occur in daylight allowing enough time for manual docking using the THC and the onboard powered-flight navigation routine.

#### 5.2.1.1 OWS Rendezvous Attitude

The SKYLAB 1 Saturn workshop (OWS) will be launched into a circular orbit of approximately 235 n.mi. altitude and oriented to a solar inertial attitude. The solar inertial attitude will be the basic orbital attitude for operational and storage modes during, and between, all missions.

For earth-pointing experiments and rendezvous, however, the Z-local vertical attitude (Z-LV) will be used for the workshop. This attitude, defined as the minus-z axis of the workshop pointed toward the earth along the local vertical, is illustrated in Figure 5.2.1-2.



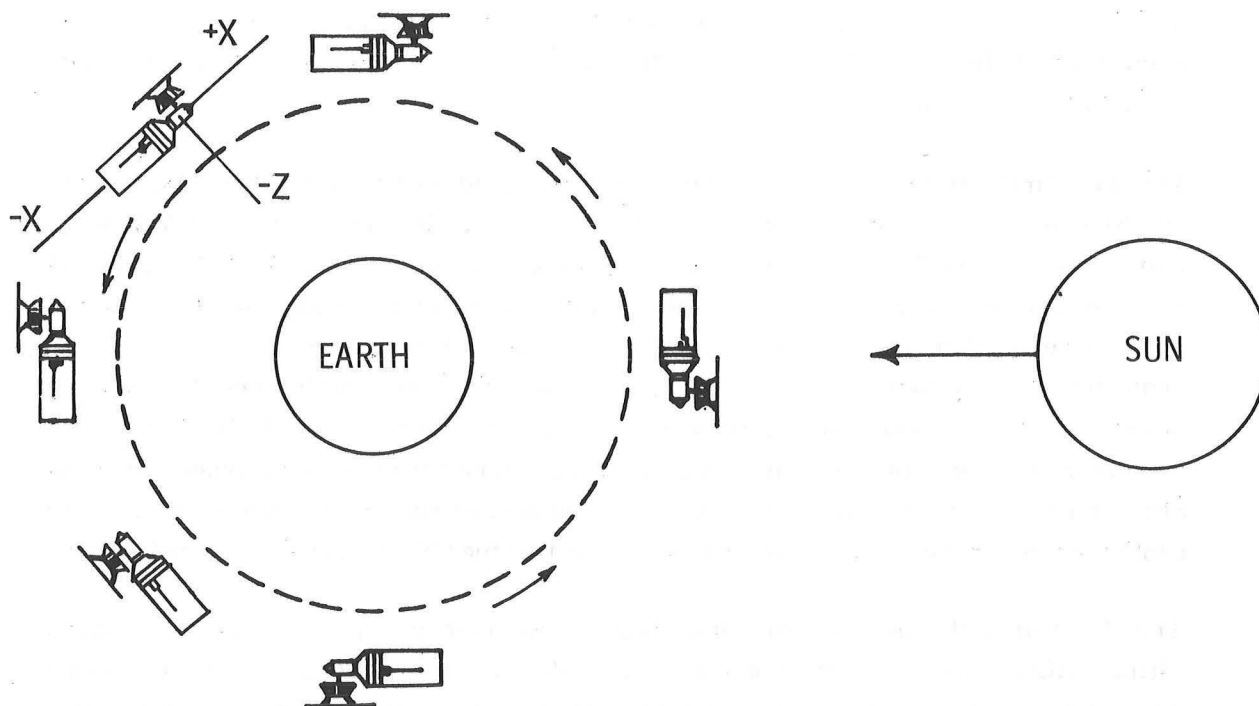


Figure 5.2.1-2. OWS Z-LV Rendezvous Attitude

Consequently, at a predetermined time, the ground sends the OWS an update consisting of maneuver times to, and from, Z-LV and pointing offset. This ensures a good Z-LV attitude for SXT and VHF tracking because the lights and the VHF transponder on the OWS, which are tracked by the CSM, are highly directional. The APOLLO telescope mount digital computer (ATMDC) aboard the OWS, using the nested CMG-TACS, then commands the maneuvers to and from Z-LV at the uplinked maneuver times.

### 5.2.2 Onboard Computation Techniques

This paragraph presents brief explanations of some of the mathematical approximation techniques used in the onboard computer as they apply to onboard targeting calculations and describes their functional use within the rendezvous-targeting programs.

The conic- and precision-integration, phase-match, and iteration techniques are described first and then discussed in paragraph 5.2.2.1. This discussion is followed by a description of External- $\Delta v$  and Lambert guidance, in turn followed by a

discussion of the application of these guidance modes in targeting and executing rendezvous maneuvers.

### Conic and Precision Integration

Two methods are available in the CMC for performing state-vector updates, conic integration and precision integration. Conic integration does not take orbital perturbations into account and is, therefore, much faster. Precision integration—as used in the CMC—does account for earth oblateness effects on the vehicle orbit and is significantly more accurate than conic.

### Phase-Match

Phase match involves precision integration of the CSM to  $t_{IG}$  followed by precision integration (and iteration) to place the OWS radially above the CSM at  $t_{IG}$ . The phase-match technique allows the onboard-targeting programs to utilize the faster conic method of updating the CSM and OWS state vectors, in solving for the rendezvous maneuvers, without losing significant accuracy. This is possible because, during the actual mission, the relative motion of the two vehicles is not appreciably affected by earth-gravity perturbations since (1) the rendezvous trajectories are approximately coplanar, and (2) the vehicles, therefore, traverse approximately the same sectors of the earth's surface, and are thus exposed to similar gravitational forces. Phase-match of the OWS and CSM orbits creates a trajectory configuration in which both vehicles effectively traverse the same sector of the earth's surface conically during the targeting calculations.

### Iteration

The iterative loops used in the NC1 and NC2 targeting programs compute the maneuver velocity change by continually modifying initial estimates of velocity changes for NC1 and NC2 until the desired terminal conditions (i.e., TPI phasing conditions; see Figure 5.2.3-2) and other intermediate maneuver constraints are satisfied. Two iterative loops are used. An outer loop that satisfies phasing-maneuver constraints and an inner loop that satisfies height-maneuver constraints. Partial derivatives relating a change in TPI phasing conditions to a change in the magnitude of NC1 or NC2 are used to modify the initial estimate of maneuver velocity change until desired TPI conditions—and intermediate constraints—are modified to within a tolerable error. The NCC targeting program uses an iterative loop to obtain the desired velocity change such that the NSR aimpoint is achieved taking into account earth oblateness effects.

#### 5.2.2.1 Targeting-program Application of Conic, Precision, Phase-match, and Iteration Techniques

The NC1 and NC2 programs use conic integration to update the CSM and OWS position vectors between maneuver points as they cycle through the rendezvous-maneuver sequence in an iterative search for NC1 and NC2 maneuver solutions. No perturbation effects are, therefore, taken into account in making these updates. To take advantage of the faster conic updates without losing significant accuracy, the CSM and OWS state vectors are phase-matched immediately upon program entry. Phase-match results in the CSM and OWS traversing approximately the same central angle during the NC1 through TPI portion of the rendezvous sequence, and, therefore, undergoing a relative motion in the targeting program similar to that which they will undergo in true earth gravitational conditions.

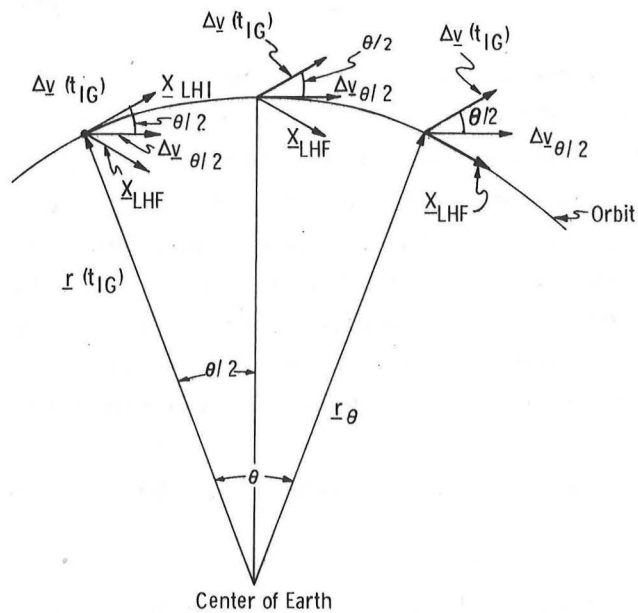
After the two state vectors are phase-matched, the NC1 and NC2 programs begin an iterative search for NC1 and NC2 maneuver solutions that satisfy both the desired TPI phasing conditions and the constraints placed on the individual maneuvers.

The post-NC2 maneuvers do not use the phase-match technique since they use precision-integration updates, where required, to advance the CSM and OWS state vectors.

#### External- $\Delta v$ Guidance Mode

In the External- $\Delta v$  guidance mode, the direction of the maneuver is determined by taking the impulsive velocity-change solution from the targeting programs and rotating the in-plane components (x and z) through an angle equal to one-half the estimated central angle that the vehicle will travel during maneuver execution. This effectively nulls the undesired components of the velocity change, introduced because of the finite length of the maneuver, and, therefore, closely approximates the impulsive velocity-change solution computed by the targeting programs.

Figure 5.2.2-1 illustrates how External  $\Delta v$  guidance is accomplished. The impulsive velocity change required at ignition time, as computed by the targeting programs, is indicated as  $\Delta \underline{v}(t_{IG})$ . If the maneuver is performed holding the attitude fixed in the direction of  $\Delta \underline{v}(t_{IG})$ , a net positive radial velocity increment—which is undesired—is also obtained, because the maneuver direction is always above the instantaneous local-horizontal direction.



$\Delta v(t_{IG})$  = local horizontal  $\Delta v$  at  $t_{IG}$

$\Delta v_{\theta/2}$  =  $\Delta v$  at  $t_{IG}$  put in while vehicle travels through  $\theta$  deg during burn, to compensate for finite burn time, i.e., on the average resulting in zero  $\Delta v$  added in the radial direction.

$X_{LHI}$  = direction of local horizontal at beginning of maneuver.

$X_{LHF}$  = direction of local horizontal at end of maneuver.

Figure 5.2.2-1. External- $\Delta v$  Guidance

To achieve an effective net radial velocity component of zero, therefore, the impulsive velocity-change at  $t_{IG}$ ,  $\Delta v(t_{IG})$  is rotated by one-half the central angle  $\theta$  the active vehicle travels during the maneuver. Maneuver execution is then performed using this rotated vector. This resultant rotated velocity-change vector  $\Delta v(\theta/2)$  is below the instantaneous local-horizontal plane for the first half of the maneuver and above that plane for the remaining half of the maneuver. The radial component of velocity thus effectively remains zero at the end of the maneuver.

### Lambert Aimpoint-guidance Mode

The Lambert-aimpoint guidance mode controls the spacecraft trajectory to intercept a given target position (aimpoint) at a given time. The velocity change required to intercept the desired aimpoint vector is periodically recomputed during the maneuver. For SPS maneuvers of more than 6-sec duration steering commands resulting in slight changes in vehicle attitude may be generated. SPS burns of less than 6-sec duration are executed at a fixed attitude in the direction of the initial Lambert velocity-change solution. Lambert guidance allows a more effective maneuver to be performed in that the CSM misses the desired aimpoint vector by a smaller amount than if the vehicle attitude had remained fixed during the maneuver.

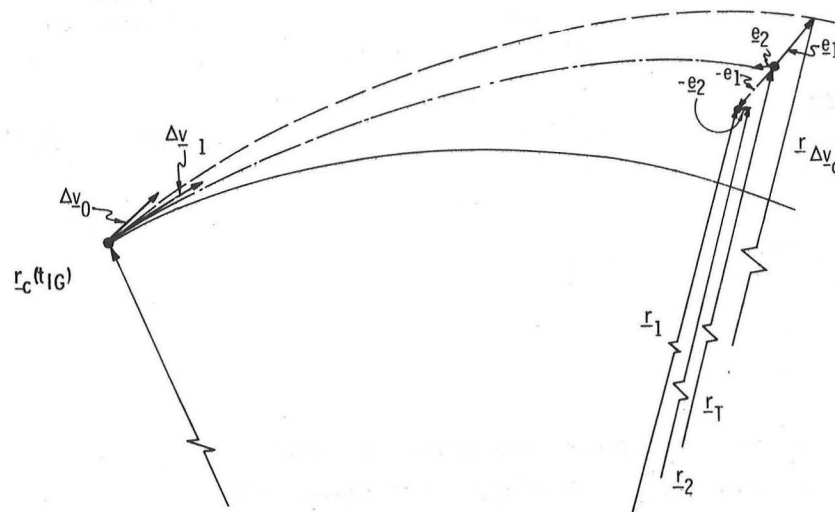
#### 5.2.2.2 Targeting-program Application of External- $\Delta v$ and Lambert-guidance Modes.

Four of the maneuvers in the rendezvous sequence—NC1, NC2, NPC, and NSR—effect their required velocity change by holding a fixed inertial attitude during maneuver execution; that is, they use External- $\Delta v$  guidance. The rest of the maneuvers—NCC, TPI, and the terminal-phase midcourse corrections—are executed by using Lambert aimpoint guidance.

The NCC, TPI, and terminal-phase midcourse corrections are computed by solving Lambert's problem from the maneuver ignition point to approximate "aimpoints" so that the desired position vector is intercepted. Since Lambert's problem conically solves for the velocity required to intercept a given target vector from an initial position vector in a specified time, a method for compensating for earth oblateness effects must be used. If the desired final position vector (aimpoint) has been determined by taking into account earth oblateness effects, the target-offset technique must be used in conjunction with solving Lambert's problem to obtain the required velocity to intercept that final position. Figure 5.2.2.-2 illustrates the technique. Lambert's problem is solved first to the true aimpoint  $\underline{r}_T$  yielding a conic required-velocity change  $\Delta \underline{v}_0$ . The CSM state with this velocity change is then precision integrated to a final position vector  $\underline{r}_{\Delta \underline{v}_0}$  that misses the true target. The negative of this miss  $-e_1$  defines an "offset aimpoint", which, in turn, is used in obtaining a new Lambert solution. This new velocity-change solution results in a CSM state vector at the intercept time that is closer to the desired intercept position vector. This iterative use of precision integration and solving Lambert's problem can be repeated until a sufficiently accurate solution has been obtained. This solution takes into account the effects of earth oblateness on the vehicle's trajectory.

Since precision integrations are time consuming, however, an alternative method can be used in certain cases. Although it is somewhat less accurate than the above method, it has the advantage of being much faster in computing the maneuver solution. This method involves determining the intercept position vector to be used in the solution of Lambert's problem by conic integration. This "conic" aimpoint is essentially equivalent to taking one target offset in the first procedure described above. The "conic" aimpoint is used in solving Lambert's problem to obtain the velocity change required.

The NCC maneuver is computed using the target-offset technique with two offsets, while the TPI and midcourse-correction maneuver computations nominally take advantage of the conic aimpoint technique in obtaining their solutions. The method to be used can be specified in the TPI and TPM programs.

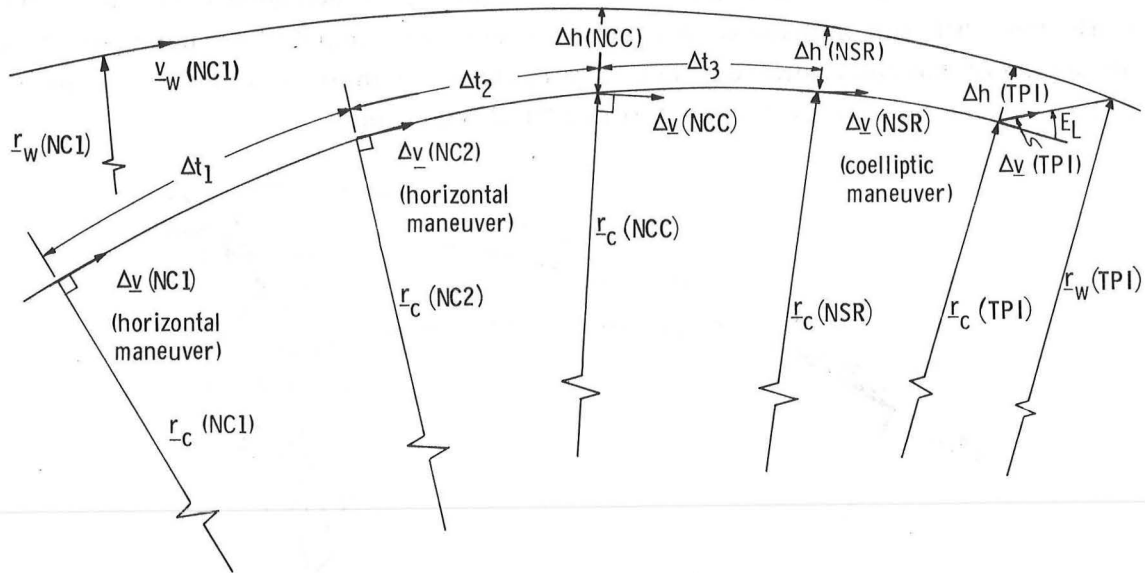


- $r_c$  — CSM and OWS position vectors at  $t_{IG}$
- $r_T$  — desired "true" position vector at intercept
- $\Delta v_0$  — delta v from 1st Lambert solution from  $r_c$  to  $r_T$
- $r_{\Delta v_0}$  — resultant intercept position from precision integration of  $r_c$ ,  $\Delta v_0$  to intercept time.
- $e_1$  — resultant miss vector of  $r_{\Delta v_0}$  from desired intercept position  
( $e_1 = r_{\Delta v_0} - r_T$ )
- $r_1$  — first offset-target vector =  $r_T - e_1$
- $\Delta v_1$  — delta v from 2nd Lambert solution from  $r_c$  to  $r_1$
- etc...  $e_2 = r_{\Delta v_1} - r_T$ ;  $r_2 = r_T - e_2$  ....

Figure 5.2.2-2. Lambert Aimpoint Guidance.

### 5.2.3 Rendezvous Targeting Program Functional Description

This paragraph briefly describes the rendezvous targeting programs giving the specific function of each within the overall rendezvous sequence, the inputs to the programs and their sources, and the program outputs. In addition, Figure 5.2.3-1 presents a schematic illustration of the overall trajectory and the part each program plays in effecting that trajectory.



$\Delta t_1$  = HALFREVX X Period of post - NC1 maneuver orbit

$\Delta t_2$  = Revs NC2/ NCC X Period of post - NC2 maneuver orbit

$\Delta t_3$  =  $\Delta t$  (NCC/ NSR)

$\underline{r}_c$  = CSM position vector

$\underline{r}_w$  = OVS position vector

$\underline{v}_w$  = OVS velocity vector

Figure 5.2.3-1. Rendezvous-maneuver Trajectory: NC1-TPI

The tables included in this paragraph list and describe individual program-required input and computed output. Some of these data are not under crew control but, rather, are internal to program operation. Other data, although not automatically displayed to the crew, can be called by the crew's keying the appropriate verb-noun on the DSKY.

#### 5.2.3.1 P31, NC1 Targeting Program

The NC1 program computes a maneuver magnitude and direction ( $\Delta \underline{v}$ ) for use by the appropriate thrusting program in executing NC1, the first phasing maneuver of the rendezvous sequence. The program uses a 4-maneuver sequence, from NC1 to TPI, in an iterative search for that value of the NC1  $\Delta \underline{v}$  that satisfies the phasing conditions imposed at the desired TPI time. These conditions, illustrated in Figure 5.2.3-2 (and shown in the overall trajectory in Figure 5.2.3-1), are basically positional and include a selected TPI time at which the LOS between the OWS and the CSM is to be a prescribed angle  $E_L$  measured from the horizontal plane at the CSM TPI position  $\underline{r}_C$ .

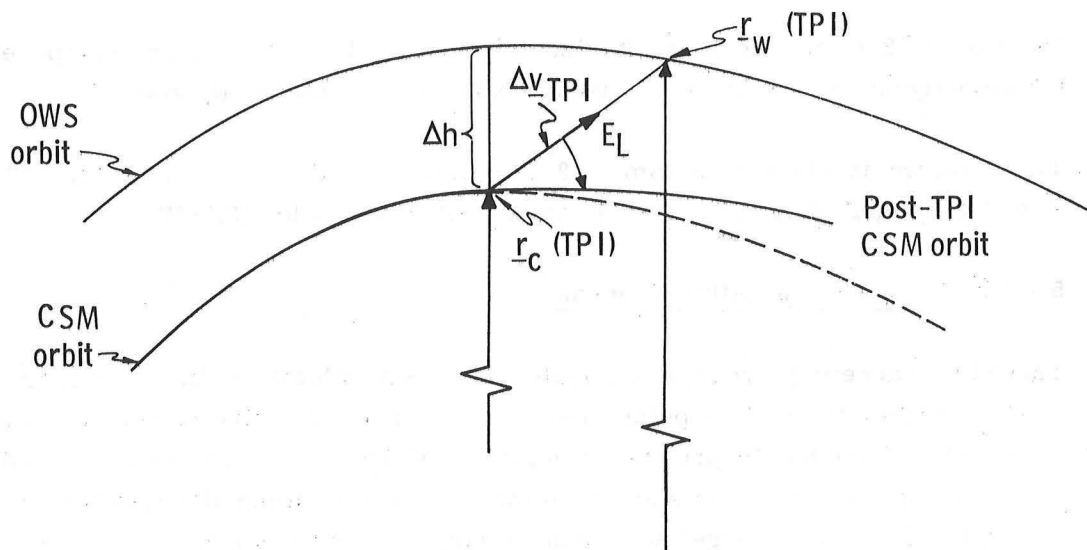


Figure 5.2.3-2. Desired TPI Phasing Conditions

Execution of the NC1 maneuver then essentially adjusts the CSM orbit such that when NC1 is followed by NC2, NCC, and NSR (with their desired maneuver constraints Figure 5.2.3-1), the TPI phasing conditions are reached at the desired TPI time.



Because the NC1 maneuver is defined (constrained) to be horizontal, the z-component (radial) of the NC1-computed-velocity-change vector (Noun 81) is nominally zero. The y-component (out-of-plane) is also nominally zero because (1) the maneuver is constrained to be parallel to the OWS orbital plane, and (2) the local-vertical coordinate system has been defined with respect to a unit normal that is perpendicular to the OWS orbital plane.

Table 5.2.3-I lists and describes the required inputs to program P31. Table 5.2.3-II describes the P31-computed output.

#### 5.2.3.2 P32, NC2 Targeting Program

The NC2 Targeting Program computes the velocity change (magnitude and direction) required at the NC2 maneuver time. These calculations satisfy the TPI phasing conditions (a selected TPI maneuver time and a LOS from the CSM to the OWS defined by a prescribed elevation angle and a  $\Delta h$ ) shown in Figure 5.2.3-2. Like NC1, the NC2 solution is reached iteratively by varying the NC2 velocity change such that when the maneuver is followed by NCC, NSR, and TPI, these selected TPI phasing conditions are met.

Because NC2 is defined to be horizontal—like NC1—the y- and z- components of the velocity-change vector (displayed in Noun 81) are nominally zero.

The required inputs to program P32 are listed and described in Table 5.2.3-III. The P32-computed output is listed and described in Table 5.2.3-IV.

#### 5.2.3.3 P33, NCC Targeting Program

The NCC Targeting Program computes the CSM velocity change required at the NCC maneuver time. Computation of NCC-required velocity change (displayed in Noun 81) is based upon previous completion of P32, which stores a desired NCC time. Program calculations are then made by determining the Lambert solution (using the two-offset target technique to compensate for earth-oblateness effects) required to intercept the desired NSR position (aimpoint) vector  $\underline{r}_C(\text{NSR})$  at the desired NSR time. The aimpoint vector used in the Lambert solution is determined as follows:

The CSM position vector  $\underline{r}_C(\text{TPI})$  at TPI is obtained using the desired TPI time and the desired phasing conditions at that time (Figure 5.2.3-2).

Table 5.2.3-I P31-Required Input

INPUT	MEANING	SOURCE	DSKY DISPLAY
$\underline{r}_C, \underline{v}_C$	CSM state vector	Stored in erasable memory. Updated by ground and by onboard computer.	—
$\underline{r}_W, \underline{v}_W$	OWS state vector	Stored in erasable memory. Normally updated from ground. Can be updated by onboard computer.	—
$\Delta t$ NCC/ NSR	Time between NCC and NSR.	Erasable-memory padload.	—
Revs NC2/ NCC	Revolutions between NC2 and NCC.	Erasable-memory padload.	
$t_{IG}^{(NC1)}$	NC1 ignition time	Erasable-memory pad. Also final NC1 pad.	V06 N95
$t_{IG}^{(TPI)}$	TPI ignition time	Erasable-memory padload. Also final NC1 pad.	V06 N37
HALFREVS	No. of half revolutions between NC1 and NC2.	Erasable-memory padload	V06 N57 (R1)
$\Delta h(NCC)$	Altitude between OWS and CSM orbits at $t_{IG}^{(NCC)}$ .	Erasable-memory padload.	V06 N57 (R2)
$\Delta h(NSR)$	Altitude between OWS and CSM orbits at $t_{IG}^{(NCC)}$ .	Erasable-memory padload.	V06 N57 (R3)
$E_L$	Elevation angle at $t_{IG}^{(TPI)}$ .	Erasable-memory padload.	Available to crew by keying V06 N55E.

Table 5.2.3-II P31-Computed Output

OUTPUT	MEANING	DSKY DISPLAY
$\Delta v(\text{NC2})$	Required impulsive velocity change at $t_{IG}(\text{NC2})$ .	V06 N84
$\Delta h(\text{NC2})$	Altitude between OWS and CSM orbits at $t_{IG}(\text{NC2})$ .	V06 N84
$\Delta v(\text{NCC})$	Required impulsive velocity change at $t_{IG}(\text{NCC})$ .	V06 N84
$\Delta \underline{v}(\text{NC1})$	Components of required velocity-change vector at $t_{IG}(\text{NC1})$ in local-vertical coordinates.	V06 N81
$t_{IG}(\text{NC2})$	NC2 ignition time	Available to crew by keying V06 N28E.
$t_{IG}(\text{NCC})$	NCC ignition time	Available to crew by keying V06 N11E.
$t_{IG}(\text{NSR})$	NSR ignition time	Available to crew by keying V06 N13E.
$\Delta \underline{v}$ NSR	Components of required velocity-change vector at $t_{IG}(\text{NSR})$ in local vertical coordinates.	Available to crew by keying V06 N82E.

Table 5.2.3-III P32-Required Input

INPUT	MEANING	SOURCE	DSKY DISPLAY
$r_C, v_C$	CSM state vector	Stored in erasable memory. Updated by ground and by onboard computer.	
$r_W, v_W$	OWS state vector	Stored in erasable memory. Normally updated from ground. Can be updated by onboard computer.	
$\Delta t \text{ NCC/NSR}$	Time between NCC and NSR.	Erasable memory padload.	
Revs NC2/ NCC	Revolutions between NC2 and NCC.	Erasable memory padload.	
$t_{IG} \text{ (NC2)}$	NC2 ignition time	Computed by P31.	V06 N28
$\Delta h \text{ (NCC)}$	Altitude between OWS and CSM orbit at $t_{IG} \text{ (NCC)}$ .	Erasable-memory padload.	V06 N57
$\Delta h \text{ (NSR)}$	Altitude between OWS orbit and CSM orbit at $t_{IG} \text{ (NSR)}$ (+ for CSM below OWS).	Erasable-memory padload.	V06 N57
$E_L$	Desired elevation angle at TPI time.	Erasable-memory padload.	Available by keying V06 N55E and observing R2.
$t_{IG} \text{ (TPI)}$	TPI ignition time	Erasable-memory padload.	V06 N37

Table 5.2.3-IV P32-Computed Output

OUTPUT	MEANING	DSKY DISPLAY
$\Delta v(NCC)$	Required impulsive velocity change at NCC.	V06 N84
$\Delta h(NCC)$	Altitude between CSM and OWS vehicle orbits at $t_{IG}(NCC)$ .	V06 N84
$\Delta v(NSR)$	Magnitude of a velocity change required at $t_{IG}(NSR)$ .	V06 N84
$\Delta \underline{v}(NC2)$	Components of required velocity change vector at $t_{IG}(NC2)$ in local vertical coordinates.	V06 N81
$t_{IG}(NCC)$	NCC ignition time	Available to crew by keying V06 N11E.
$t_{IG}(NSR)$	NSR ignition time	Available to crew by keying V06 N13E.
$\Delta \underline{v}(NSR)$	Components of required velocity change vector at $t_{IG}(NSR)$ in local vertical coordinates.	Available to crew by keying V06 N82E.

- . The CSM velocity vector at TPI is determined by making the CSM orbit coelliptic with the OWS orbit using the position vector determined in step 1.
- . This CSM state vector is then precision integrated backward to the NSR time—retaining coelliptic orbits—yielding the desired CSM position vector at NSR.

Because NCC is an aimpoint maneuver, it can compensate for trajectory dispersions due to errors in NC1 and NC2 targeting and maneuver executions. Thus, if targeted accurately, NCC can hold TPI time slips to a minimum. For all SKYLAB missions, therefore, the rendezvous sequences are such that the NCC maneuver occurs well within rendezvous sensor range so that effective rendezvous navigation can precede the maneuver ensuring an accurate maneuver calculation.

The P33-required input and P33-computed output are shown in Tables 5.2.3-V and 5.2.3-VI, respectively.

#### 5.2.3.4 P34, NSR Targeting Program

The NSR Targeting Program computes the velocity change required to put the CSM into an orbit that is coelliptic to that of the OWS. After the NSR maneuver is executed, then, the altitude differential between the two vehicle orbits remains approximately constant until the time of the TPI maneuver.

Generally, a coellipticizing maneuver would have components in the active vehicle's orbital plane only, i.e., the out-of-plane component would be zero. In this case, however, since the preceeding maneuver, NCC, is a Lambert maneuver to the NSR aimpoint, and since this aimpoint is constrained to be in the OWS orbital plane, (difference in orbital precession between the OWS orbit and CSM orbit from NSR to TPI is very small) NSR maneuver execution provides an opportunity to reduce the out-of-plane velocity of the CSM, relative to the OWS orbit, to zero. (The NCC maneuver forces a node at the NSR point.) For this reason, P34 adds the negative of the out-of-plane velocity of the CSM relative to the OWS orbit to the coelliptic maneuver solution. Thus, the NSR maneuver has in-plane components to coellipticize the orbits and the out-of-plane component to zero the out-of-plane CSM velocity component relative to the OWS orbit. P34, therefore, displays values for the x-, y-, and z-components of the required NSR velocity change in Noun 81.

Table 5.2.3-V P33-Required Input

INPUT	MEANING	SOURCE	DSKY DISPLAY
$\underline{r}_C, \underline{v}_C$	CSM state vector	Stored in erasable memory and updated periodically by ground or by onboard computer.	_____
$\underline{r}_W, \underline{v}_W$	OWS state vector	Stored in erasable memory. Normally updated by ground. Can be updated by onboard computer.	_____
$t_{IG}(NCC)$	NCC ignition time	Computed by P32.	V06 N11
$t_{IG}(NSR)$	NSR ignition time	Computed by P33.	V06 N13
$t_{IG}(TPI)$	TPI ignition time	Erasable memory padload.	V06 N37
$\Delta t$ NCC/ NSR	Time between NCC and NSR maneuvers.	Erasable memory padload.	_____
$E_L$	Desired elevation angle at TPI time.	Erasable memory padload.	Available to crew by keying V06 N55E. (R2)

Table 5.2.3-VI P33-Computed Output

OUTPUT	MEANING	DSKY DISPLAY
$\Delta \underline{v}(NSR)$	Components of required impulsive velocity-change vector at $t_{IG}(NSR)$ in local-vertical coordinates.	V06 N82
$\Delta \underline{v}(NCC)$	Components of required impulsive velocity-change vector at $t_{IG}(NCC)$ in local-vertical coordinates.	V06 N81
$t_{IG}(NSR)$	NSR ignition time.	Available to crew by keying V06 N13E.
$t_{IG}(TPI)$	TPI ignition time.	Available to crew by keying V06 N37E.

After the NSR maneuver is performed, the resulting CSM trajectory to TPI is in the OWS plane (or close to it since no maneuver can be targeted and executed perfectly) and remains at an approximately constant differential altitude below the OWS orbit.

The P34-required input and P34-computed output are shown in Tables 5.2.3-VII and Table 5.2.3-VIII, respectively.

#### 5.2.3.5 P35, TPI Targeting Program

The TPI Targeting Program computes the velocity required to place the CSM on an intercept trajectory with the workshop, with intercept occurring at a specified central angle of travel of the workshop (130 deg) from the TPI ignition point. This central angle yields a corresponding time of flight between  $t_{IG}$  (TPI) and the intercept time. See Figure 5.2.3-3.

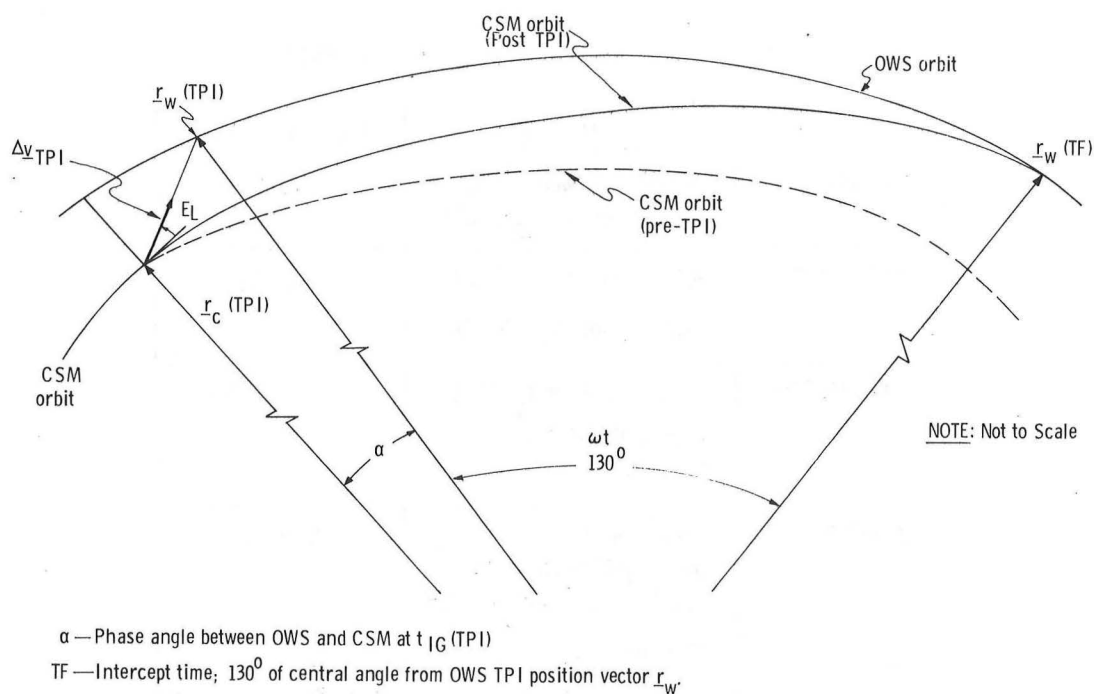


Figure 5.2.3-3. OWS Central Angle of Travel from TPI to Intercept.



Table 5.2.3-VII P34-Required Input

INPUT	MEANING	SOURCE	DSKY DISPLAY
$\underline{r}_C, \underline{v}_C$	CSM state vector	Stored in erasable memory and updated by ground and by onboard computer.	
$\underline{r}_W, \underline{v}_W$	OWS state vector	Stored in erasable memory. Normally updated by ground. Can be updated by onboard computer.	
$t_{IG}^{(NSR)}$	NSR ignition time	Computed by P33.	V06 N13
$t_{IG}^{(TPI)}$	TPI ignition time	Erasable memory padload.	Available to crew by keying V06 N37E.
$E_L$	Elevation angle at TPI ignition time.	Erasable memory padload.	Available to crew by keying V06 N55E.

Table 5.2.3-VIII P34-Computed Output

OUTPUT	MEANING	DSKY DISPLAY
$\Delta h^{(NSR)}$	Altitude between OWS and CSM orbits at $t_{IG}^{(NSR)}$ .	V06 N75
$\Delta t^{(NSR/TPI)}$	NSR-computed $t_{IG}^{(TPI)}$ minus input $t_{IG}^{(NSR)}$ .	V06 N75
$\Delta t^{(TPI/TPI)}$	NSR-computed $t_{IG}^{(TPI)}$ minus P34-input $t_{IG}^{(TPI)}$ .	V06 N75
$\Delta \underline{v}^{(NSR)}$	Components of required velocity-change vector at $t_{IG}^{(NSR)}$ in local-vertical coordinates.	V06 N81
$\underline{Y}_C, \dot{\underline{Y}}_C$	CSM out-of-plane position and velocity relative to OWS orbital plane.	Available to crew by keying V06 N90E.
$\dot{\underline{Y}}_W$	OWS out-of-plane velocity relative to CSM orbital plane.	Available to crew by keying V06 N90E.
$t_{IG}^{(TPI)}$	TPI ignition time.	Available to crew by keying V06 N37E.

P35 nominally determines the TPI maneuver time by an iterative search for the desired elevation angle  $E_L$  of the workshop above the CSM (although the time option is also available to the crew; see paragraph 5.2.5). (This desired elevation angle, also used in the calculations for the previous targeting programs, is padloaded and defines the LOS from the CSM to the OWS as measured from the horizontal plane of the CSM TPI position, as shown in Figure 5.2.3-3.) The time calculated by P35 for  $t_{IG}(TPI)$  should then be close to the desired TPI time used in the NC1 and NC2 targeting programs; due to burn execution errors and small navigation state errors, however, these values will not be exactly the same.

After the TPI time is obtained, P35 advances the CSM and OWS state vectors to this time and computes the maneuver solution by solving Lambert's problem from the CSM TPI position vector  $r_C(TPI)$  to the workshop position vector  $r_W(TF)$  at intercept. To account for the earth's oblateness effects in determining the velocity change required at TPI, two options are available. The crew specifies the desired option in Noun 55 of P35. The more accurate one is utilizing the OWS position vector at intercept derived by precision integration and the target-offset technique (with  $N = 2$  offsets) to obtain an offset aimpoint to be used in obtaining the velocity change required. This involves three precision integrations to intercept and three solutions of Lambert's problem, and is, therefore, time consuming. A technique that is not quite as accurate, but is very fast in obtaining a solution, is to determine the aimpoint to be used in the Lambert problem by integrating the workshop state from  $t_{IG}(TPI)$  to intercept conically. No precision integration is used and Lambert's problem is solved only once. The maneuver solution resulting from using this technique is essentially equivalent to taking one target offset using the precision OWS position vector at intercept. This latter technique (with  $N=0$  offsets) is nominally used because it is fast and, although a small  $\Delta v$  error is incurred (approximately 1.0 fps), it is easily corrected during the midcourse maneuvers following TPI.

Tables 5.2.3-IX and 5.2.3-X show P35-required input and P35-computed output, respectively.

#### 5.2.3.6 P36, Terminal-phase Midcourse (TPM) Targeting Program

The Terminal-phase Midcourse Targeting program is essentially the same as the TPI program with the exception that no search occurs for the ignition time. Nominally, two midcourses are scheduled after TPI, each occurring at a fixed time from TPI. The ignition times for the midcourses are specifically chosen so that adequate rendezvous navigation can take place before a final solution is requested. The ignition

time of each midcourse maneuver is determined by the crew response to the Noun 45 display. Specifically,  $t_{IG}$  is the response time plus a 3-min increment.

Because TPI cannot be computed and executed perfectly due to (1) the small navigation errors existing at TPI, (2) incomplete modeling of gravity perturbations, and (3) maneuver-execution errors, the midcourse solutions will not be zero.

P36 computation of the maneuver solution uses the time of flight computed in the TPI program minus the time increment between TPI and the midcourse being performed as the time of flight to intercept. This time of flight is then used to obtain an updated OWS position vector at intercept.

Again, either of two techniques can be used to compute the maneuver solution, i.e., target offset technique ( $N = 1$ , or  $2$ ) or use of a conic aimpoint in the Lambert solution ( $N = 0$ ). The technique used is specified in R3 of Noun 55 during P35. Since the range to the target is about 10 n.mi. at the first midcourse and approximately 5 n.mi. at the second, using the conic aimpoint option ( $N = 0$ ) provides a very accurate maneuver solution (and a very fast one since no precision integration is involved). This option is, therefore, normally used.

Tables 5.2.3-XI and 5.2.3-XII show P36-required input and P36-computed output, respectively.

Table 5.2.3-IX P35-Required Input

INPUT	MEANING	SOURCE	DSKY DISPLAY
$\underline{r}_C, \underline{v}_C$	CSM state vector	Stored in erasable memory and updated by ground and by onboard computer.	—
$\underline{r}_W, \underline{v}_W$	OWS state vector	Stored in erasable memory. Normally updated by ground. Can be updated by onboard computer.	—
$t_{IG}(TPI)$	TPI ignition time	Computed by P34 program.	V06 N37
NN	Number of precision offsets made in generating offset target vector for TPI. NOTE. — If set 00000 conic integration used to generate target vector.	Loaded by P35 to 00000.	V06 N55
$\omega t$	Central angle traveled by OWS between TPI and intercept point.	Fixed-memory constant.	—
$E_L$	Elevation angle between CSM and OWS LOS and CSM local horizontal at $t_{IG}(TPI)$ .	Erasable-memory padload.	V06 N55

Table 5.2.3-X P35-Computed Output

OUTPUT	MEANING	DSKY DISPLAY
$\Delta v(\text{TPI})$	TPI maneuver magnitude	V06 N58
$\Delta v(\text{TPF})$	TPF maneuver magnitude	V06 N58
$\Delta t(\text{TPI})$	Difference between TPI-computed $t_{IG}$ and P35-input.	V06 N58
$\Delta \underline{v}(\text{TPI})$	Components of required velocity-change vector at $t_{IG}(\text{TPI})$ in local-vertical coordinates.	V06 N81
$\Delta \underline{v}(\text{TPI})(\text{LOS})$	Components of required velocity-change vector at $t_{IG}(\text{TPI})$ in line-of-sight coordinates.	Available to crew by keying V06 N59E.
$t_{IG}(\text{TPI})$	P35-computed $t_{IG}(\text{TPI})$ given an elevation angle.	V06 N37
$E_L$	P35-computed elevation angle given a $t_{IG}$ .	V06 N55
$\phi$	CSM central angle of travel between TPI and intercept( $\alpha + \omega t$ ). See Figure 5.2.3-3.	Available to crew by keying V06 N52E (R1).

Table 5.2.3-XI P36-Required Input

INPUT	MEANING	SOURCE	DSKY DISPLAY
$\underline{r}_C, \underline{v}_C$	CSM state vector	Stored in erasable memory. Updated by ground and by onboard computer.	—
$\underline{r}_W, \underline{v}_W$	OWS state vector	Stored in erasable memory. Normally updated by ground. Can be updated by onboard computer.	—
t(TF)	Intercept time	Stored in erasable memory from P35.	—
NN	Number of precision offsets.	Defined in R1 of Noun 55 of P35.	—
$\Delta t$	Time increment	Fixed-memory constant of 3 min.	

Table 5.2.3-XII P36-Computed Output

OUTPUT	MEANING	DSKY DISPLAY
$\Delta \underline{v}$ (TPM) (LOS)	Components of required velocity-change vector at $t_{IG}$ (TPM) in line-of-sight coordinates.	V06 N59
$\Delta \underline{v}$ (TPM) (LV)	Components of required velocity-change vector at $t_{IG}$ (TPM) in local vertical coordinates.	Available to crew by keying V06 N81E.
$\phi$	Central angle CSM travels between $t_{IG}$ (TPM) and intercept time.	Available to crew by keying V06 N52E.

Table 5.2.3-XIII P38-Required Input

INPUT	MEANING	SOURCE	DSKY DISPLAY
$r_C, v_C$	CSM state vector	Stored in erasable memory. Updated by ground and by onboard computer.	—
$r_W, v_W$	OWS state vector	Stored in erasable memory. Normally updated by ground. Can be updated by onboard computer.	—
$t$	Time of last maneuver $t_{IG}$ (NC1)	Stored in erasable memory from last program to compute a $t_{IG}$ .	V06 N39
$t_{IG}(PC)$	PC ignition time.		V06 N33

Table 5.2.3-XIV P38-Computed Output

OUTPUT	MEANING	DSKY DISPLAY
$\Delta \underline{v}$ (PC) (LV)	Components of required velocity-change vector at $t_{IG}$ (PC). NOTE. -R2 contains Y-dot CSM. R1(x) and R3(z) are zero.	V06 N81
$\underline{y}_C, \dot{\underline{y}}_C$	CSM out-of-plane position and velocity relative to OWS orbital plane.	Available to crew by keying V06 N90E.
$\dot{\underline{y}}_W$	OWS out-of-plane velocity relative to CSM orbital plane.	Available to crew by keying V06 N90E.

#### 5.2.4 Targeting-program Operational Summary

All the targeting programs are operated in a similar way. The program displays existing data. The crew either loads new input data and options into the program via the DSKY, or accepts the data displayed. After the crew has responded to the input displays, all the targeting programs display VERB 16 NOUN 45. The crew normally performs SXT (or COAS) marking during this display and monitors accumulation of VHF marks. A VERB 32 ENTR response to the display allows the program to recycle the targeting computations and to obtain a preliminary solution. A PRO response to the Noun 45 display obtains a final targeting solution and a second Noun 45. As shown in the figure, a second PRO response to the Noun 45 then causes the targeting program to exit.

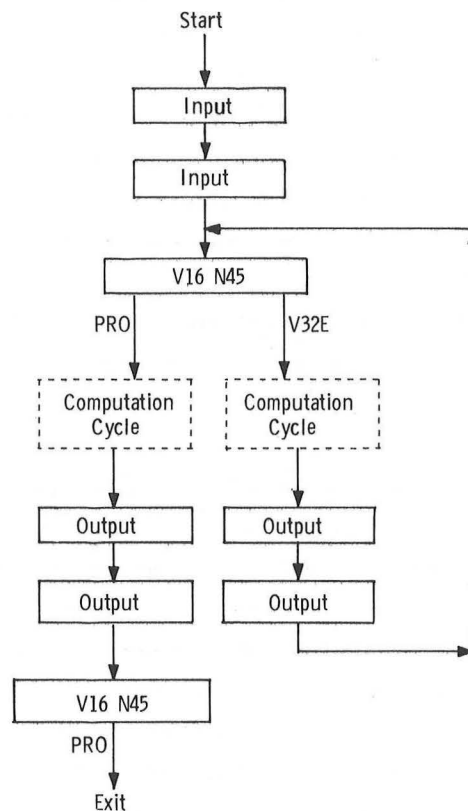


Figure 5.2.4-1. Targeting Program Simplified Flowchart



As shown, Noun 45 is displayed at the end of every computation cycle—whether that cycle is preliminary or final. The contents of Noun 45 are:

R1	xxBxx	Number of VHF and SXT (or COAS) marks incorporated since the last W-matrix reinitialization
R2	xxBxx	Time from ignition
R3	-00001	Preliminary cycle (after V32E)
	-00002	
	or	
	xxx.xx	
	deg MGA	Final cycle (after PRO)

When R3 contains the approximate middle gimbal angle (MGA) at  $t_{IG}$  (after the maneuver to the thrusting attitude; see Section 6.0) the CSM thrust axis is aligned along the velocity-to-be-gained direction. This enables the crew to determine if a realignment of the IMU is required before thrusting.

The decision whether to recycle and obtain a preliminary solution or to PRO and obtain a final solution is made in accordance with premission planning, taking into account the amount of time left before ignition. A rule of thumb for the targeting programs is for the crew to PRO (on Noun 45) to obtain a final solution approximately 12 min before  $t_{IG}$ . This allows enough time for the program to compute a targeting solution; and allows the crew to perform the final PRO on Noun 45 to exit to the thrusting program with enough time for the maneuver to the thrusting attitude and premaneuver preparation.

In either case, upon receipt of a VERB 32 ENTR (recycle) or a PRO response, the program resets UPDATFLG prohibiting further incorporation of marks into the onboard state-vector. For the recycle response, this prohibition is temporary and lasts only for the time the computations are being performed. Before displaying the first preliminary computation, the program sets UPDATFLG again allowing incorporation of marks. Presumably, the crew will wish to perform marking again during the next Noun-45 display. For the PRO response, the prohibition is permanent for the targeting program being performed. Marking should not be performed, therefore, after a PRO response to Noun 45 since the marks will not be incorporated into the state vector.

## MARKING

If VHF marking has been enabled by the crew's keying VERB 87 ENTR, VHF marks are taken automatically at the rate of about one per minute. Optics marks are nominally performed by the crew at the same rate. During a long tracking period (15 or 20 min) it is theoretically most desirable to take SXT marks once a minute throughout the period. Since this is not always possible, the recommended procedure is to take the marks in batches during a six-min period at the beginning and a six-to eight-min period at the end.

If the situation is such that the crew can take only a limited number of marks, these marks should be taken as close to the maneuver time as possible.

During batch marking, if a recycle (VERB 32 ENTR response to the Noun-45 display) is desired and at least five minutes have passed since the last mark, it is recommended that the crew take three optics marks before requesting the recycle.

NOTE. — After a W-Matrix reinitialization (the mark counter reads zero) about ten marks are required to obtain steady state state-vector estimates.

## XDELVFLG

Another internal function of all the targeting programs is the setting or resetting of XDELVFLG. Programs P30, P31, P32, P34 and P38 set XDELVFLG, requiring the thrusting program executing the maneuver to perform the guidance computations in the External  $\Delta v$  mode; programs P33, P35 and P36 reset XDELVFLG requiring the thrusting programs to perform these computations in the Lambert mode. (For a detailed explanation of both modes, refer to Section 6.0; refer also to paragraph 5.2.2 for a schematic description of these modes.)

## ALARMS

Should the alarms listed below occur during a targeting program, the program displays the alarm in FL V05 N09 and illuminates the PROG light. The alarm appears in R1 and R3 of Noun 09 if it is the only alarm; in both R2 and R3 if it is the second alarm; and only in R3 if it is the third alarm. R3 always contains the latest alarm. For all the alarms described in this paragraph, the targeting programs have been coded to allow the crew to key either VERB 32 ENTR (recycle) or PRO to the V05 N09 display. The effects of these responses can be different, however,

depending upon the alarm to which the response is made.. For some alarms, the crew can also access erasable memory and modify the  $\epsilon_1$  and  $\epsilon_2$  convergence criteria.

The alarms that can occur during the targeting programs, and their causes, are listed in the following table. In addition, the text following the table gives brief explanations of the causes for the alarms, and, where applicable, describes possible workaround procedures.

<u>Alarm</u>	<u>Cause</u>	<u>Program</u>
00600 Failure in phase-match iteration		P31, P32
00601 Failure in height-maneuver iteration		P31, P32
00602 Failure in outer-loop iteration		P31, P32
00603 Failure in QRDTPI iteration		P31, P32, P33
00611 No $t_{IG}$ for a given elevation angle		P34, P35

#### 00600

The occurrence of this alarm, although very unlikely, means that the program is unable to update the OWS state vector to be radially above or below the active vehicle. The recycle response takes the program to the beginning and allows the crew to check inputs for reasonableness. The PRO response allows the program to bypass the Noun-84 display and to set the Noun-81 display to all zeros, indicating no solution. The crew can then load the ground solution in Noun 81. Other workaround procedures, however, would be for the crew to request state-vector uplink from the ground, or to access erasable memory and modify the convergence criteria.

#### 00601

Failure of the program to converge in this case usually indicates unreasonable input. For example, the  $\Delta h$  entered in Noun 57 is unreasonably high or the number of half-revs between either NC1 and NC2 or NC2 and NCC is a small fraction, in effect asking the program for a very rapid change in altitude—which is not possible since the maneuver is constrained to be horizontal. A PRO response sets Noun 81 to zero. (The crew can then load the ground solution in Noun 81.)

The recycle response to the V05 N09 and a rechecking of the inputs to the program is a possible workaround procedure for this alarm.

#### 00602

Should there be a failure in the outer-loop iteration causing a 00602 alarm, a PRO response to V05 N09 allows both P31 and P32 to run to completion and to compute a solution. The assumption is that this solution will be approximately correct, since the inner loops have converged. In any case, the solution should be compared with that of ground before being used. Another—and less likely—approach is for the crew to change the convergence tolerance  $\epsilon_1$  in the outer loop to a higher value. This approach requires accessing the erasable-memory address of  $\epsilon_1$ .

#### 00603

The QRDTPI Routine searches for the OWS state vector that satisfies the  $\Delta h$  and elevation-angle ( $E_L$ ) geometry constraints as shown in Figure 5.2.3-2. Should this search fail, causing a 00603 alarm, a PRO response to the V05 N09 sets Noun 81 to zero indicating no solution. (The crew then has the option of loading the ground solution in Noun 81.) A VERB 32 ENTR recycles the program allowing the crew to recheck the inputs—particularly those for  $\Delta h$  and  $E_L$ . Accessing erasable memory allows the crew to modify the convergence criteria.

#### 00611

This alarm in P34 or P35 indicates that the program cannot find a time of ignition for the given elevation angle. The workaround procedures are slightly different for each program. In P34, the crew can key PRO, VERB 32 ENTR, or VERB 34 ENTR in response to the V05 N09 display. Keying PRO allows the program to proceed with the knowledge that the input TPI time will be unchanged. Keying VERB 32 ENTR—the recommended procedure—allows the program to recycle to the beginning and allows the crew to redefine the input parameters. [The crew should also key VERB 06 NOUN 37 ENTR to verify input value of  $t_{IG}$  (TPI).] Keying VERB 34 ENTR terminates the program.

For P35, a PRO response to the V05 N09 alarm display recycles the program to the beginning and allows the crew to redefine the input parameters. The crew can then change the initial estimate of  $t_{IG}$  (NOUN 37).

### 5.2.5 Onboard Targeting-program Procedures

Minimum keystroke (MINKEY) program sequencing is normally used throughout the SKYLAB rendezvous, although manual sequencing can also be used. (Refer to paragraph 4.2.1.) For this reason, the procedures described here for the onboard targeting programs are within the broader context of MINKEY rendezvous. Those procedures that are not strictly targeting-program functions are described only briefly.

MINKEY provides the crew an automatic method of sequencing the various navigation, alignment, targeting, and thrusting tasks required for rendezvous and docking. The crew has only to select the initial targeting program and key PRO to the FL V50 N25 (with R1=00017) request for MINKEY performance; all other programs within the sequence are then automatically selected by the MINKEY controller. The sequence essentially involves (1) initiating option 4 of the Universal Tracking Program, P20 (2) selecting the appropriate targeting program, and (3) selecting either P40 or P41 for thrusting. If the crew keys ENTR to the FL V50 N25, thus selecting manual sequencing, he must then manually select all the programs in the sequence. (Refer to paragraph 4.2.1.2.2 for a detailed description of manual-sequencing procedures.) If REFSMFLG is reset, P20 is not turned on, nor is the request for MINKEY displayed. The rendezvous must then be accomplished manually.

The various starting points at which MINKEY can be entered are reset points corresponding to the targeting-program entry; they follow the order of the nominal rendezvous-maneuver sequence (see paragraph 5.2.1) with the exception of the pre-NPC maneuver segment (reset point 8).

The reset points for entering the MINKEY sequence and their corresponding targeting programs, initiated at these points, are as follows:

	<u>Reset Point</u>	<u>Targeting Program Entered</u>
1.	Pre-NC1	P31
2.	Pre-NC2	P32
3.	Pre-NCC	P33
4.	Pre-NSR	P34
5.	Pre-TPI	P35
6.	Pre-TPM (TPM-1, TPM-2)	P36

7. Terminal Phase
8. Pre-NPC

P37\*  
P38\*\*

MINKEY sequencing can be interrupted and would require re-initiation if any of the following DSKY inputs occur during the sequence.

1. VERB 37 ENTR xx ENTR
2. VERB 34 ENTR to a program-generated flashing display
3. VERB 96 ENTR—stops integration and selects non-integrating P00
4. VERB 36 ENTR—causes a fresh start
5. VERB 56 ENTR—terminates P20 running in the background.

Within the MINKEY sequence, certain displays are common to all the targeting programs, although the displays are not generated by the targeting programs. These are the R07-generated FL V50 N18 and the P20-R60-generated FL V50 N18 and V06 N18. The crew observes these displays immediately upon keying VERB 37 ENTR xx ENTR where xx corresponds to the targeting-program numbers 31-38. To avoid repeating these displays in the procedural description of each targeting program, this common portion of MINKEY sequencing is described here.

Key VERB 37 ENTR xx ENTR.

Upon entry, each targeting program sets:

UPDATFLG to allow state-vector updating by optics and VHF marks.  
TRACKFLG to allow rendezvous tracking.

Only upon initial entry into the MINKEY sequence, observe the flashing R07 request to perform MINKEY sequencing.

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\* P37 performs no targeting, but provides displays of range and range rate and establishes x-axis tracking.

\*\* Pre-NPC is not part of the normal MINKEY sequence. If it is required, it must be selected at the desired point (normally following NC1) by the crew's keying VERB 37 ENTR 38 ENTR.

FL V50 N25

R1 00017 Request to perform MINKEY  
R2 Blank  
R3 Blank

NOTE.—The crew sees FL V50 N25 again only if the MINKEY sequence is interrupted and re-entered.

PRO—to start MINKEY sequence. Observe flashing P20-R60 display of required gimbal angles and request to perform automatic maneuver to tracking attitude.

ENTR—to perform manual sequencing.

NOTE.—The FL V50 N18 display occurs only if  $\Delta\theta$  is greater than 10 deg.

FL V50 N18

R1 xxx.xx deg OGA Desired gimbal angles  
R2 xxx.xx deg IGA  
R3 xxx.xx deg MGA

NOTE.—To perform automatic maneuver, verify SC CONT switch in CMC and CMC MODE switch in AUTO.

PRO—to perform automatic maneuver to tracking attitude. Observe nonflashing display of final gimbal angles as automatic maneuver is being performed. Monitor maneuver on FDAI. If maneuver approaches gimbal lock, use RHC to complete maneuver manually.

FL V06 N18

R1 xxx.xx deg OGA Final gimbal angles  
R2 xxx.xx deg IGA  
R3 xxx.xx deg MGA

When maneuver is completed, observe first targeting-program display.

Nominally, after insertion and performance of a P52 realignment, the ground uplinks, via P27, the CSM and OWS state vectors. The crew monitors the P27 uplink and then receives and records—via voice link—preliminary NC1 pad data. Ground voice links final NC1 pad data approximately 30 minutes before the NC1 maneuver is to be performed. The crew then selects the NC1 targeting program and enters MINKEY sequencing at reset point 1.



1. Key VERB 37 ENTR 31 ENTR. (See common procedures.) Observe flashing display of  $t_{IG}$ (NC1).

NOTE.—Nominally in SKYLAB, marktaking is not performed during P31, since the OWS is not within the 300-nautical mile tracking range considered necessary to improve the state vector.

1a. FL V06 N95

R1 00xxx. hr  $t_{IG}$  (NC1) (GET)  
 R2 000xx. min  
 R3 0xx.xx sec

VERB 25 ENTR—to load pad  $t_{IG}$  (NC1) if displayed  $t_{IG}$  is not same as final NC1 pad. PRO.

PRO—when satisfied with displayed  $t_{IG}$ . Observe flashing display of stored half revs,  $\Delta h$  (NCC) and  $\Delta h$  (NSR).

1b. FL V06 N57

R1 xxxxx half revs  
 R2 xxxx.x n.mi  $\Delta h$  (NCC)  
 R3 xxxx.x n.mi  $\Delta h$  (NSR)

where R1 is the number of half revolutions between NC1 and NC2; R2 is the altitude between CSM and OWS orbits at  $t_{IG}$  (NCC); R3 is the altitude between the CSM and OWS orbits at  $t_{IG}$  (NSR).

NOTE.—The sign for R2 and R3 is plus when the CSM is below the OWS.

VERB 25 ENTR—to load pad values if displayed values not same. PRO.

PRO—when satisfied with display. Observe flashing display of  $t_{IG}$  (TPI).

1c. FL V06 N37

R1 00xxx. hr  $t_{IG}$  (TPI) (GET)  
 R2 000xx. min  
 R3 0xx.xx sec

VERB 25 ENTR—to load pad  $t_{IG}$  (TPI) if displayed values not same as final NC1 pad. PRO.

PRO—when satisfied with  $t_{IG}$  (TPI). Observe flashing Noun-45 display of mark counters, TFI, and code indicating not last pass.

1d. FL V16 N45

R1 xxBxx VHF-Optics mark counters  
 R2 xxBxx min-sec TFI (NC1)  
 R3 -00001 preliminary cycle

NOTE.—Upon a VERB 32 ENTR response, program resets UPDATFLG temporarily prohibiting further updating of state vectors. Upon PRO response, program sets FINALFLG indicating final pass through targeting computations and also resets UPDATFLG.

VERB 32 ENTR—to recycle the targeting computations to obtain a preliminary solution. Observe flashing display of preliminary Noun-84 data.

PRO—to terminate navigation, and obtain a final targeting solution. Observe flashing display of final Noun-84 data.

1e. FL V06 N84

R1 xxxx.x fps  $\Delta v$ (NC2)  
 R2 xxxx.x n.mi.  $\Delta h$ (NC2)  
 R3 xxxx.x fps  $\Delta v$ (NCC)

where R1 contains the resultant velocity-to-be-gained during NC2 maneuver; R2 contains the altitude between the CSM and OWS orbits at  $t_{IG}$  (NC2); R3 contains the required impulsive velocity-to-be-gained during the NCC maneuver.

PRO—observe flashing display of either preliminary or final Noun 81-velocity-change computations depending upon response (step 1d) to FL V16 N45 display.

1f. FL V06 N81

R1	xxxx.x fps	$\Delta v_x$ (LV) NC1
R2	xxxx.x fps	$\Delta v_y$ (LV)
R3	xxxx.x fps	$\Delta v_z$ (LV)

where R1 is the x-component, in local-vertical coordinates, of the impulsive velocity-change at  $t_{IG}$  (NC1); R2 is the y-component; and R3 is the z-component.

NOTE.—The ground solution is prime for NC1; the crew, therefore, compares the x-component of the final Noun-84 display with that of ground. If onboard value is not within preset mission limits, the crew overwrites CMC solution with that of ground voiced as final NC1 pad data.

PRO—observe flashing Noun-45 display.

NOTE.—After the PRO to FL V06 N81, P31 sets XDELVFLG requiring that P40 or P41 computations be performed in the External  $\Delta v$  mode.

1g. FL V16 N45

R1	xxBxx	VHF-Optics mark counters
R2	xxBxx	min-sec TFI (NC1)
R3	-00001	preliminary cycle
or	xxx.xx	deg MGA
or	-00002	final cycle (IMU not aligned)

where R1 is the number of VHF and optics marks accumulated since last W-matrix reinitialization; R2 is the time from NC1 ignition; R3 is (1) -00001 if computation was preliminary, (VERB 32 ENTR on step 1d), (2) value of middle gimbal angle at thrusting attitude if IMU aligned and computation was final (PRO on step 1d) or (3)-00002 if IMU not aligned and computation was final (PRO on step 1d).

VERB 32 ENTR—to recycle for another preliminary solution. Observe preliminary FL V06 N84.

PRO—to exit to thrusting program or to obtain final comp. Observe either final FL V06 N84 or PROG number on DSKY change to 40 or 41 depending upon which thrusting program is called by R07, the MINKEY Controller.

At the completion of the targeting program, R07 computes the magnitude of the required velocity-change vector to determine whether to select RCS or SPS thrusting program. The rule used is if  $v_G \geq 10$  fps, P40 (SPS thrusting) is chosen; if  $v_G$  is  $<10$  fps, P41 (RCS thrusting) is chosen. Nominally, for NC1, P40 is used. After completion of the NC1 maneuver, the crew trims the residual of the x-component of  $v_G$  and voices the NC1 residuals to the ground. The ground confirms the burn, and, using MSFN tracking data, computes the CSM state vector. In addition, the ground sends the OWS a NAV load and a Z-local vertical update. The crew then nominally (1) calls P00 to prepare for P27 uplink of CSM and OWS state vectors; (2) receives preliminary NC2 pad, and plane-change decision and pad; and (3) performs a P52 (option 3) IMU realignment. If plane-change is desired, crew keys VERB 48 ENTR and loads maneuver rate, selects P38, as shown, and begins MINKEY sequence (reset point 8) for NPC burn. Otherwise, the crew enters MINKEY sequence at reset point 2.

NOTE.—Should pre-NPC (reset point 8) be necessary, it must be called manually by the crew. MINKEY will then automatically sequence through P38 targeting, P52 plane-change alignment, P40 or P41 thrusting, P52 in-plane alignment, and end this segment with a FL VERB 37 request for a new program. Crew returns to the nominal sequence (reset point 2) for MINKEY by keying VERB 37 ENTR 32 ENTR.

2. Key VERB 37 ENTR 32 ENTR. (See common procedures.) Observe flashing display of  $t_{IG}$  (NC2).

2a. FL V06 N28

R1 00xxx. hrs  $t_{IG}$  (NC2)(GET)  
 R2 000xx. min  
 R3 0xx.xx sec

VERB 25 ENTR—to load pad  $t_{IG}$  if displayed  $t_{IG}$  not same as final NC2 pad. PRO.

PRO—when satisfied with displayed  $t_{IG}$ . Observe flashing display of  $\Delta h$  (NCC) and  $\Delta h$  (NSR).

2b. FL V06 N57

R1 Blank  
 R2 xxxx.x n.mi.  $\Delta h$  (NCC)  
 R3 xxxx.x n.mi.  $\Delta h$  (NSR)

NOTE.—The sign for R2 and R3 is plus when the CSM is below the OWS.

where R2 is altitude between the CSM and OWS orbits at  $t_{IG}$  (NCC); and R3 is altitude between the CSM and OWS orbits at  $t_{IG}$  (NSR).

PRO—copy Noun 57 values and PRO. Observe flashing display of  $t_{IG}$  (TPI).

2c. FL V06 N37

R1 00xxx. hr  $t_{IG}$  (TPI) (GET)  
 R2 000xx. min  
 R3 0xx.xx sec

VERB 25 ENTR—to load pad  $t_{IG}$  (TPI) if displayed  $t_{IG}$  not same as NC2 pad. PRO.

PRO—when satisfied with displayed  $t_{IG}$ . Observe flashing Noun 45—display of mark counters, TFI, and code indicating not last pass.

2d. FL V16 N45

R1	xxBxx	VHF—Optics mark counters
R2	xxBxx	min—sec TFI (NC2)
R3	-00001	preliminary cycle

- Perform SXT marking until sufficient marks have been accepted.

NOTE.—Upon a VERB 32 ENTR, program resets UPDATFLG temporarily prohibiting further updating of state vectors by marks. Upon a PRO, program sets FINALFLG indicating final pass through targeting computations and also resets UPDATFLG.

VERB 32 ENTR—to recycle the targeting computations, take more marks and obtain a preliminary solution. Observe flashing display of preliminary Noun-84 data.

PRO—to terminate navigation, and obtain a final targeting solution. Observe flashing display of final Noun-84 data.

2e. FL V06 N84

R1	xxxx.x fps	$\Delta v$ (NCC)
R2	xxxx.x n.mi	$\Delta h$ (NCC)
R3	xxxx.x fps	$\Delta v$ (NSR)

where R1 contains the impulsive  $\Delta v$  required to accomplish NCC maneuver at  $t_{IG}$  (NCC); R2 the altitude between the CSM and OWS orbits at  $t_{IG}$  (NCC); and R3 impulsive  $\Delta v$  required to accomplish NSR maneuver at  $t_{IG}$  (NSR).

PRO—observe flashing display of either preliminary or final Noun-81 velocity-change computations depending upon response (step 2d) to FL V16 N45 display.

2f. FL V06 N81

R1	xxxx.x fps	$\Delta v_x$ (LV) NC2
R2	xxxx.x fps	$\Delta v_y$ (LV)
R3	xxxx.x fps	$\Delta v_z$ (LV)

where R1 is the x-component, in local-vertical coordinates, of required impulsive  $\Delta v$  at  $t_{IG}$  (NC2); R2 is the y-component; and R3 is the z-component.

NOTE.—The ground solution is prime for NC2. The crew, therefore, compares the x-component of the final Noun-81 display with that of ground. If onboard value is not within preset mission limits, the crew overwrites the CMC solution with that of ground voiced as final NC2 pad data.

PRO—observe flashing display of Noun 45.

2g. FL V16 N45

R1	xxBxx	VHF-Optics mark counters
R2	xxBxx	min-sec TFI (NC2)
R3	-00001	preliminary cycle
<u>or</u>	xxx.xx	deg MGA
<u>or</u>	-00002	final cycle (IMU not aligned)

where R1 is the number of VHF and optics marks accumulated since last W-matrix reinitialization; R2 is the time from NC2 ignition; R3 is (1) -00001 if computation was preliminary, (VERB 32 ENTR on step 2d), (2) value of middle gimbal angle at thrusting attitude if IMU aligned and computation was final (PRO on step 2d) or (3) -00002 if IMU not aligned and computation was final (PRO on step 2d).

VERB 32 ENTR—to recycle for another preliminary solution. Observe preliminary FL V06 N84.

PRO—to exit to thrusting program or to obtain final comp. Observe either final FL V06 N84 or PROG number on DSKY change to 40/41 depending upon which thrusting program is called by R07, the MINKEY Controller.

After completion of the NC2 maneuver, the crew trims the residual of the x-component of  $\underline{v}_G$  and voices NC2 residuals to the ground for confirmation. The crew then calls P20 to perform SXT tracking and initiates R27 to track OWS with VHF for chart solutions. The crew also performs preliminary NCC targeting, after receiving and recording ground NCC and NSR solutions, and calls P33.



3. Key VERB 37 ENTR 33 ENTR. (See common procedures.) Observe flashing display of  $t_{IG}$  (NCC).

3a. FL V06 N11

R1 00xxx. hr  $t_{IG}$  (NCC) (GET)  
 R2 000xx. min  
 R3 0xx.xx sec

VERB 25 ENTR—to load pad  $t_{IG}$  (NCI) if displayed  $t_{IG}$  is not same as final NCC pad. PRO.

PRO—when satisfied with displayed  $t_{IG}$ . Observe flashing Noun 13 display of  $t_{IG}$  (NSR).

NOTE.— $t_{IG}$  (NSR) is computed to be the time loaded in Noun 11 plus the erasable-memory  $\Delta t$  NCC/NSR.

3b. FL V06 N13

R1 00xxx. hr  $t_{IG}$  (NSR) (GET)  
 R2 000xx. min  
 R3 0xx.xx sec

VERB 25 ENTR—to load pad  $t_{IG}$  (NSR) if displayed  $t_{IG}$  is not same as final NCC pad. PRO.

PRO—when satisfied with  $t_{IG}$  (NSR). Observe flashing display of  $t_{IG}$  (TPI).

3c. FL V06 N37

R1 00xxx. hr  $t_{IG}$  (TPI) (GET)  
 R2 000xx. min  
 R3 0xx.xx sec

VERB 25 ENTR—to load pad  $t_{IG}$  (TPI) if displayed  $t_{IG}$  is not same as final TPI pad. PRO.

PRO—when satisfied with displayed  $t_{IG}$ . Observe flashing Noun-45 display.

3d. FL V16 N45

R1    xxBxx    VHF-Optics mark counters  
 R2    xxBxx    min-sec TFI (NCC)  
 R3    -00001    preliminary cycle

- Perform SXT marking
- Perform R27 procedures. (Refer to paragraph 4.2.1.3.)

VERB 32 ENTR—to recycle the targeting computations and temporarily terminate state-vector update by marks to obtain a preliminary solution. Observe flashing display of preliminary Noun-82 data.

PRO—to terminate state-vector update by marks, and obtain a final targeting solution. Observe flashing display of final Noun-82 data.

3e. FL V06 N82

R1    xxxx.x fps     $\Delta v_x$  (LV) NSR  
 R2    xxxx.x fps     $\Delta v_y$  (LV)  
 R3    xxxx.x fps     $\Delta v_z$  (LV)

where R1 is x-component, in local-vertical coordinates, of the impulsive velocity change at  $t_{IG}$  (NSR); R2 is the y-component; and R3 is the z-component.

PRO—observe flashing display of either preliminary or final Noun-81 velocity-change computations depending upon response to Noun 45.

3f. FL V06 N81

R1    xxxx.x fps     $\Delta v_x$  (LV) NCC  
 R2    xxxx.x fps     $\Delta v_y$  (LV)  
 R3    xxxx.x fps     $\Delta v_z$  (LV)

where R1 is x-component, in local-vertical coordinates, of the impulsive velocity-change at  $t_{IG}$  (NCC); R2 is the y-component; and R3 is the z-component.

NOTE.—For final solution, crew compares the CMC, the ground, and the chart solutions. If the CMC solution agrees with either the chart or the ground solution within a planned tolerance for the x-, y-, and z-components of the  $\underline{y}_G$ , the CMC solution is used. If the CMC solution does not agree with either of the other two, the crew compares the chart and ground solutions. If they agree within this tolerance, the crew uses the chart solution. Should all three disagree, the crew uses the ground solution.

VERB 25 ENTR—to load other than CMC solution.

PRO—to continue. Observe flashing Noun-45 display.

3g. FL V16 N45

R1	xxBxx	VHF-Optics mark counters
R2	xxBxx	min-sec TFI (NCC)
R3	-00001	preliminary cycle
<u>or</u>	xxx.xx	deg MGA
<u>or</u>	-00002	final cycle (IMU not aligned)

where R1 is the number of VHF and SXT marks accumulated since last W-matrix reinitialization; R2 is time from NCC ignition; and R3 is (1) -00001 if computation was preliminary (VERB 32 ENTR on step 3d;) (2) value of middle gimbal angle at thrusting attitude if IMU aligned and computation was final (PRO on step 3d), or (3)-00002 if IMU not aligned and computation was final.

VERB 32 ENTR—to recycle for preliminary solution. Observe preliminary FL V06 N84.

PRO—to exit to thrusting program or to obtain final comp. Observe either final FL V06 N84 or PROG number on DSKY change to 40 or 41 depending upon which thrusting program is called by R07, the MINKEY Controller.

After completion of the NCC maneuver, the crew trims the x-, y-, and z-components of  $\underline{y}_G$  and voices the NCC residuals to ground for burn confirmation. The crew then performs SXT tracking, as well as VHF tracking for chart solutions and enters P34.

4. Key VERB 37 ENTR 34 ENTR. (See common procedures.) Observe flashing display of  $t_{IG}$  (NSR).

4a. FL V06 N13

R1 00xxx. hr  $t_{IG}$  (NSR) (GET)  
 R2 000xx. min  
 R3 0xx.xx sec

VERB 25 ENTR—to load pad  $t_{IG}$  (NSR) if displayed  $t_{IG}$  not same as final NSR pad. PRO.

PRO—when satisfied with displayed  $t_{IG}$ . Observe flashing Noun 45.

4b. FL V16 N45

R1 xxBxx VHF-Optics mark counters  
 R2 xxBxx min-sec TFI (NSR)  
 R3 -00001 preliminary cycle

- Perform SXT marking.
- Perform R27 procedures. (Refer to paragraph 4.2.1.3.)

VERB 32 ENTR—to recycle for preliminary solution. Observe flashing display of preliminary Noun-75 data.

PRO—to terminate state-vector update by marks, and obtain a final targeting solution. Observe flashing display of final Noun-75 data.

4c. FL V06 N75

R1 xxxx.x n.mi.  $\Delta h$  (NSR)  
 R2 xxBxx min-sec  $\Delta t t_{IG}$  (TPI) -  $t_{IG}$  (NSR)  
 R3 xxBxx min-sec  $\Delta t t_{IG}$  (TPI) P34 -  $t_{IG}$  (TPI) P31

PRO—observe flashing of either preliminary or final Noun-81 velocity-change computations depending upon response to Noun 45.

4d. FL V06 N81

R1	xxxx.x	fps $\Delta v_x$ (LV) NSR
R2	xxxx.x	fps $\Delta v_y$ (LV)
R3	xxxx.x	fps $\Delta v_z$ (LV)

where R1 is x-component, in local-vertical coordinates, of the impulsive velocity change at  $t_{IG}$  (NSR); R2 is the y-component; and R3 is the z-component.

NOTE.—For final solution, crew compares the CMC, the ground, and the chart solutions. If the CMC solution agrees with either the chart or the ground solution within a planned tolerance for the x-, y-, and z-components of the  $\underline{v}_G$ , the CMC solution is used. If the CMC solution does not agree with either of the other two, the crew compares the chart and ground solutions. If they agree within this tolerance, the crew uses the chart solution. Should all three disagree, the crew uses the ground solution.

VERB 25 ENTR—to load other than CMC solution.

PRO—to continue. Observe flashing Noun-45 display.

4e. FL V16 N45

R1	xxBxx	VHF-Optics mark counter
R2	xxBxx	min-sec TFI (NSR)
R3	-00001	preliminary cycle
<u>or</u>	xxx.xx	deg MGA
<u>or</u>	-00002	final cycle (IMU not aligned)

where R1 is number of VHF and SXT marks accumulated since last W-matrix reinitialization; R2 is time from NSR ignition; and R3 is (1) -00001 if computation was preliminary (VERB 32 ENTR on step 4b), (2) value of middle gimbal angle at thrusting attitude if IMU aligned and computation was final (PRO on step 4b), or (3) -00002 if IMU not aligned and computation was final.

VERB 32 ENTR—to recycle for another preliminary solution. Observe FL V06 N75.

PRO—to exit to thrusting program or to obtain final comp. Observe either final FL V06 N75 or PROG number on DSKY change to 40 or 41 depending upon which thrusting program is called by R07, the MINKEY Controller.

After the maneuver, which puts the CSM in an orbit that is coelliptic with, and nominally below, the OWS, the crew trims the NSR residuals to ensure nominal terminal-phase conditions, and voices residuals to the ground. After ground confirmation of the burn, the crew maneuvers headsup and enters the TPI Targeting Program, P35.

5. Key VERB 37 ENTR 35 ENTR. (See common procedures.) Observe flashing display of  $t_{IG}$  (TPI).

5a. FL V06 N37

R1	00xxx	hr $t_{IG}$ (TPI)-(GET)
R2	000xx	min
R3	0xx.xx	sec

- Change to heads-up attitude. Refer to paragraph 4.2.1.

NOTE.—Keying Verb 58 sets V50N18FL enabling P20-R60 automatic maneuver to new attitude loaded in Noun 78. Crew observes FL V50 N18 and V06 N18 and the return of  $t_{IG}$  (TPI).

PRO. Observe flashing display of integration option and elevation angle.

5b. FL V06 N55

R1	0000n	Number of target offsets
R2	000.00 deg	elevation angle
R3	Blank	

where R1 indicates either conic integration (+00000) or precision integration (+00002) with two offsets to determine the target vector at intercept time; and R2 contains either +00000 if CMC is to calculate an elevation angle based on a  $t_{IG}$  time or +027.00 deg, the nominal pad-loaded value for  $E_L$ .

NOTE.—If  $t_{IG}$  option desired, verify that R2 contains pad value for  $E_L$ . If  $E_L$  option desired, verify R2 contains +00000.

VERB 24 ENTR—to load new values. PRO.

PRO—to continue. Observe flashing Noun-45 display.

5c. FL V16 N45

R1	xxBxx	VHF-optics mark counter
R2	xxBxx	min-sec TFI (TPI)
R3	-00001	preliminary cycle

- Perform SXT marking.
- Set Digital Event Timer with R2 and perform R27 procedures to calculate chart solutions, based on DET. Refer to paragraph 4.2.1.3.2.

VERB 32 ENTR—to temporarily terminate state-vector update by marks and to recycle the targeting computations to obtain a preliminary solution. Observe flashing display either of preliminary  $t_{IG}$  (TPI) (NOUN 37) or of preliminary elevation angle (NOUN 55).

PRO—to terminate state-vector update by marks, and obtain a final targeting solution. Observe final  $t_{IG}$  (TPI) (NOUN 37) or final elevation angle (NOUN 55).

5d.  $t_{IG}$  Option

FL V06 N37

R1 00xxx. hrs  $t_{IG}$  (TPI) (GET)  
 R2 000xx. min  
 R3 0xx.xx sec

VERB 25 ENTR—to load different  $t_{IG}$  (TPI). If final pass and MINKEY, a new elevation angle is computed. PRO. Observe FL V06 N55.

PRO—observe FL V06 N58.

5d. Elevation-angle Option

FL V06 N55

R1 xxxxxx  
 R2 xxx.xx Elevation angle  
 R3 Blank

PRO—to continue.



5e. FL V06 N58

R1    xxxx.x fps        $\Delta v$  (TPI)  
 R2    xxxx.x fps        $\Delta v$  (TPF)  
 R3    xxBxx min-sec  $\Delta t$  slip in  $t_{IG}$  (TPI)

where R1 is magnitude of required velocity-change at TPI; R2 is magnitude of required velocity-change at TPF; and R3 is difference between  $t_{IG}$  (TPI) as calculated by this program and  $t_{IG}$  (TPI) input in Noun 37. Display is modulo one hour.

PRO

5f. FL V06 N81

R1    xxxx.x fps  $\Delta v_x$  (LV)  
 R2    xxxx.x fps  $\Delta v_y$  (LV)  
 R3    xxxx.x fps  $\Delta v_z$  (LV)

NOTE.—When the CMC computes a final solution, the crew, having computed the backup TPI chart solution using VHF ranging data, compares the CMC, chart, and ground TPI solutions and proceeds as advised in premission planning.

VERB 25 ENTR—to load other than CMC solution. PRO.

PRO—to continue.

5g. FL V16 N45

R1    xxBxx    VHF- Optics mark counter  
 R2    xxBxx    min-sec TFI (TPI)  
 R3    -00001    preliminary cycle  
or    xxx.xx    deg MGA  
or    -00002    final cycle (IMU not aligned)

where R1 is number of VHF and SXT marks accumulated since last W-matrix reinitialization; R2 is time from TPI ignition; and R3 is (1) -00001 if preliminary computation (VERB 32 ENTR on step 5c), (2) value of middle gimbal angle at thrusting attitude if IMU aligned and computation was final (PRO on step 5c), or (3) -00002 if IMU not aligned and computation was final.

NOTE.—If the  $t_{IG}$  option has been chosen and crew wishes to recycle, R27 data points will be based on original DET setting.

VERB 32 ENTR—to recycle for another preliminary solution. Observe either FL V06 N37 or FL V06 N55.

PRO—to exit to thrusting program or to obtain final comp. Observe FL V06 N37, FL V06 N55, or PROG number on DSKY change to 40 or 41 depending upon which thrusting program is called by R07, the MINKEY Controller.

TPI, normally an SPS maneuver, nominally occurs just before orbital midnight. The burn attitude is headsup and the burn is executed when the elevation angle to the OWS is approximately 27.0 deg. Rendezvous navigation with SXT tracking is continued and P36 is called to compute the midcourse corrections. Nominally, two midcourse corrections will be performed to minimize propagated state errors and reduce RCS fuel consumption during TPF braking. P36 will, therefore, be called twice to compute these maneuvers.

6. Key VERB 37 ENTR 36 ENTR. (See common procedures.) Observe flashing Noun 45 display.

6a. FL V16 N45

R1   xxBxx VHF-Optics mark counters  
 R2   xxBxx min-sec TFI ( + from TPI)  
 R3   -00001 preliminary cycle

NOTE.—P36 computes  $t_{IG}$  to be 3 min from time of response to Noun-45 display.

- Perform SXT marking.
- Set DET with R2 and perform R27 procedures for backup chart solutions based on DET.

VERB 32 ENTR—to recycle for another targeting solution. Observe preliminary Noun 59.

PRO—to terminate state-vector update by marks and obtain a final targeting solution. Observe final Noun 59.

6b. FL V06 N59

R1   xxxx.x fps  $\Delta v$  LOS (TPM)  
 R2   xxxx.x fps  $\Delta v$  LOS  
 R3   xxxx.x fps  $\Delta v$  LOS

where Noun 59 displays x, y, and z line-of-sight components.

NOTE.—Compare CMC solution with chart solutions.

VERB 25 ENTR—to load other than CMC solution.

PRO—to continue.

6c. FL V16 N45

R1   xxBxx   VHF-Optics mark counter  
 R2   xxBxx   min-sec TFI (TPM)  
 R3   -00001   preliminary cycle  
or   xxx.x   deg   MGA  
or   -00002   final cycle (IMU not aligned)

where R1 is number of VHF and SXT marks accumulated since last W-matrix re-initialization; R2 is time from TPI ignition; and R3 is (1) -00001 if preliminary computation (VERB 32 ENTR on step 5c), (3) value of middle gimbal angle at thrusting attitude if IMU aligned and computation was final (PRO on step 5c), or (3) -00002 if IMU not aligned and computation was final.

VERB 32 ENTR—to recycle for another preliminary solution. Observe preliminary FL V06 N59.

PRO—to exit to thrusting program or to obtain final comp. Observe either FL V06 N59 or PROG number of DSKY change to 40 or 41 depending upon which program is called by R07, the MINKEY Controller.

The crew uses the CMC solution for TPM-1 if it appears reasonable. Otherwise, crew uses chart solution. If both solutions appear unreasonable, crew bypasses TPM-1. The crew recalls P36, takes additional marks on OWS, performs TPM-2 and enters P37.

7. Key VERB 37 ENTR 37 ENTR. (See common procedures.) Observe flashing Noun 54 display.

7a. FL V16 N54

R1	xxx.xx n.mi.	Range to OWS
R2	xxxx.x fps	Range-rate CSM-OWS
R3	xxx.xx deg	Angle ( $\theta$ ) between CSM + x-axis and the local-horizonal.

NOTE.—This display is updated about every 2 sec.

PRO—Monitor. At R=1.5 n.mi., key PRO.

NOTE.—PRO calls P48, The Rendezvous Thrust Monitor, and obtains R and R-dot via R27. Crew adjusts rate of closure according to checklist specifications.

8. Key VERB 37 ENTR 38 ENTR. (See common procedures.) Observe flashing Noun 39 display.

NOTE.—The NPC Targeting Program, P38 (shown here as reset point 8) is normally entered between P31 and P32 if needed.

8a. FL V06 N39

R1 00xxx. hr  $t_{IG}$  of last maneuver (GET)  
 R2 000xx. min  
 R3 0xx.xx sec

VERB 25 ENTR.—to change display.

PRO—to continue.

8b. FL V06 N33

R1 00xxx. hr  $t_{IG}$  (NPC) (GET)  
 R2 000xx. min  
 R3 0xx.xx sec

NOTE.— $t_{IG}$  (NPC) is computed from CSM state vector to occur 90 deg after time displayed in Noun 39, i.e., at anode.

VERB 25 ENTR—to load ground  $t_{IG}$  (NPC) if value displayed not same as final NPC pad. PRO.

PRO—to continue. Observe FL V16 N45.

8c. FL V16 N45

R1 xxbxx VHF-optics mark counter  
 R2 xxBxx min-sec TFI (NPC)  
 R3 -00001 preliminary cycle

VERB 32 ENTR—to recycle the targeting computations, take more marks, and obtain a preliminary solution. Observe flashing preliminary Noun-81 display.

PRO—to terminate navigation, and obtain a final targeting solution. Observe final Noun-81 display.

8d. FL V06 N81

R1 0000.0 fps  
 R2 xxxx.x fps  $\Delta v_y$  (NPC)  
 R3 0000.0 fps

NOTE.—If  $\Delta v_y$  is computed to be less than 0.1 fps, R2 displays zeros.

VERB 22 ENTR—to load ground value if final Noun-81 display does not agree with final NPC pad value. PRO.

PRO—When satisfied with display. Observe FL V16 N45.

8e. FL V16 N45

R1 xxBxx VHF-Optics mark counter  
 R2 xxBxx min-sec TFI (NPC)  
 R3 -00001 preliminary cycle  
or xxx.xx deg MGA  
or -00002 final cycle (IMU not aligned)

where R1 is number of VHF and SXT marks accumulated since last W-matrix reinitialization; R2 is time from NPC ignition; R3 is (1) -00001 if Noun-81 computation was preliminary (VERB 32 ENTR on step 8c), (2) value of middle gimbal angle at thrusting attitude for CSM +x-axis aligned with initial thrust direction if Noun-81 computation was final (PRO on step 8c), and (3) -00002 if computation was final and IMU not aligned.

VERB 32 ENTR—to recycle for another preliminary solution. Observe FL V06 N81.

PRO—to obtain final comp or to exit to P52 to perform pulse torquing. Observe either FL V06 N81 or FL V06 N22.

The computer automatically sequences through P52, and P40 or 41 (depending upon value of  $v_G$ ). If P40 is performed, sequence re-enters P52 to perform post-plane-change pulse torquing. At completion of pulse torquing, computer displays

FL VERB 37 requesting new program. Crew keys in P32, and continues rendezvous sequence at reset point 2.

If P41 is performed, computer must determine if pulse torquing was performed. If so, sequence continues as if P40 had been performed. If not, computer displays FL VERB 37 and crew keys in P32 and, again, continues rendezvous sequence at reset point 2.



SECTION 6.0

POWERED FLIGHT

## 6.1 INTRODUCTION TO POWERED FLIGHT

Four programs constitute the powered-flight major modes for the command and service module (CSM). Two of the four are monitor programs; one uses 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 uses 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.
- P48, the Rendezvous Thrust Monitor Program—paragraph 6.2.4.

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.

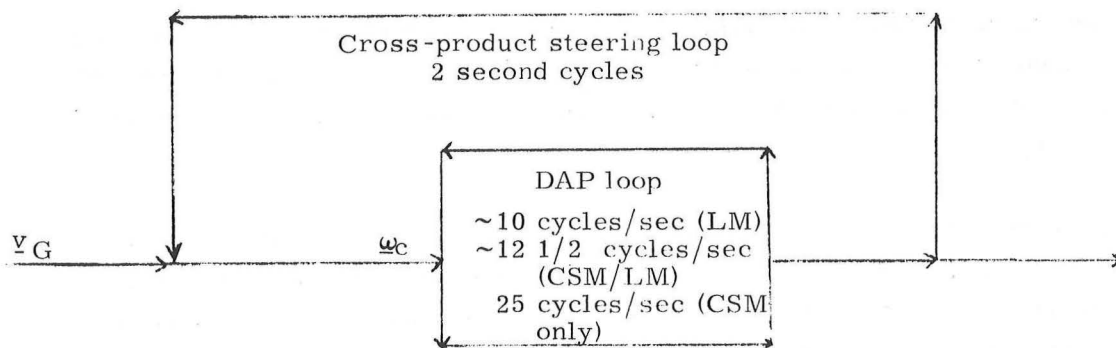


Figure 6.1-1. Steering and DAP Loops

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 vehicle configurations, the

DAP loop operation within the larger steering loop is discussed separately in the introduction to the CSM vehicle, subsection 6.2.

All four 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 use the cross-product steering subroutine to update the velocity-to-be-gained vector ( $\underline{v}_G$ ); the CSM P40 also uses 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, SPS and RCS burns; aerodynamic forces during boost and entry). In contrast with the Coasting Integration Routine, AVERAGEG is used when a short computing time is required.\*

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  $\Delta v$ . 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

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\* The Coasting Integration Routine takes longer than AVERAGEG and uses multiple iterations to arrive at a precision solution.

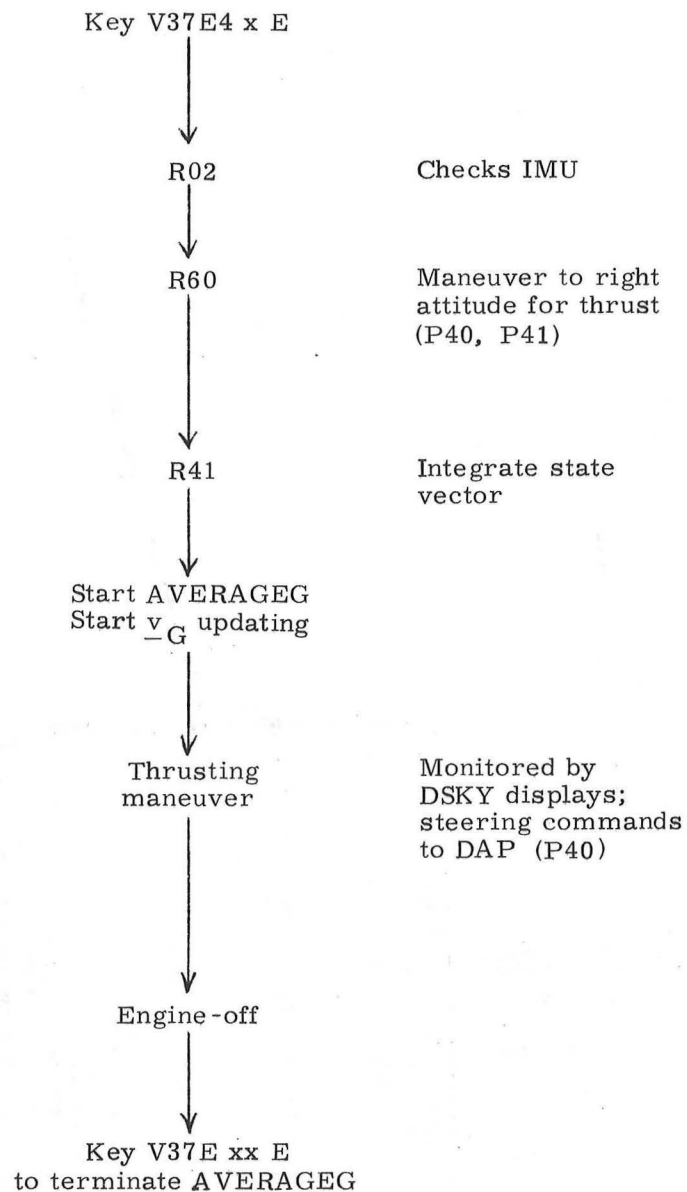


Figure 6.1-2. Powered-flight Logic

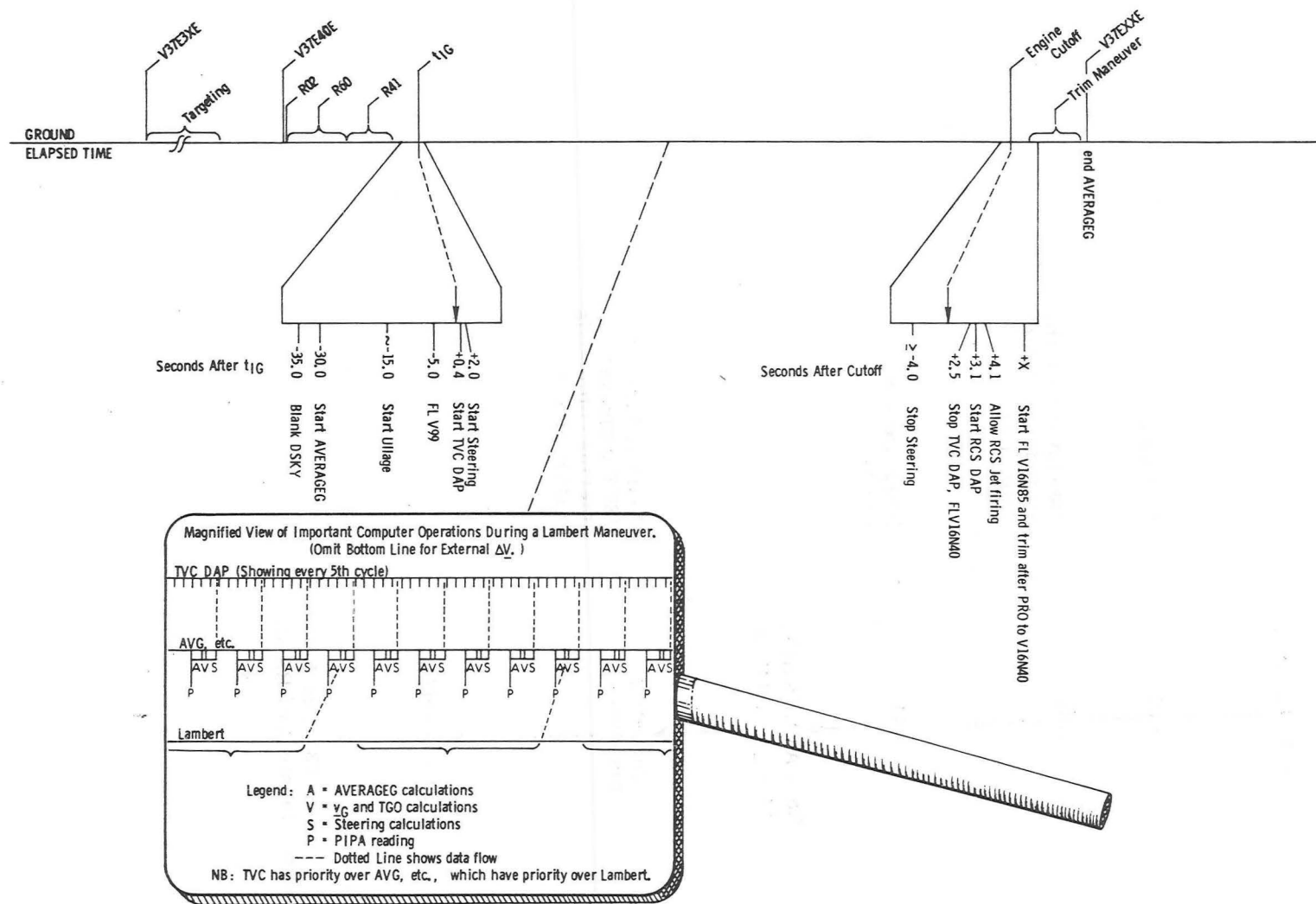


Figure 6.1-3. Typical Timeline for a CSM P40 Maneuver

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. 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, updates the CSM mass, 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 velocity.

The general objective of cross-product steering is to align  $(\underline{a}_T - c\underline{b})$  with  $\underline{v}_G$ , where:

$$\underline{v}_G = \underline{v}_R - \underline{v} = \text{required velocity} - \text{actual velocity}$$

$$\underline{b} = \frac{d\underline{v}_R}{dt} - \underline{g}$$

$$\underline{a}_T = \text{thrust acceleration}$$

$c$  = a mixing factor empirically chosen to minimize fuel consumption and optimize or control vehicle attitude change during the maneuver. The nominal values of  $c$  are as follows for the programs listed:

P30, P31, P32, P34, and P38 (External $\Delta v$ )	0
P33, P35, P36, (Lambert)	1

Steering, then, generates the rate-command inputs to the CSM TVC DAPs. These inputs are derived from the components of a vector  $\underline{\omega}_c$  expressed in body-axis coordinates. (The roll component is ignored;\* the pitch and yaw components are

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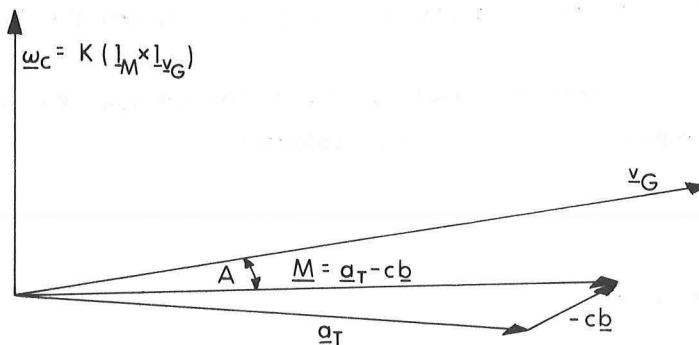
\*Since body orientation about  $\underline{a}_T$  is not critical, roll control can be handled independently via a separate roll autopilot.



sent to the pitch and yaw TVC DAPs, respectively.) The vector  $\underline{\omega}_c$  is the cross-product between the unit vectors along  $\underline{v}_G$  and  $\underline{M} = \underline{a}_T - c\underline{b}$ , multiplied by a constant of proportionality K, the steering gain. (See the figure below.) The equation is shown as follows:

$$\underline{\omega}_c = K (\underline{1}_M \times \underline{1}_{v_G})$$

The magnitude of  $\underline{\omega}_c$ , representing the total rate commands, is proportional to the angle A, and is in the direction such that  $\underline{M}$  will rotate towards  $\underline{v}_G$ ;  $\underline{\omega}_c$  vanishes when the desired alignment is achieved (i.e.,  $A = 0$ ). Controlling  $\underline{M}$  is, essentially, controlling  $\underline{a}_T$  because (1)  $-c\underline{b}$  is small relative to  $\underline{a}_T$  (for external  $\Delta v$  burns,  $c\underline{b}$  is identically zero), and (2)  $\underline{a}_T$  is relatively fixed in the body-axis frame since thrust passes through the c.g. in the steady state.



K is chosen to balance the conflicting requirements of speed of response and closed-loop stability. The initial burn attitude is chosen to align  $\underline{v}_G$  and  $\underline{M}$  at ignition,  $(\underline{a}_T - c\underline{b}) \times \underline{v}_G = 0$ . For external  $\Delta v$  burns, where  $c = 0$ , initial alignment satisfies the equation  $\underline{a}_T \times \underline{v}_G = 0$ . The value of  $\underline{a}_T$  used is a pre-burn estimate based on nominal thrust and expected c.g. offsets.

For P40 and P41, 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 P40, the computations are used to generate steering commands and to update the estimate of engine cut-off time. In P41, 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  $\Delta v$  and Lambert Aimpoint. Figure 6.1.2-1 gives a general flow of the cross-product steering logic.

#### 6.1.2.1 External- $\Delta v$ Guidance Mode

The External- $\Delta v$  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 c.g. (center of gravity); c.g. motion; or DAP commands to compensate for slosh, etc.

The External- $\Delta v$  mode is used to control maneuvers in which a constant thrust attitude is desired. Such maneuvers may be targeted in either P30, P31, P32, P34, or P38. Examples of CSM External- $\Delta v$  maneuvers are as follows:

NC1 targeting	P31
NC2 targeting	P32
NSR targeting	P34
Plane-change (PC)	P38

The guidance program accepts input data from the above targeting programs in the form of an impulsive  $\Delta v$  required in local vertical coordinates 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. This rotation accounts for real-burn gravitational forces, which were not considered in the impulsive  $\Delta v$  targeting calculations. After it has computed this compensated  $\Delta v$ , the program overwrites the contents of NOUN 81 (local vertical  $\Delta v$  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  $\Delta v$ , as displayed in NOUN 81, have changed.



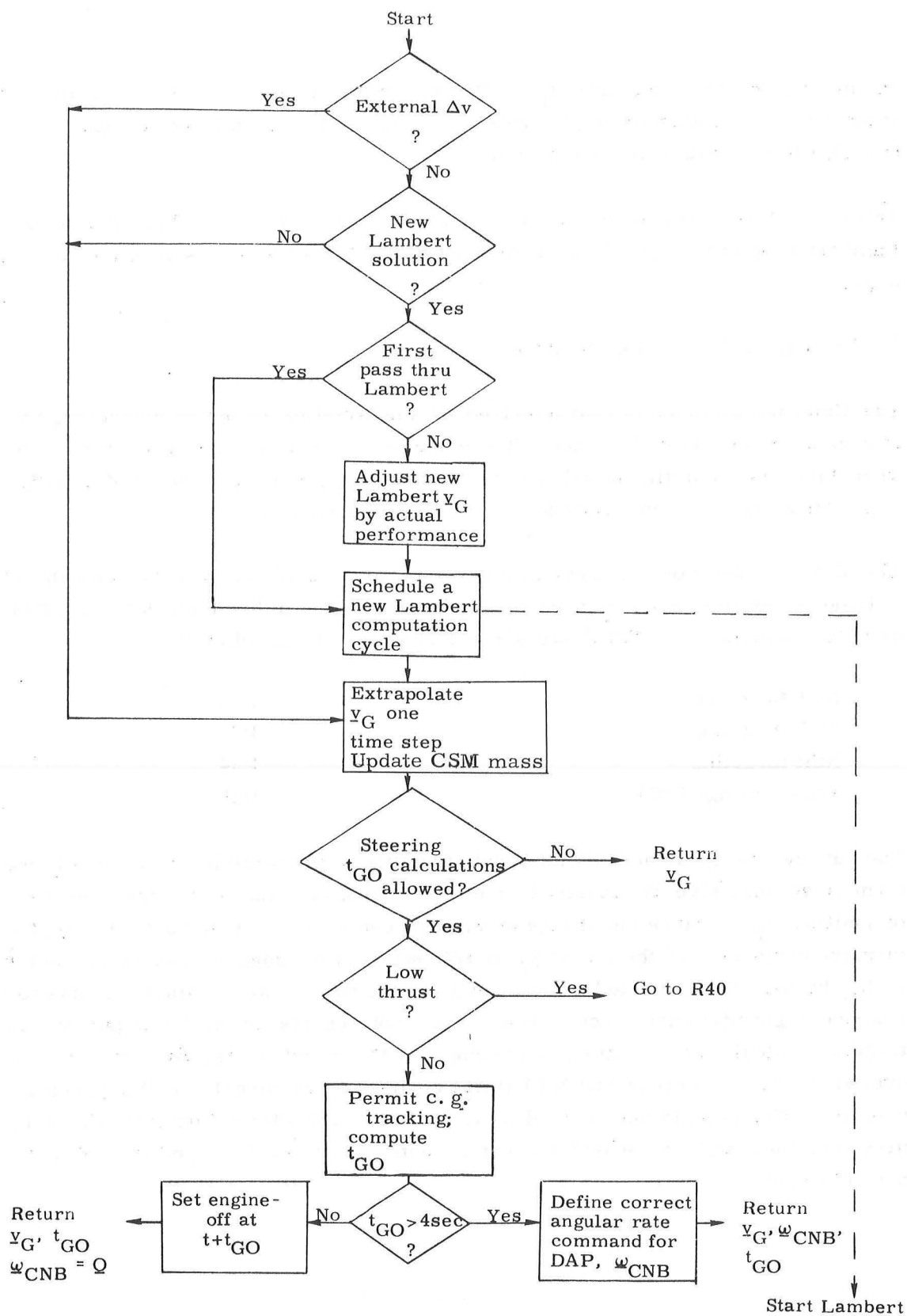


Figure 6.1.2-1. Logic Flow of CSM Cross-product Steering

Figure 6.1.2-1 shows how the External- $\Delta v$  mode fits into the Cross-product Steering Routine for the CSM.

#### 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.)

Such maneuvers may be targeted by P33, P35, and P36. Examples of CSM Lambert maneuvers are as follows:

NCC targeting	P33
Rendezvous intercept	P35
Rendezvous midcourse maneuver	P36

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 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.

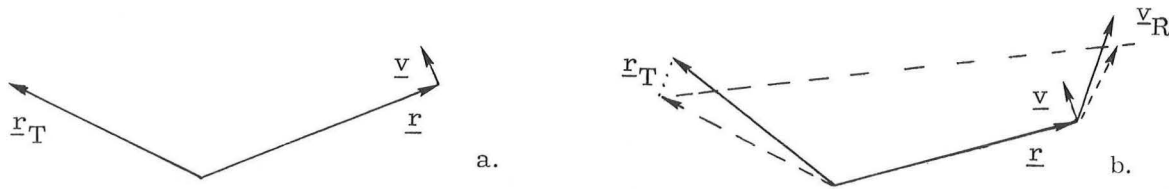


Figure 6.1.2-2. Lambert Routine Vectors

A switch is set in the Lambert targeting programs (P33, P35 and P36) to indicate whether  $\underline{r}_T$  is within a specified cone angle,  $\epsilon$ , 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  $\Delta v$  are avoided. In the intercept targeting programs (P33, P35 and P36) the cone angle  $\epsilon$  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  $\pm$ 15-deg sector is either intentionally selected, during NCC targeting (P33), during the TPI targeting (P35), or is the result of a rendezvous midcourse correction maneuver (P36) during an intercept trajectory targeted for more than 180 deg, the Lambert Routine increases the cone angle  $\epsilon$  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 P33, P35 and P36,  $\epsilon$  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  $\underline{v}$  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  $\underline{v}_G$ .

## 6.2 CMC POWERED-FLIGHT PROGRAMS

The Command Module Computer (CMC) has two thrust monitor programs—P47 and P48 (used with VHF during rendezvous final phase) and 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

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\* Although use of a lunar module is not planned for a SKYLAB mission, references to the LM have not been deleted, since the CSM-alone and TVC DAPs retain the capability to perform maneuvers with the LM attached.

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 (c.g.) when there is no c.g. 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 sec and jet firings are commanded only if the 5-deg 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 and the estimated engine-trim angles in the pitch and yaw planes. (The values are displayed in R03. Refer to paragraph 9.2.1). 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 sec by TVCEXEC, computes piecewise-linear approximations to the curves of  $I_{xx}$ ,  $I_{AVG}$ , and  $I_{AVG}/Tl_x$  versus CSM propellant weight. These curves are given in parametric form, with LM mass as the parameter.

P40 initiates the operations of the TVC DAP after ignition. At 0.5-sec intervals, ROLL DAP and a routine to update the FDAI needles are called. Four sec before the end of the burn, the engine shutdown sequence is begun. After SPS engine shutdown, there is a 2.5-sec delay while the TVC DAP continues to function as the thrust level decays. RCS jet firings start approximately 1.5 sec 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 sec. During changeover from RCS to TVC, there is a short period (0.5 to 1 sec) 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 CSM-alone DAP. For the CSM/LM, the needles are not reestablished with the CSM-alone 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 CSM-alone digital autopilot (CSM-alone DAP) can be selected by the crew to provide rotational and translational control of the vehicle before and after a P40-guided SPS maneuver. It can also be selected to provide the same control before, during, and after a P41-guided RCS maneuver. During these times, a desired vehicle state (i.e., a desired attitude and rotation rate) can be specified. By means of a phase-plane switching logic and a jet-firing logic, the CSM-alone DAP will maintain the difference between actual and desired vehicle state to within a certain tolerance (deadbands on attitude and rate). If the difference is within the tolerance, the CSM-alone DAP will request no action. If, however, the difference exceeds the

tolerance, the CSM-alone DAP will cause RCS jets to be fired to bring the difference back within tolerance.

The Docked DAP can also be selected to provide rotational and translational control before, during, and after a P41-guided maneuver. Refer to Section 11 for a description of the Docked DAP.

P40 will compute a pre-burn state and, with crew approval, the CSM-alone DAP will use this as its desired state. Two ways of changing the desired state are use of the rotational hand controller and execution of the attitude maneuver routine R60.

### 6.2.1 P40, Service Propulsion System (SPS) Maneuver

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,

$$\frac{F_{\text{SPS}}}{m} \cdot \Delta t_{\text{min}}$$

In the expression above,  $F_{\text{SPS}}$  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  $\Delta t_{\text{MIN}}$  is the minimum burn time for which the particular SPS engine being considered has been successfully tested. Currently,  $\Delta t_{\text{MIN}}$  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 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, VHF or Optics marks should not be accepted in P20 (Options 0 or 4) 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.

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\* Although use of a lunar module is not planned for a SKYLAB mission, references to the LM have not been deleted, since the CSM-alone and TVC DAPs retain the capability to perform maneuvers with the LM attached.



#### 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 $\Delta v$ and Lambert Aimpoint)

Cross-product steering is used to guide the thrust direction. The two modes, External  $\Delta v$  and Lambert aimpoint, use the cross-product steering concept to control the thrust direction relative to the velocity-to-be-gained ( $\underline{v}_G$ ) vector direction and to terminate thrust when the desired velocity increment has been achieved. (Refer to paragraph 6.1.2.) The two modes differ in method of computing  $\underline{v}_G$ . External  $\Delta v$  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  $\Delta v$ , 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 the cross-product steering subroutine, External  $\Delta v$ , and Lambert aimpoint, refer to paragraphs 6.1.2, 6.1.2.1, and 6.1.2.2, respectively.

#### 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

TABLE 6.2.1-1  
DISPLAYS ASSOCIATED WITH P40 (CSM) (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 cutoff (TFC) 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 $v_G$ magnitude Sum of velocity acquired	R1 xxBxx min, sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec
FL V16 N85	P40	Display remaining $v_G$	Components of $v_G$	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 (CSM) (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 (CSM)

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

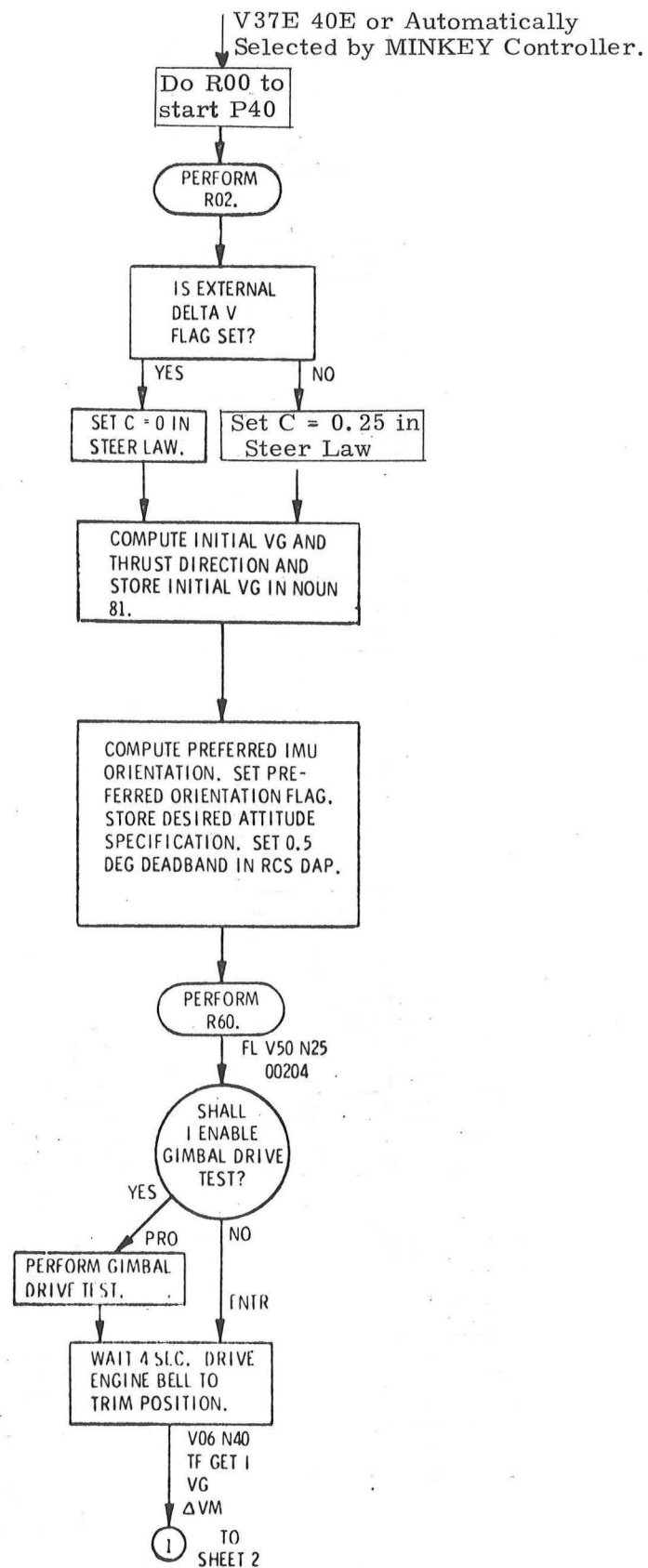


Figure 6. 2. 1-1. SPS Maneuver Program (CSM P40) (Sheet 1 of 3)

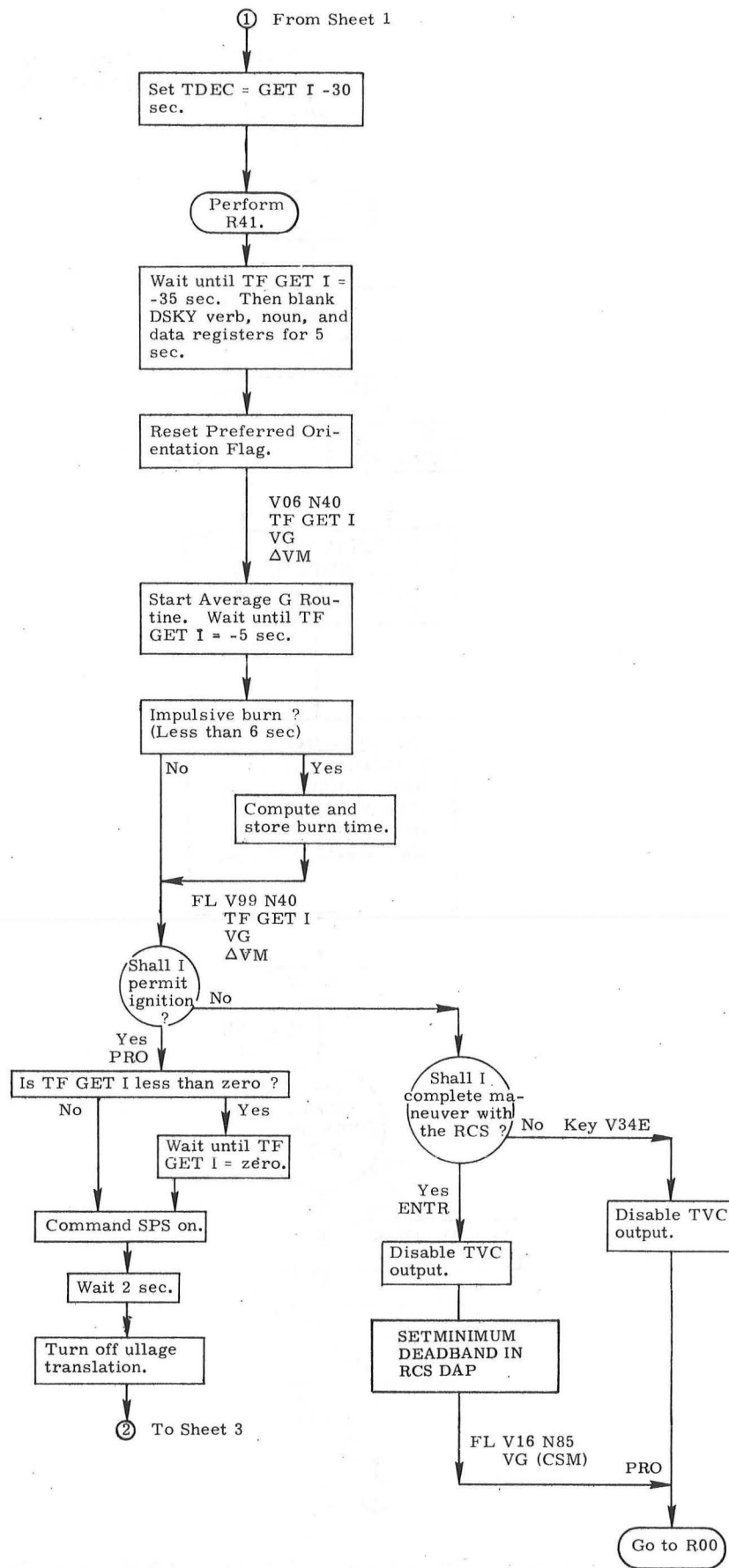


Figure 6.2.1-1. SPS Maneuver Program (CSM P40) (Sheet 2 of 3)

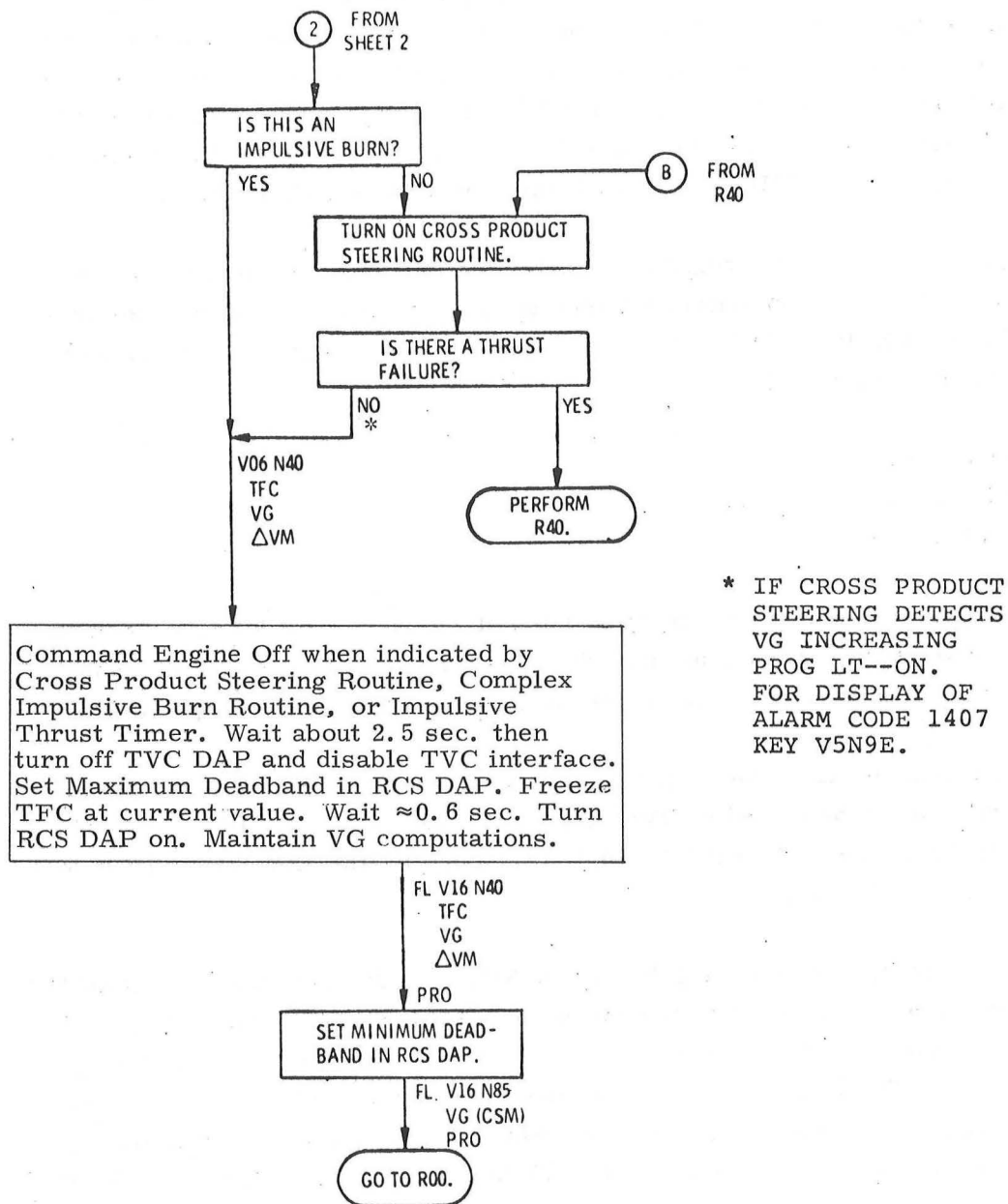


Figure 6.2.1-1. SPS Maneuver Program (CSM P40) (Sheet 3 of 3)

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 SPS and TVC, and performing R60. P40 can also be selected automatically by the MINKEY controller. Refer to paragraph 4.2.1. 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  $\underline{y}_G$  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  $\underline{y}_G$  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 CSM-alone 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  $\underline{v}_G$  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 OWS (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 Timelines

Figure 6.2.1-2 relates the P40 flowchart to crew observance and response.

COMPUTER PERFORMANCE

ASTRONAUT/DSKY

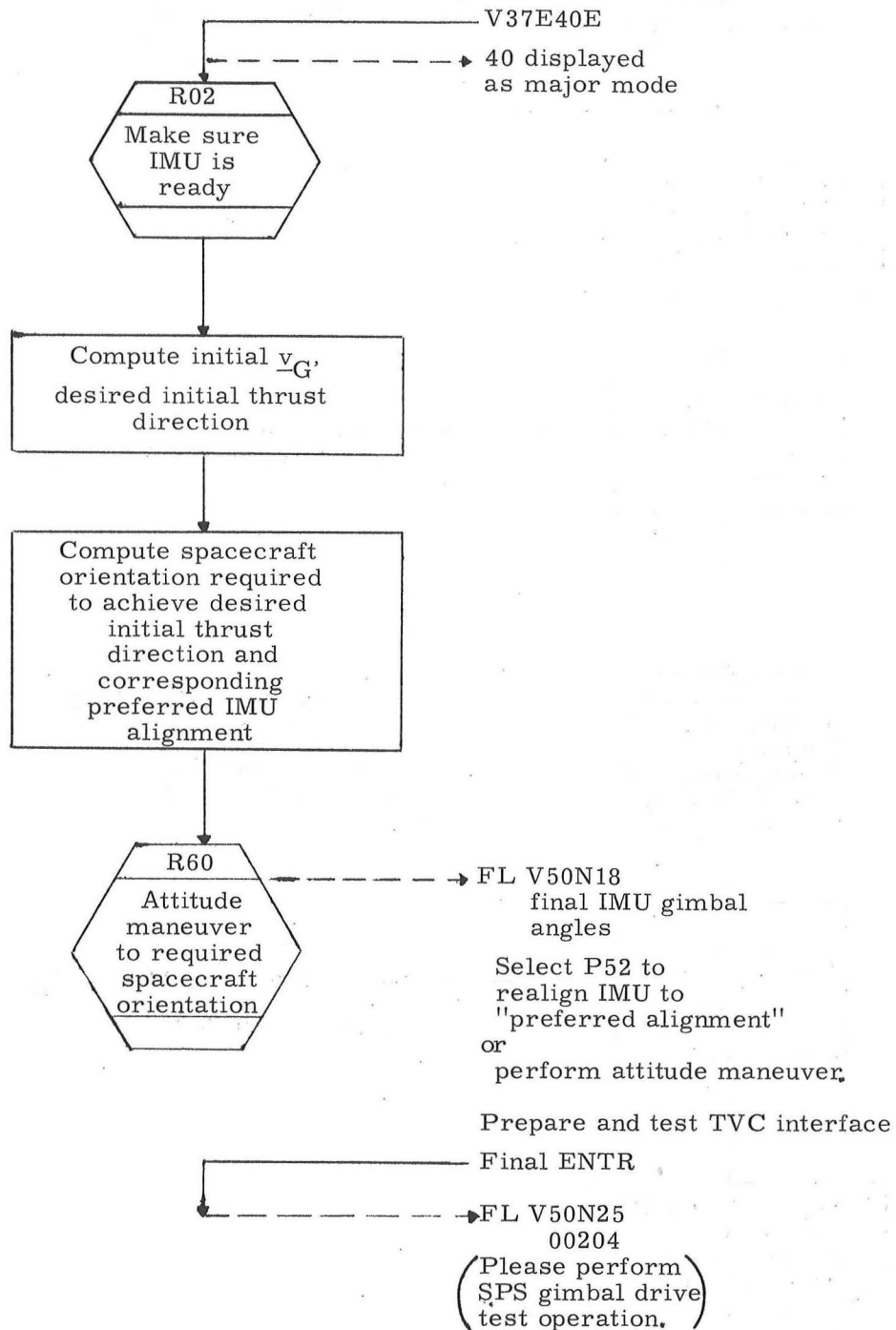


Figure 6. 2. 1-2. Timelines of SPS Maneuver Program (CSM P40)  
(Sheet 1 of 4)

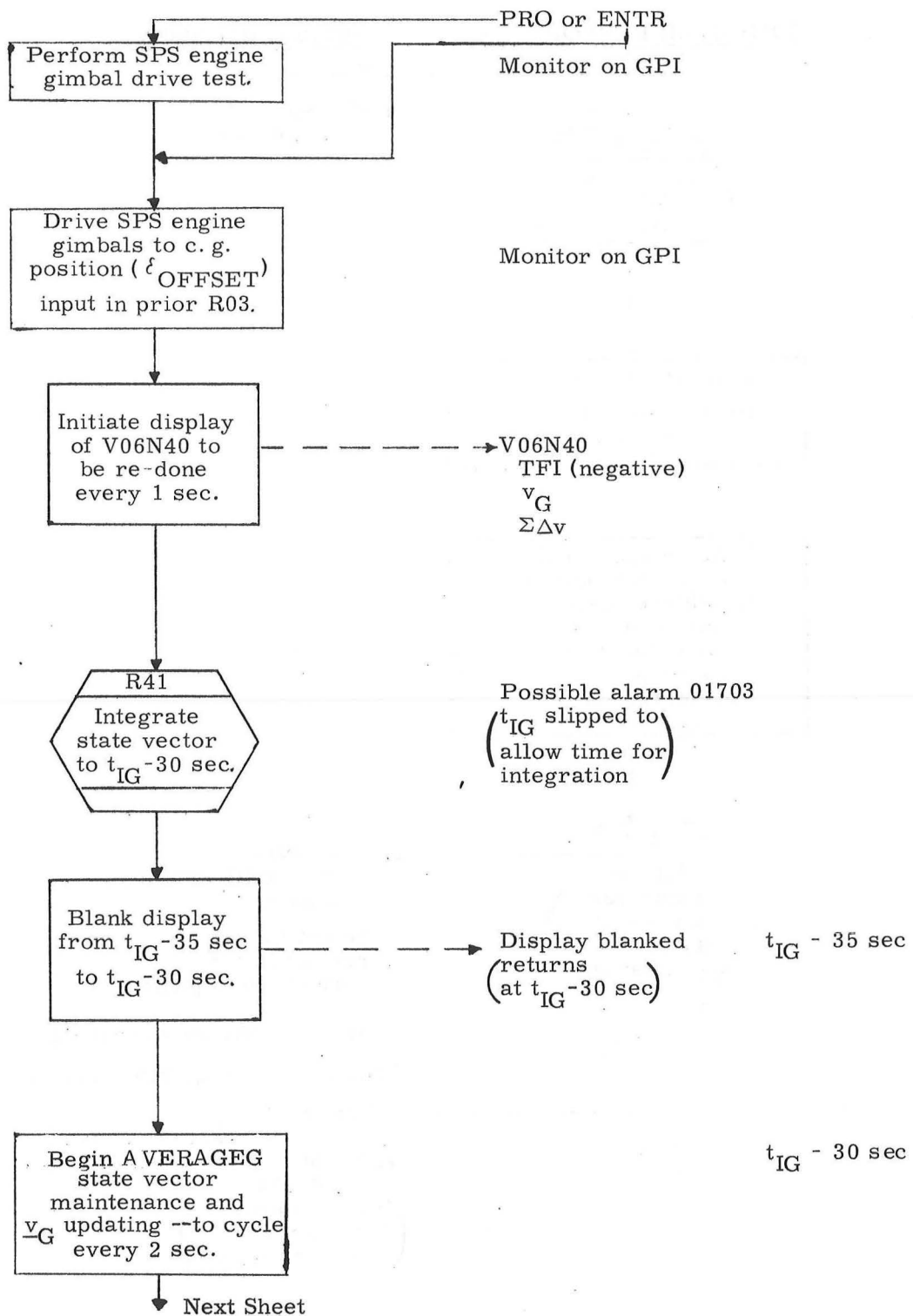


Figure 6.2.1-2. Timelines of SPS Maneuver Program (CSM P40)  
(Sheet 2 of 4)

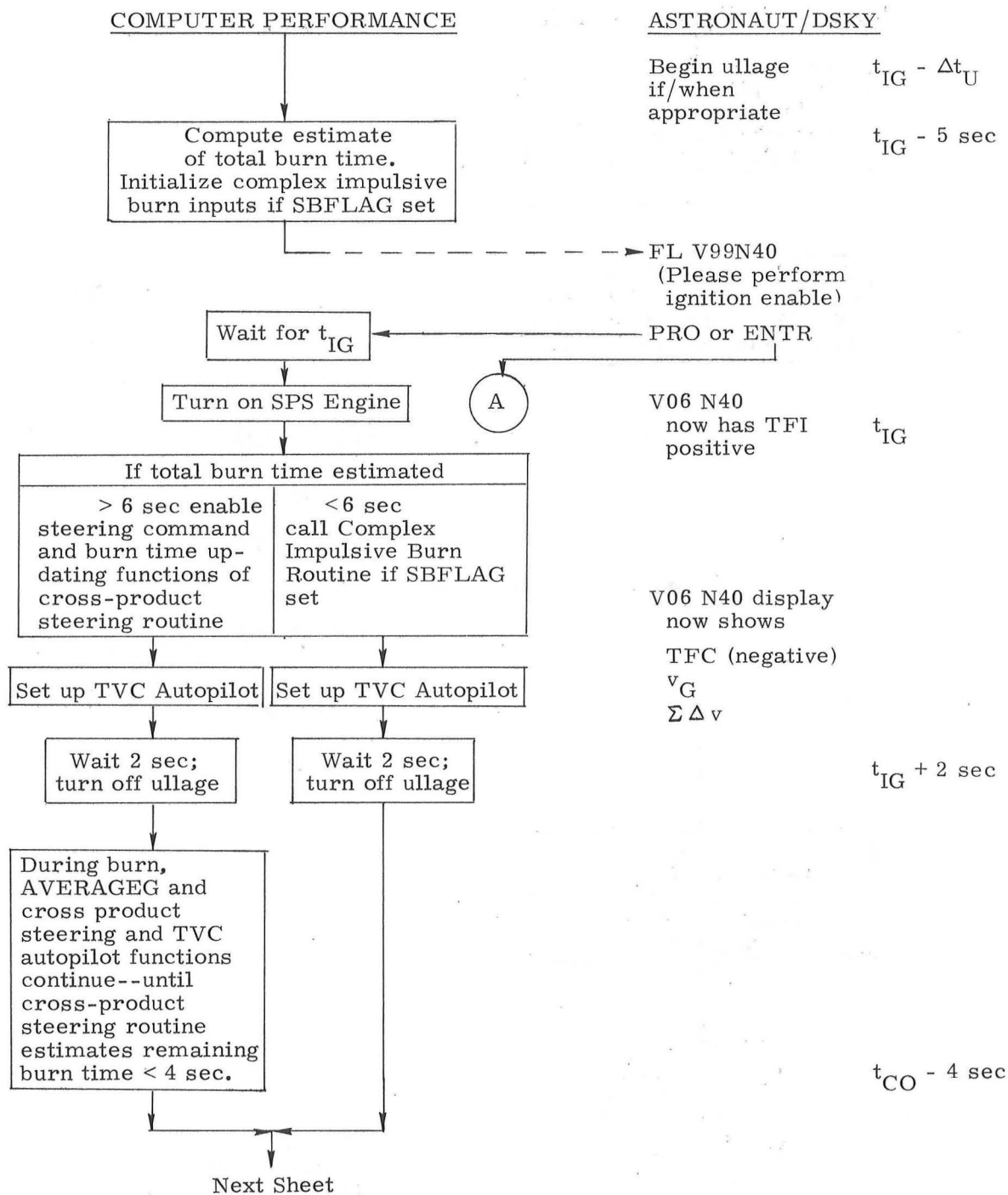


Figure 6.2.1-2. Timelines of SPS Maneuver Program (CSM P40)  
(Sheet 3 of 4)

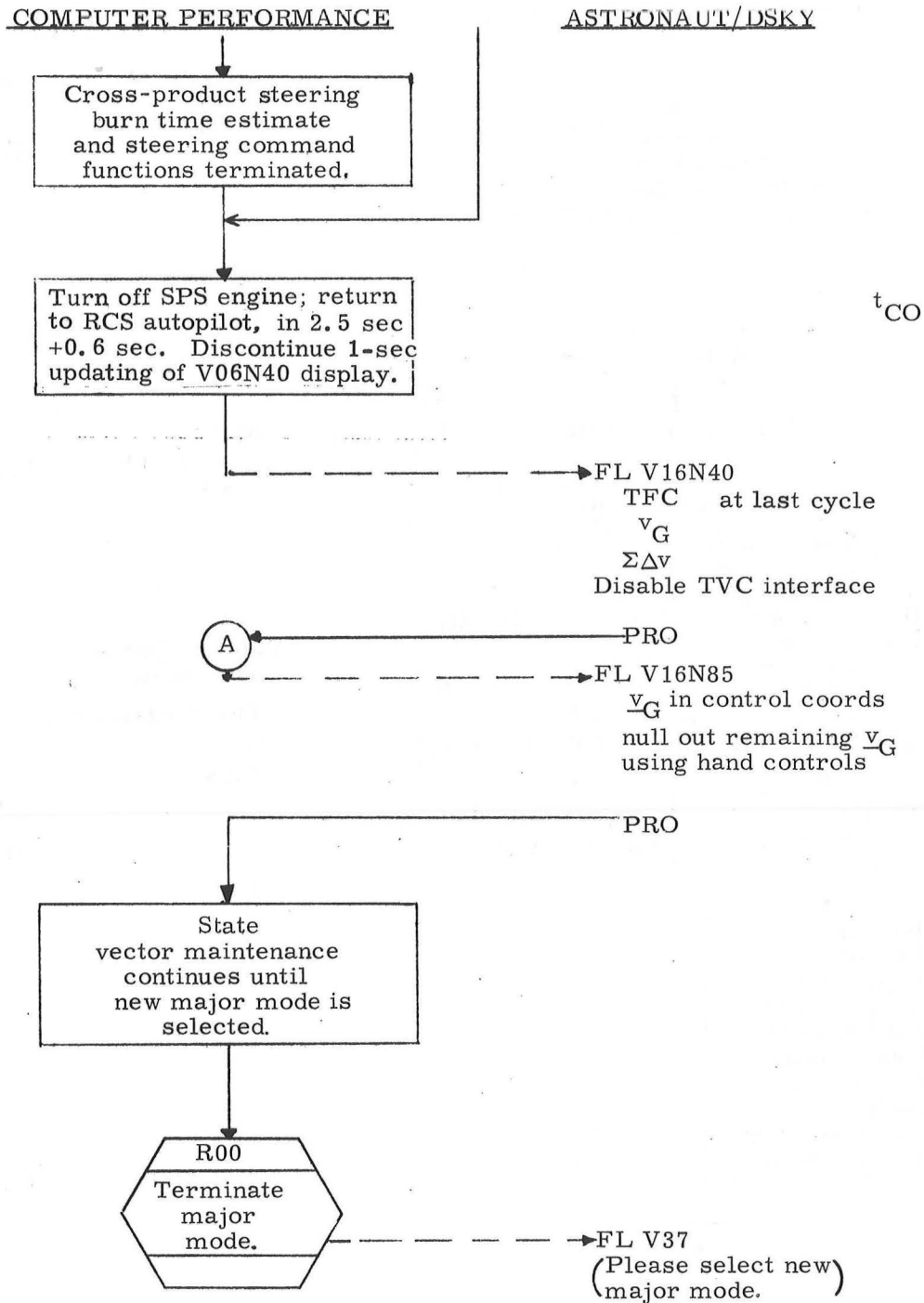


Figure 6. 2. 1-2. Timelines of SPS Maneuver Program (CSM P40)  
(Sheet 4 of 4)

#### 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 2.5 seconds from return of control to P40) will behave as in a late ignition. The crew should key PRO for immediate ignition or key ENTR to go directly to VERB 16 NOUN 85 to perform the maneuver via RCS. 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  $\Delta V$  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; a 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.

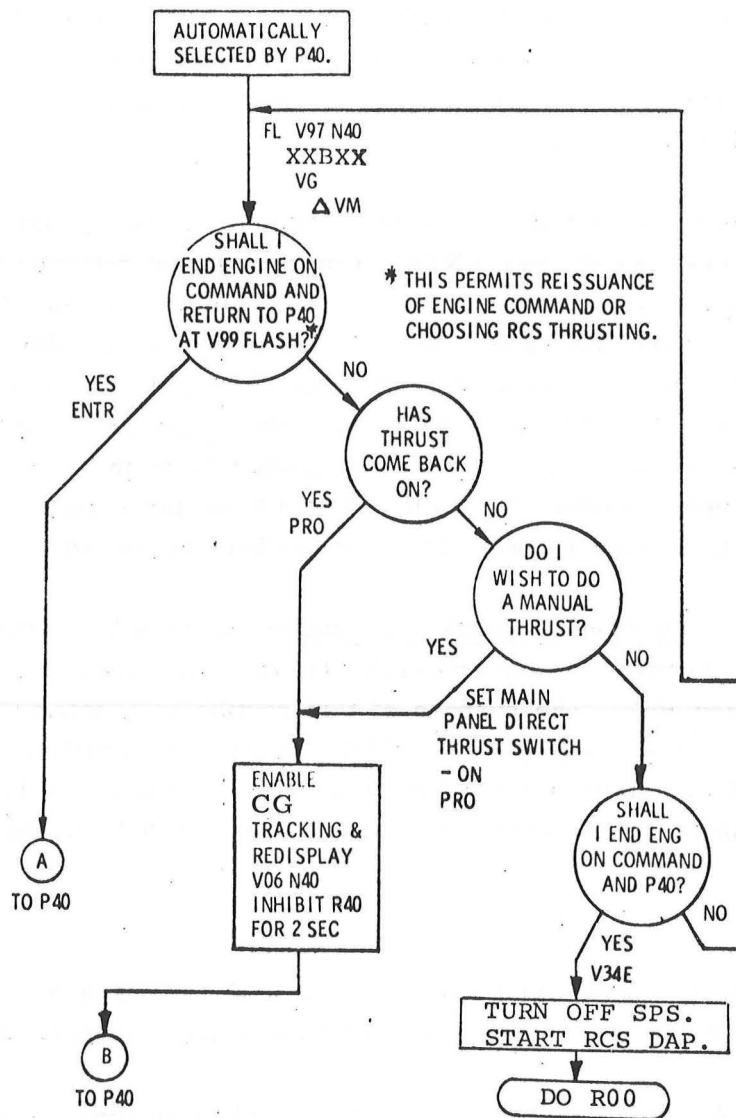


Figure 6.2.1-3. SPS Thrust Fail Routine (CSM R40)

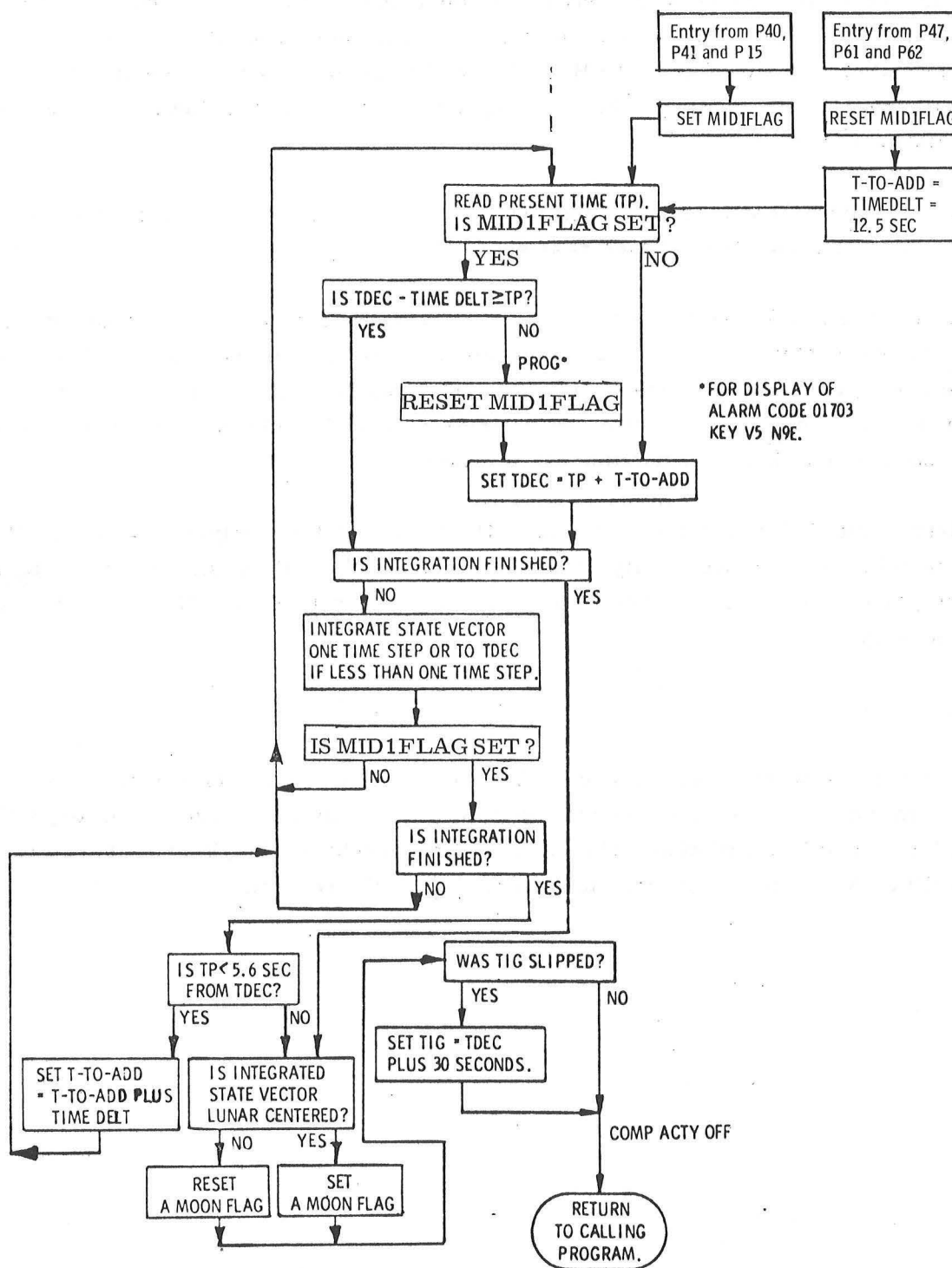


Figure 6.2.1-4. State Vector Integration Routine (CSM R41)



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  $\underline{v}_G$  and the vector  $(\underline{a}_T - B)$ , used to compute  $T_{GO}$ , is greater than 90 deg. In effect, the alarm covers the logically possible, but pragmatically improbable, situation for which a negative time (i.e., past time) to cutoff would be indicated. 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 hardware restart occur during P40, the RESTART light would go on. A hardware or software restart occurring during an automatic attitude maneuver, R60, will terminate this routine. The crew can recover by keying PRO to the flashing VERB 50 NOUN 18 that returns to the DSKY after the restart.

### 6.2.2 P41, Reaction Control System (RCS) Maneuver

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  $\Delta v$ ) 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  $v_G$  is less than,

$$\frac{F_{\text{SPS}}}{m} \cdot \Delta t_{\text{min}}$$

In the above expression,  $F_{\text{SPS}}$  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  $\Delta t_{\text{MIN}}$  is the minimum burn time for which the particular SPS engine being considered has been successfully tested. Currently,  $\Delta t_{\text{MIN}}$  equals 0.5 sec. The maximum  $v_G$  that can be acquired by an RCS burn (P41) can be determined by:

$$|v_G| = \frac{w_{\text{prop}}}{w_{\text{tot}}} g_E \text{ ISP}_{\text{RCS}}$$

where  $w_{\text{prop}}$  is the weight of RCS fuel available,  $w_{\text{tot}}$  is the total weight of the vehicle,  $g_E$  is gravitational acceleration at the earth's surface, and

$$\text{ISP}_{\text{RCS}} = \frac{F_{\text{RCS}}}{w_{\text{prop}}} = 276.45 \text{ sec}$$

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

\* Although use of a lunar module is not planned for a SKYLAB mission, references to the LM have not been deleted, since the CSM alone and TVC DAPs retain the capability to perform maneuvers with the LM attached.

the current state vector without correspondingly changing the thrusting parameters, VHF or Optics marks should not be accepted in P20 (Option 0 and 4) 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) or the Docked DAP Data Load Routine (R04) and a prethrust program (P3x) must be performed. In addition, the IMU must be powered up and aligned.

Upon selection—either by the crew or by the MINKEY controller—P41 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  $\underline{y}_G$  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 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 CSM-alone DAP or Docked DAP to begin the maneuver via R60.

TABLE 6.2.2-1

## DISPLAYS ASSOCIATED WITH P41 (CSM)

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 xxxxxx R2 xxxxxx R3 xxxxxx *
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 re-maining $\underline{v}_G$	Components of $\underline{v}_G$	R1 xxxxx.x ft/sec R2 xxxxx.x ft/sec R3 xxxxx.x ft/sec
FL V16 N44	R30	Display orbital parameters	Apogee altitude Perigee altitude Time of free fall	R1 xxxxx.x n.mi. R2 xxxxx.x n.mi. R3 xxBxx min,sec
V06 N85	P41	Display $\underline{v}_G$	Three components of $\underline{v}_G$ to be acquired, in control coordinates	R1 xxxxx.x ft/sec R2 xxxxx.x ft/sec R3 xxxxx.x ft/sec
FL V16 N54	R31	Display	Range Range rate Theta	R1 xxx.xx n.mi. R2 xxxxx.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 (CSM)

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

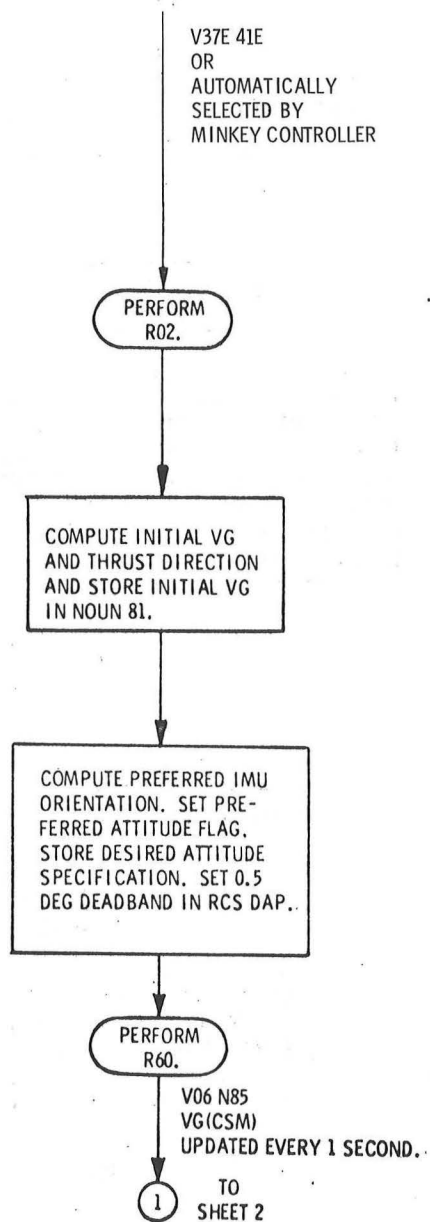


Figure 6.2.2-1. RCS Manuever Program (CSM P41) (Sheet 1 of 2)

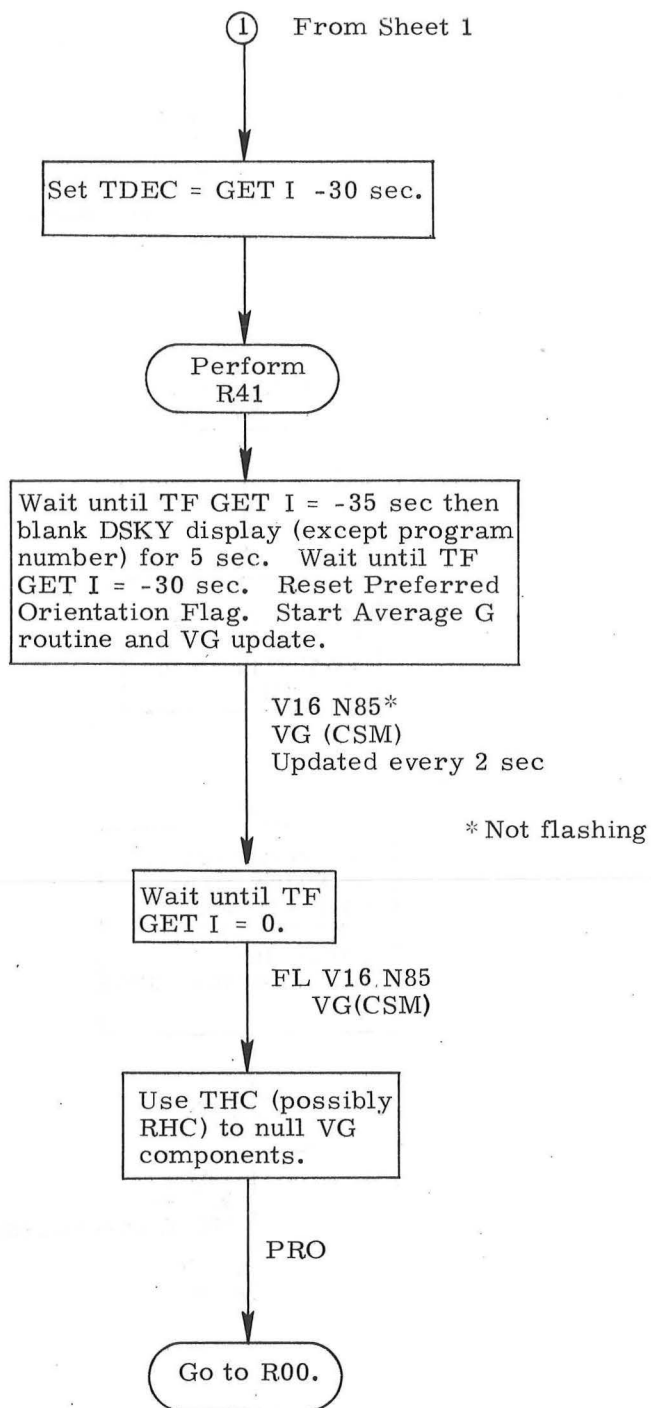


Figure 6.2.2-1. RCS Maneuver Program (CSM P41) (Sheet 2 of 2)

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  $\Delta v$  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., R3—showing time of free-fall—should read minus 59 minutes 59 seconds. The crew keys 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 Timelines

The timelines 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 hardware restart occur during P41, the RESTART light on the DSKY will be illuminated. A hardware or software restart will terminate the automatic attitude maneuver (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.

COMPUTER PERFORMANCE

ASTRONAUT/DSKY

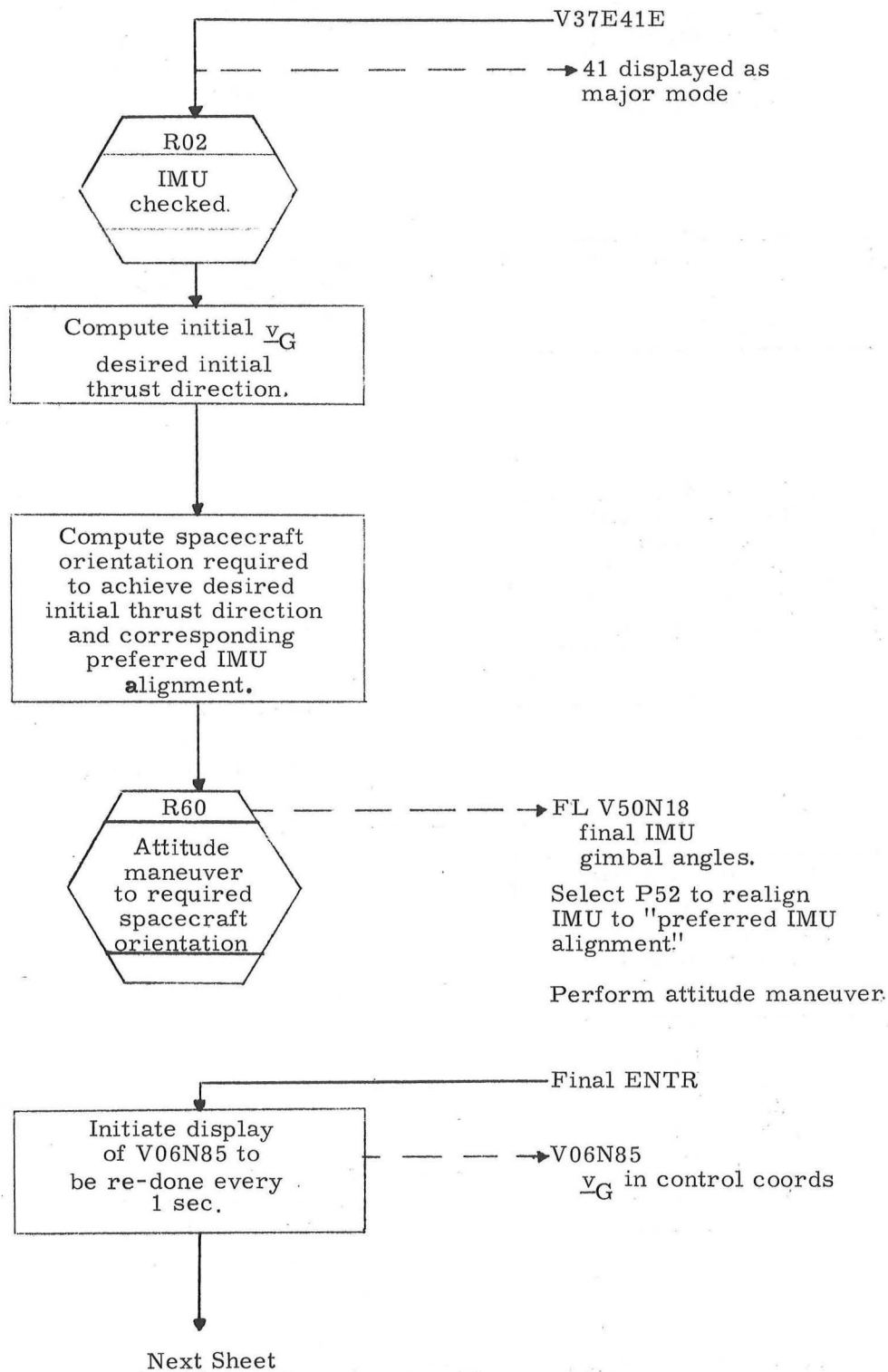


Figure 6.2.2-2. Timelines of RCS Maneuver Program (CSM P41)  
(Sheet 1 of 2)

COMPUTER PERFORMANCE

ASTRONAUT/DSKY

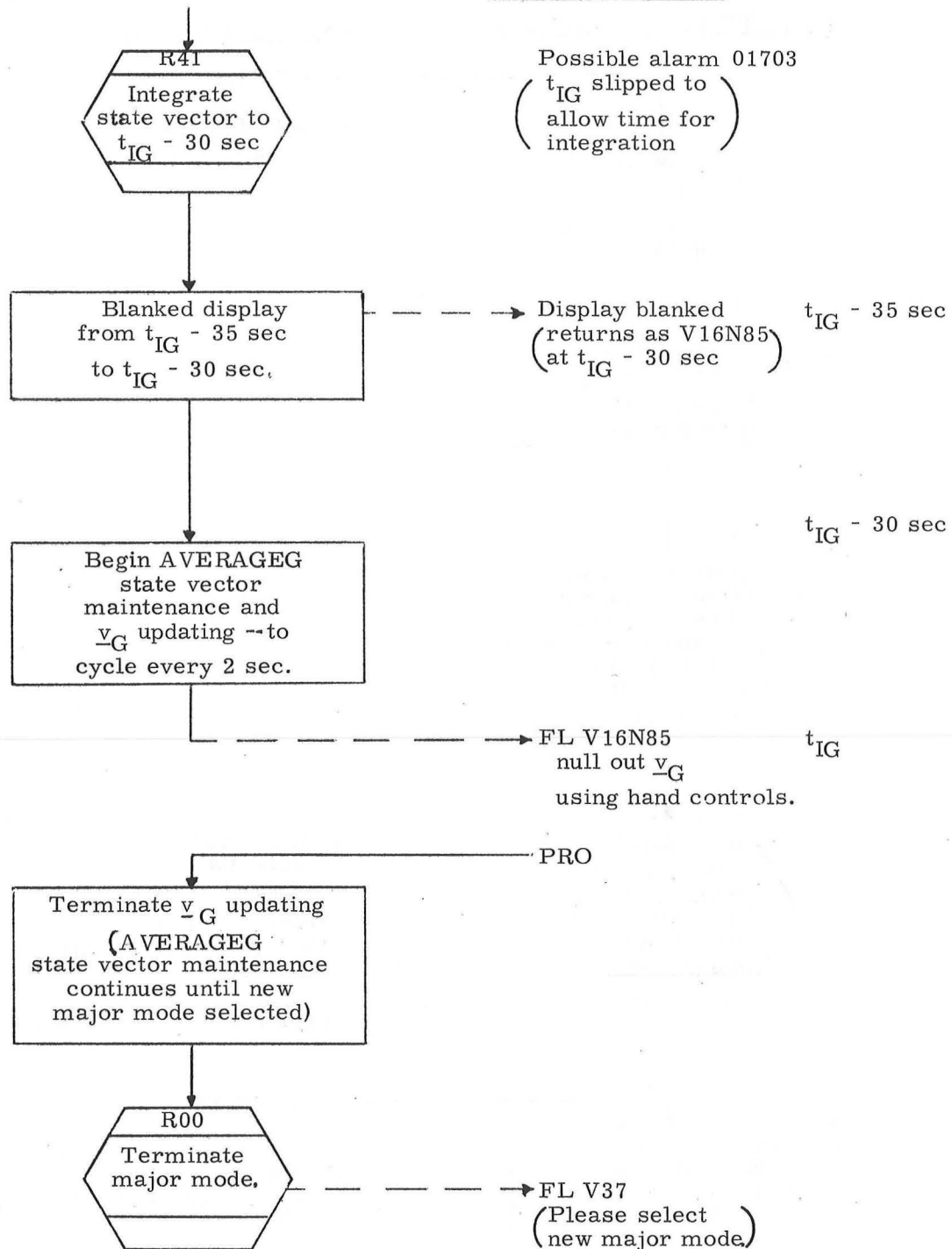


Figure 6.2.2-2. Timelines of RCS Maneuver Program (CSM P41)  
(Sheet 2 of 2)

### 6.2.3 P47, Thrust Monitor

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 final docking maneuver in rendezvous is done using THC manual control.

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 the time that the AVERAGEG routine is turned on by the program. (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  $\Delta v$ , 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 this immediately to terminate AVERAGEG and thus avoid accumulation of PIPA bias errors.

TABLE 6.2.3-I

## DISPLAYS ASSOCIATED WITH P47 (CSM)

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 $\Delta y$ 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 N62E	Astronaut	Display	Velocity Rate of altitude change Altitude	R1 xxxxxx. ft/sec R2 xxxxxx. 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 (CSM)

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

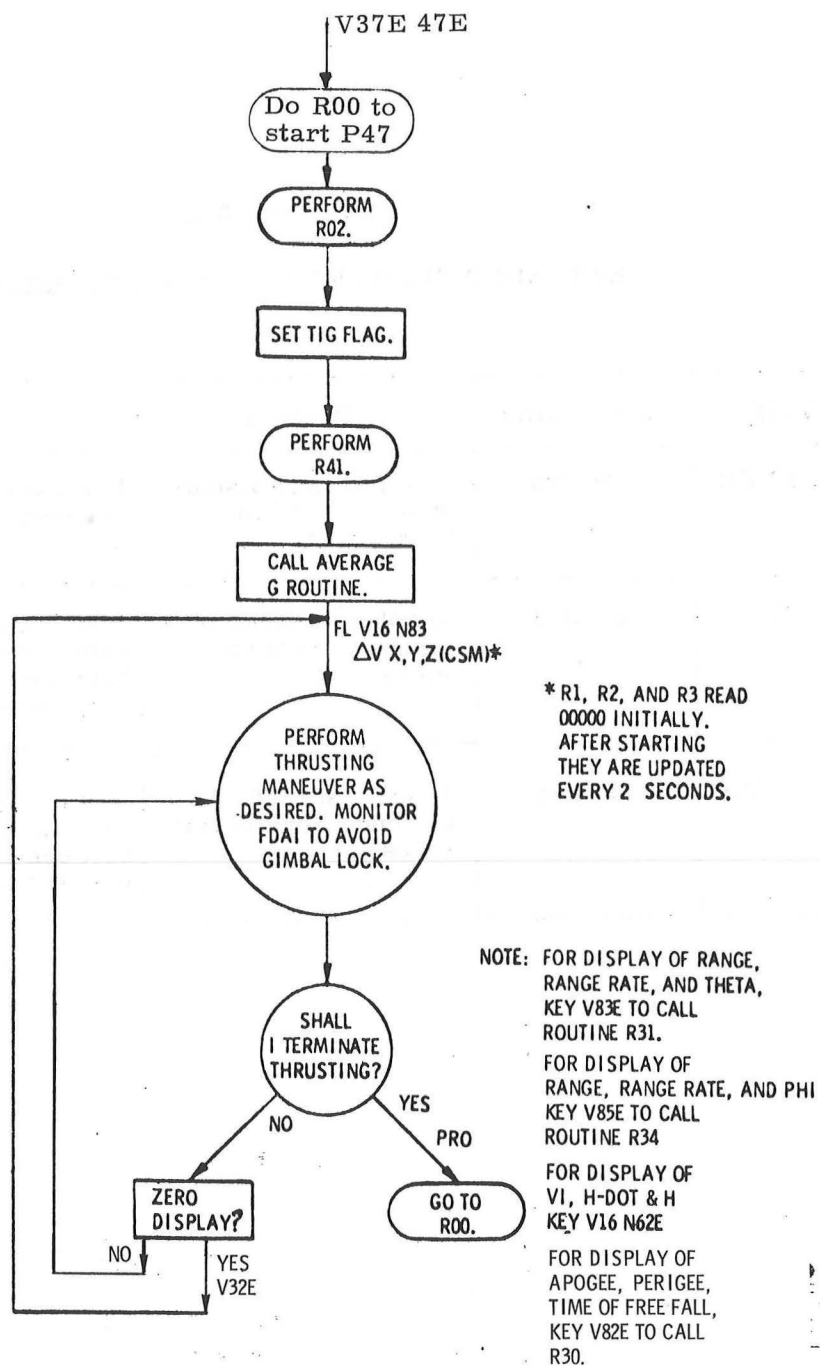


Figure 6.2.3-1. Thrust Monitor Program (CSM P47)

#### 6.2.3.2 Timelines

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 hardware restart occur, the RESTART light on the DSKY would be illuminated; no other effect would be noticed by the crew.



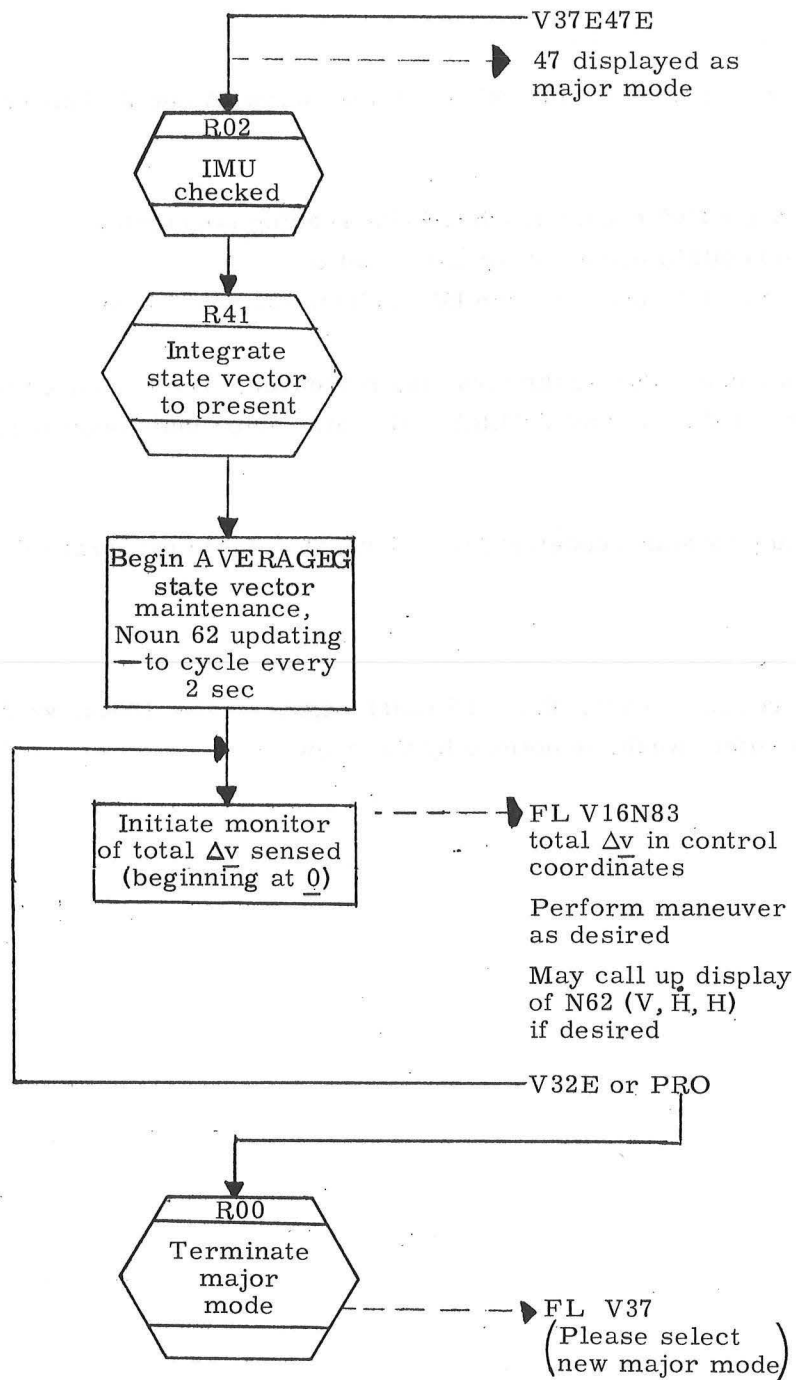


Figure 6.2.3-2. Timelines of Thrust Monitor Program (CSM P47)

#### 6.2.4 P48, Rendezvous Thrust Monitor

P48 is used during the rendezvous braking phase (TPF) to monitor both the relative motion of the spacecraft and any CSM thrusting. (See Figure 4.2.3-1.)

After the last of the targeted maneuvers, the CSM is nominally less than two nautical miles from the OWS and closing at a range rate on the order of 30 fps. The crew then performs braking in a series of translation maneuvers which reduces the range rate as a function of the range. The braking phase is terminated with station-keeping (zero range rate) at a distance from the OWS of approximately 120 ft.

During TPF, the crew uses P48 to monitor the relative motion parameters range, range rate, and theta—where theta is defined as the elevation angle between the local-horizontal plane and the +X-body-axis line of sight to the OWS. These parameters are provided continually, both during coasting and powered flight, by the VHF Range Rate Mark Processing Routine, R27. The inertial state vector is updated in P48 by the Average-G routine, and the crew can monitor the progress of a thrusting maneuver in terms of the velocity gained along the CSM body coordinates. (For an explanation of Average-G use, refer to subsection 6.1. For R27, refer to paragraph 4.2.1.3.)

##### 6.2.4.1 P48 Procedures

Tables 6.2.4-I and -II present the displays and extended verbs associated with P48. Figure 6.2.4-1 is the program flowchart. See also paragraph 4.2.1.3.3 for a discussion of R27 modes.

Before entering P48, the crew can align the CSM +X-axis to the OWS line of sight either nominally in P37 (selected by MINKEY) or, in P00, by performing Verb 89. Upon entering P48, the CMC MODE switch is placed in HOLD. The crew can then maintain COAS boresighting by (1) nulling the LOS rates with Y- or Z-translation, and (2) trimming with the RHC.

During a translation maneuver, R27 incorporates only the  $\Delta v_X$ -component into its estimate of the range state vector. But, since Y, Z-translation can have a  $\Delta V$ -component along the LOS, the range rate will be in error if the accumulated  $\Delta V_{Y,Z}$  is non-zero. RHC re-alignment to the LOS, however, resolves all accumulated  $\Delta V_{LOS}$  back along the X-axis, and the range rate is once again accurate. For this reason, the crew should recycle P48—V32E response to Noun 83, which zeroes all accumulated  $\Delta V$ —only when the COAS is boresighted.

TABLE 6.2.4-I

## DISPLAYS ASSOCIATED WITH P48 (CSM)

DSKY	Initiated by	Purpose	Condition	Register
V05 N09E	Astronaut	Display PROG alarm	00205 Bad PIPA reading detected 00210 ISS not on 00220 IMU orientation unknown	R1 xxxxx R2 xxxxx R3 xxxxx*
V25 N72E	Astronaut	Start or terminate R27 optimization sequence	GET ( $t_D$ )	R1 oxxxx. hr R2 oooxx. min R3 oxx. xx sec
FL V16 N76	P48	R27 optimization	Range (VHF R-dot filter) Range rate Time from optimization	R1 xxx. xx n. mi. R2 xxxx. x fps R3 xxBxx min-sec
FL V16 N77	P48	Current relative motion	Range (VHF R-dot filter) Range rate Theta	R1 xxx. xx n. mi. R2 xxxx. x fps R3 xxx. xx deg
FL V16 N83	P48	Display $\Delta v$ 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 xxBxx min, sec
FL V16 N54	R31	Display	Range (state vectors) Range rate Theta	R1 xxx. xx n. mi. R2 xxxx. x ft/sec R3 xxx. xx deg
FL V16 N53	R34	Display	Range (state vectors) Range rate Phi	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

In P48, R27 is automatically established in the current mode. Subject to the restriction specified in paragraph 6.2.4.2, however, the crew can perform an optimization at any time by loading Noun 72.

The contents of Noun 76 and Noun 77 are as indicated in Figure 4.2.1.3-6, where "theta" replaces "phi," and TFO is fixed at +59B59 (current mode). The angle  $\theta$ , in P48, is computed from the CSM Average-G state vector, and, with R27 in the current mode,  $\theta$  is updated with each mark—about once every two seconds. The time required for the filter to converge to its  $\pm 0.4$  fps-accuracy is about 100 seconds. This time delay is not affected by any  $\pm X$ -translation during convergence.

P48 should be terminated as soon as possible in order to avoid the accumulation of PIPA bias and Average-G errors.

TABLE 6.2.4-II  
EXTENDED VERBS FOR USE WITH P48 (CSM)

VERB	Identification	Purpose	Remarks
76	—	Initialize R27	DSKY displays time of optimization; zeros indicate current mode.
82	Do R30	Compute and display relevant orbital parameters	DSKY displays apogee, perigee, and time of free fall
83	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	Do R34	Display second set of rendezvous parameters	DSKY displays range, range rate and phi, the angle between local horizontal and the sextant LOS
89	Do R63	Align CSM +X-axis to the OWS line of sight	Must be in P00; V89 assumes +X attitude desired; monitor MGA during maneuver.

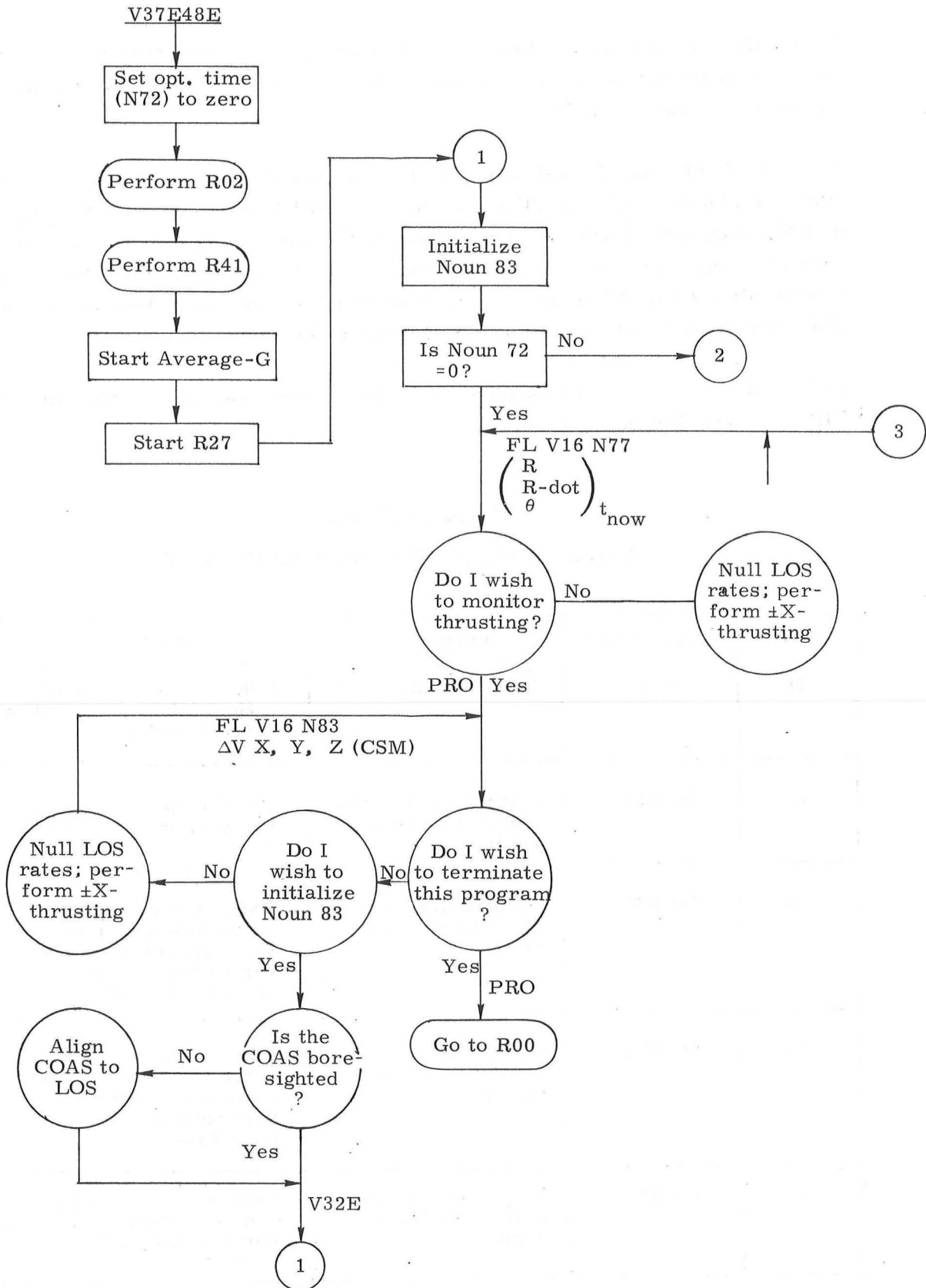


Figure 6.2.4-1. Rendezvous Thrust Monitor Program (P48)  
(Sheet 1 of 2)

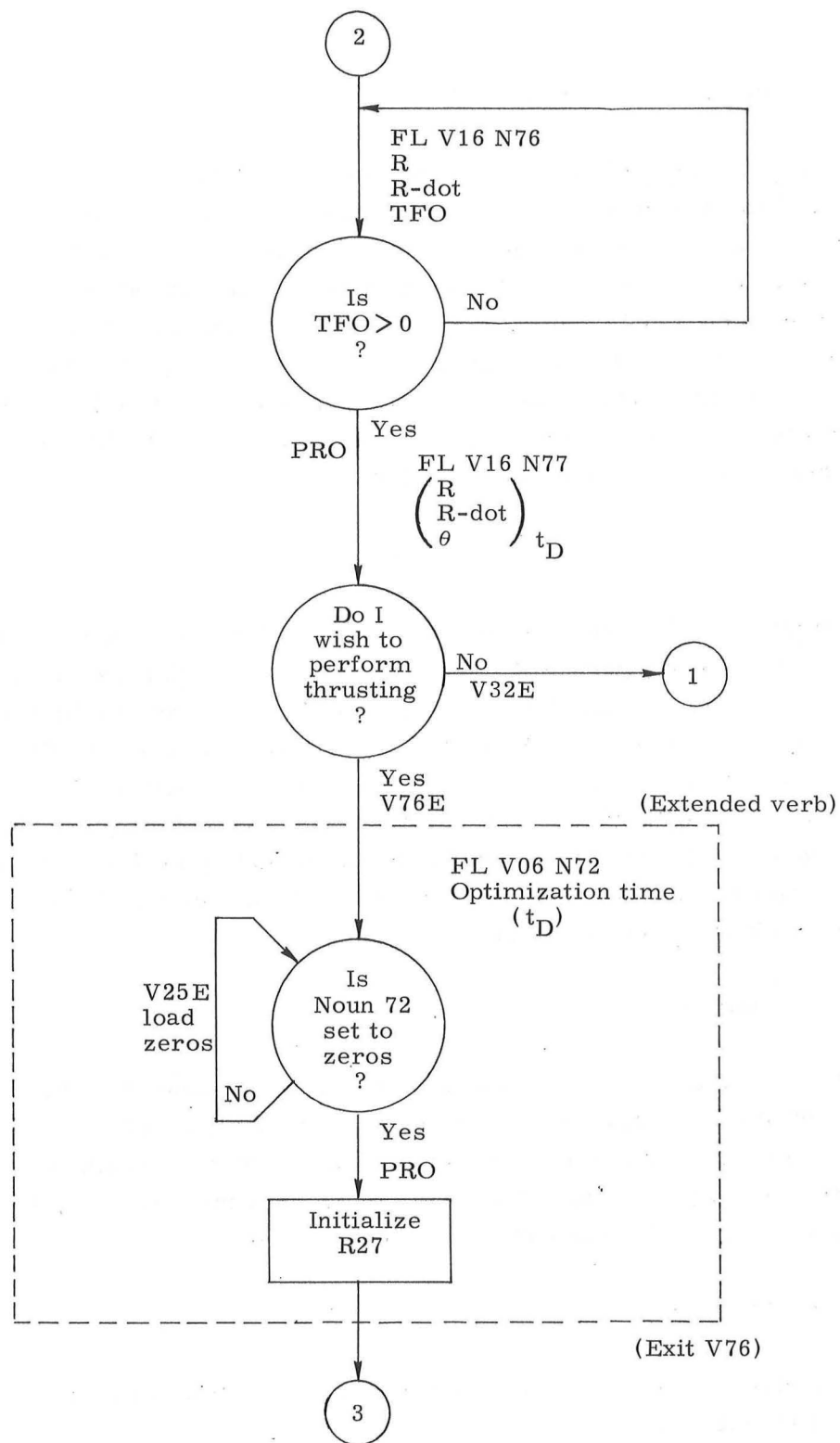


Figure 6.2.4-1. Rendezvous Thrust Monitor Program (P48)  
(Sheet 2 of 2)

#### 6.2.4.2 Restrictions and Limitations

Operational Limit—Because the filter does not estimate range derivatives of higher order than acceleration, the error in range rate will begin to diverge if the CSM continues on a non-intercept trajectory and the range is within some multiple of the projected miss distance. This multiple is typically between 2 and 5. For example, a range-rate error of more than  $\pm 1.0$  fps can be expected if, after braking to the 500-ft gate (5.0 fps), the projected miss distance is greater than 150 ft. On the other hand, this same range-rate error can be expected at the 3000-ft gate (20.0 fps) if the projected miss distance is greater than 600 ft. Under such circumstances, the crew should initialize R27 by performing Verb 76.

Optimization—The crew can perform a range-state optimization in P48 so long as no  $\pm X$ -translation is performed during the time R27 is within the optimization interval. (See paragraph 4.2.1.3.3.1.) Coasting flight is a requirement for optimization; any thrusting other than normal to the line of sight will invalidate the filter's polynomial expansion around the time  $t_D$ . If the crew wishes to perform X-translation at any time within an optimization interval, it should first perform Verb 76, loading zeros into Noun 72, in order to re-establish the current mode (see Figure 6.2.4-1). If the optimization continues to completion, an automatic 4-minute sequence of optimizations will be established.

#### 6.2.4.3 Alarms

The program alarm codes associated with P48 are listed in Table 6.2.4-I. Alarm code 00205 can occur during a thrusting maneuver, indicating detection of a bad PIPA reading. This maneuver should be terminated immediately, since the Noun 83 display and the Average-G state vector will no longer be valid. For explanations of alarm codes 00210 and 00220, refer to paragraph 6.2.1.6.

#### 6.2.4.4 Restarts

All displays in P48 are restart-protected. R27 restart protection is presented in paragraph 4.2.1.3.5.



SECTION 7.0

ALIGNMENT



## 7.1 GENERAL

The following alignment programs enable the flight crew to establish and maintain the spacecraft's inertial attitude reference:

- P50 — ATM Orientation Determination Program (subsection 7.2)
- P51 — IMU Orientation Determination Program (subsection 7.3)
- P52 — IMU Realign Program (subsection 7.4)
- P53 — Backup IMU Orientation Determination Program (subsection 7.5)
- P54 — Backup IMU Realign Program (subsection 7.6)
- P55 — ATM Star Tracker Gimbal Angle Program (subsection 7.7)

In addition, the following extended verbs, described in subsection 7.8, are used to control the orientation of the stable member and the optics:

- V41 N20 - Coarse Align ISS
- V41 N91 - Coarse Align OCDU
- V42 - Fine Align ISS
- V40 - Zero ICDU

Table 7.1-I lists the principal GNCS components and their functions; Figure 7.1-1 shows the inertial subsystem (ISS) interfaces for the CSM. The stabilization loop shown in the figure holds the stable member in a constant orientation relative to inertial space by isolating the stable member from roll, pitch, and yaw motions of the spacecraft. The stabilization loop operates as follows: (1) the inertial reference integrating gyros (IRIGs) mounted on the stable member generate error signals to indicate any change in the inertial orientation of the stable member; (2) the error signals are amplified by servo amplifiers in the power and servo assembly (PSA) and fed to gimbal torque motors that rotate the stable member about the outer-, middle-, and inner-gimbal axes (Figure 7.1-2); (3) the amount and direction of stable-member rotation are such as to reduce the IRIG error signal to zero, returning the stable member to its original orientation. In this condition, the ISS is said to be in the inertial-reference mode.

The IMU Realign Program (P52) and its backup (P54) permit realignment of the IMU by: (1) either coarse aligning (with a gyro pulse torquing trim), or gyro pulse torquing from the present orientation to the new orientation; or (2) the above pulse sighting on two celestial bodies using some combination of CSM optics, ATM Sun Sensor, or ATM Star Tracker. Of the two methods, the latter will produce the more accurate alignment.

When realigning to a different orientation, the stable member is first rotated to the new orientation (called coarse align) and then, if possible, sightings are performed (called fine align).

TABLE 7.1-I

APOLLO (SKYLAB) GUIDANCE, NAVIGATION AND  
CONTROL SYSTEM PRINCIPAL COMPONENTS

Component	Function
Navigation Base (NB)	Attachment fixture to hold IMU and OUA in precise alignment to spacecraft structure.
Inertial Measurement Unit (IMU)	Maintain an inertial reference from which to measure vehicle attitude and velocity changes.
Optical Unit Assembly (OUA)	Contains a sextant (SXT) and a Scanning Telescope (SCT) used to determine line-of-sight vectors to celestial bodies and the OWS.
Power and Servo Assembly (PSA)	Provide central mounting point for GNCS power supplies, amplifiers, and other modular electronic components.
Signal Conditioner Assembly (SCA)	Receives signals from GNCS and converts them to a form suitable for telemetry equipment input.
Command Module Computer (CMC)	Performs guidance, navigation, and control calculations and data management.
Coupling Data Unit (CDU)	Analog-to-digital conversion of IMU gimbal angles and OUA shaft and trunnion angles; digital-to-analog conversion of computer-derived data.
Display and Keyboard (DSKY)	Input-output device between astronaut and CMC.
Guidance and Navigation Indicator Control Panel (GNICP)	Mounting panel for GNCS and OUA controls and indicators.

Figure 7.1-1. CSM Inertial Subsystem Interface

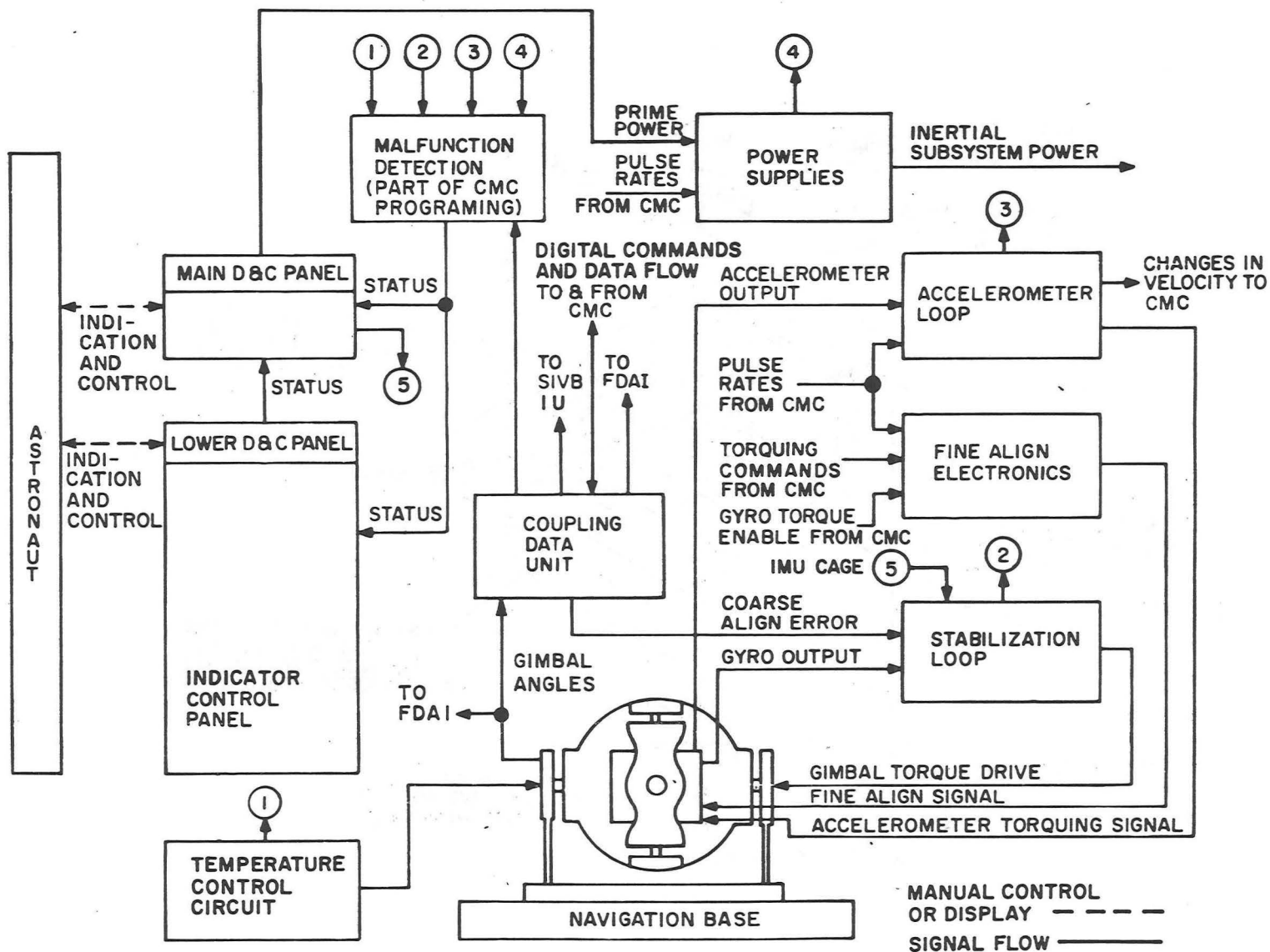
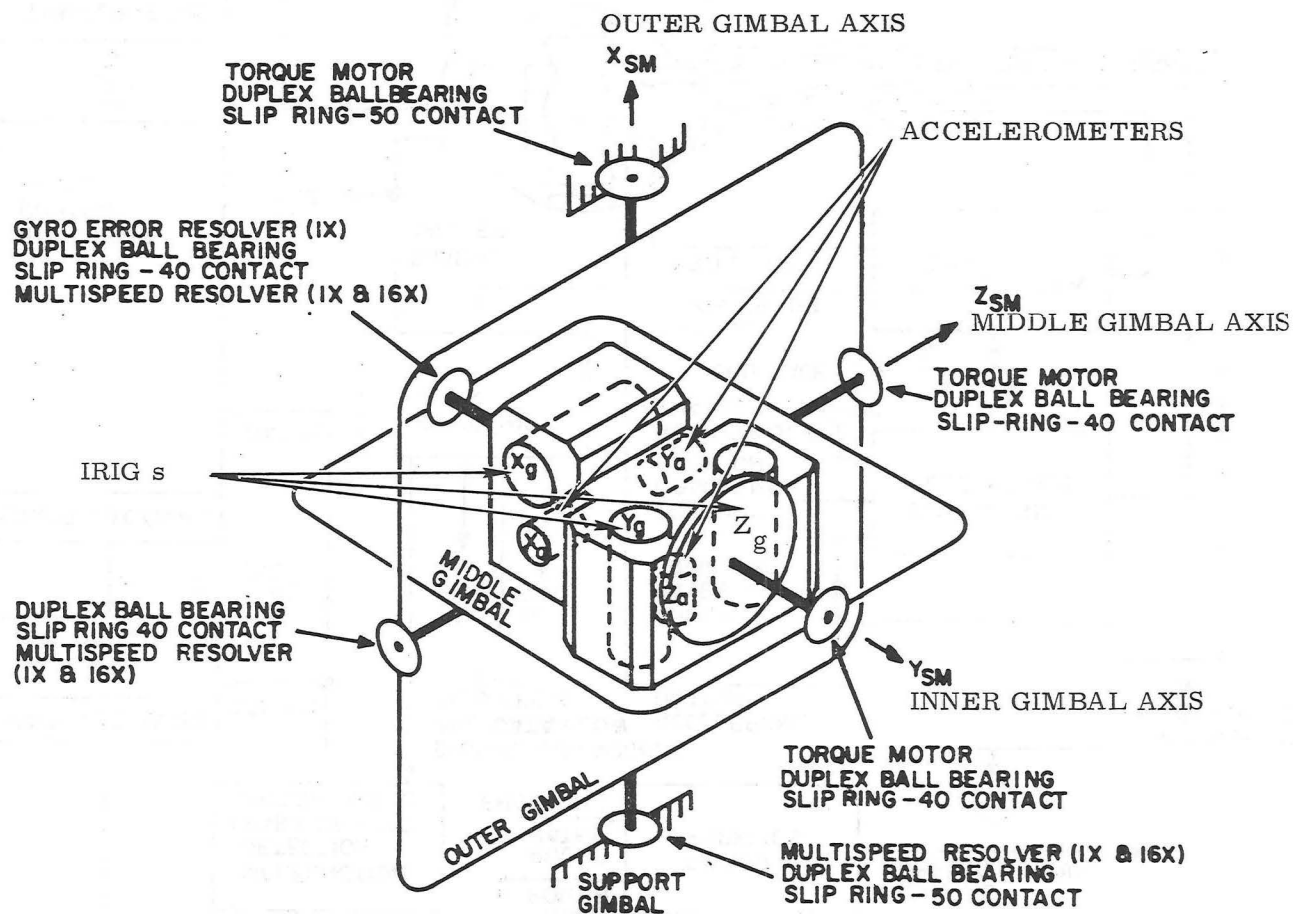


Figure 7.1-2. IMU Gimbal Assembly



The coarse-alignment procedure is as follows. First, the CMC calculates the required gimbal-angle changes, then supplies to the coupling data unit (CDU) a train of pulses corresponding to these changes; the CDU, in turn, supplies an equivalent analog signal to the PSA servo amplifiers, which drive the gimbal-torque motors to the desired angles. Gyro trim then torques the gyros to achieve precision alignment formerly only possible by the slower, pulse-torquing procedure.

The disadvantage of the coarse-alignment procedure is that, during the process, the error signals from the IRIGs are disconnected from the PSA servo amplifiers. Opening the stabilization loop causes temporary loss of inertial reference, and any change in spacecraft attitude during the procedure will result in stable-member orientation error.

By the above procedure, coarse alignment to any set of gimbal angles can be accomplished within a period of about 15 seconds. The pulse-torquing procedure can take significantly longer—0.55 deg/sec, one gimbal axis at a time.

During the pulse-torquing procedure, the stabilization loop remains closed, isolating the stable member from vehicle rotation. The procedure is as follows: (1) the CMC selects one IRIG at a time and issues a number of pulses corresponding to the angular change required about the selected IRIG axis; (2) the pulses are received by the fine-align electronics (within the PSA), which then issues a precisely controlled dc current through a winding in the selected IRIG; (3) the current's passing through the winding induces torque to the gyro wheel, causing the IRIG to generate an error signal; (4) as described at the beginning of this section, the error signal is amplified and fed to a gimbal torque motor to reposition the stable member. The pulse-torquing procedure can induce errors up to 0.002 degrees per degree of torquing.

#### 7.1.1 Coordinate Systems

The stable member's inertial orientation must be stored in the computer for it to serve as a reference for propulsion-system burns, navigation, maneuvers, and crew displays. Attitude information is referred to several coordinate systems that are defined here:

- a. Basic Reference Coordinate System.—This is an inertial, nonrotating coordinate system, oriented in a fixed direction with respect to the stars. The origin is located at the earth's center of mass; the orientation is defined by the line of intersection of the mean earth equatorial plane and the plane defined by the mean orbit of the earth on approximately January 1, 1950. The x-axis is along this line of intersection, with the positive sense in the direction of the ascending node of the ecliptic on the equator; the z-axis is along the mean earth north pole; and the y-axis completes the right-handed triad. The vectors stored in the computer to describe the navigation stars and sun positions, as well as spacecraft position and velocity, refer to the Basic Reference Coordinate System.
- b. Vehicle, or Body, Coordinate System.—This coordinate system represents the spacecraft's structure. In the CSM, the x-axis lies along the vehicle's longitudinal axis, positive in the SPS thrust direction. The positive z-axis is defined by an alignment target located at the top of the service module (below the astronaut's feet when in the couch) and is normal to the x-axis. The y-axis is defined to complete the right-handed triad.
- c. Navigation Base Coordinate System.—These axes are parallel to the axes of the Vehicle Coordinate System and are defined with respect to the navigation base mounting references.
- d. Stable Member, or Platform, Coordinate System.—The orientation of this coordinate system with respect to the Basic Reference Coordinate System defines the current stable-member inertial orientation. The axes of this coordinate system can be considered to be fixed to the stable-member structure and move within the IMU on gimbals. The origin of the Stable Member Coordinate System is at the center of the stable member.

The current stable-member inertial orientation is stored in the CMC as a transformation matrix from the Basic Reference Coordinate System to the Stable Member Coordinate System; this matrix is called REFSMMAT. Of the many orientations that the stable member can assume, the three primary alignments are defined below. All vectors refer to basic reference coordinates:

1) Preferred Alignment:

$$\begin{aligned}\underline{u}_{xsm} &= \text{unit}(\underline{x}_b); \\ \underline{u}_{ysm} &= \text{unit}(\underline{u}_{xsm} \times \underline{r}); \\ \text{or, if } \underline{r} &\approx \text{parallel to } \underline{x}_b \text{ in P40 and P41,} \\ \underline{u}_{ysm} &= \text{unit}[\underline{u}_{xsm} \times (\text{unit } \underline{r} + 0.125 \text{ unit } \underline{v})]; \\ \underline{u}_{zsm} &= \underline{u}_{xsm} \times \underline{u}_{ysm},\end{aligned}$$

where  $\underline{u}_{xsm}$ ,  $\underline{u}_{ysm}$ , and  $\underline{u}_{zsm}$  are the stable-member unit vectors;  $\underline{x}_b$  = vehicle x-axis at the desired vehicle attitude for propulsion system ignition;  $\underline{r}$  = vehicle position vector at ignition; and  $\underline{v}$  = vehicle velocity vector at ignition.

2) Nominal Alignment (local vertical):

$$\begin{aligned}\underline{u}_{xsm} &= (\underline{u}_{ysm} \times \underline{u}_{zsm}), \\ \underline{u}_{ysm} &= \text{unit}(\underline{v} \times \underline{r}), \\ \underline{u}_{zsm} &= \text{unit}(-\underline{r}),\end{aligned}$$

where  $\underline{r}$  and  $\underline{v}$  represent the vehicle position and velocity at the time of alignment.

3) During a rendezvous sequence, the following orientation can be obtained for plane-change alignment:

$$\begin{aligned}\underline{x}_{sm} &= \text{unit}(\underline{x}_{smo} \cos 45 \pm \underline{y}_{smo} \sin 45) \\ &\text{prior to plane change, and} \\ \underline{x}_{sm} &= \text{unit}(\underline{x}_{smo} \cos 45 \mp \underline{y}_{smo} \sin 45) \\ &\text{following plane change;} \\ \underline{y}_{sm} &= \text{unit}(\underline{z}_{sm} \times \underline{x}_{sm}); \\ \underline{z}_{sm} &= \underline{z}_{smo};\end{aligned}$$

where the subscript o refers to the orientation existing before the current realignment. The program will select the appropriate sign for the  $\underline{y}_{smo}$  term to avoid going through gimbal lock.

e. Earth-fixed Coordinate System.—The origin of this rotating system is at the earth's center of mass. The z-axis lies along the earth's true rotational, or polar, axis. The x-axis is along the line from the origin towards the intersection of the Greenwich meridian and the equatorial plane. The y-axis is in the equatorial plane and completes the right-handed triad.

f. APOLLO Telescope Mount Sensor Coordinate System.—The axes of this coordinate system are defined with respect to the ATM acquisition sun sensor and the ATM star tracker. The +z-axis is defined to be in the

same direction as the sun-sensor axis. The -y-axis is defined to be in the same direction as the star tracker when the star-tracker gimbal angles are zero. (The star tracker is assumed to be perpendicular to the +z-axis when its inner-gimbal angle is zero.) When the CSM is docked to the workshop, the ATM Orientation Determination Program (P50) can compute the orientation of this coordinate system with respect to the Navigation-base Coordinate System.

- g. Sextant-base Coordinates.—The articulating line-of-sight (LOS) of the SXT and the LOS of the SCT are positioned by rotating a mirror in the SXT and a prism in the SCT about a shaft axis and a trunnion axis. The shaft axes of both instruments are fixed at approximately 33 deg above the CM +z-axis in the CM x,z plane. When the mirror rotation about the shaft axis is at "zero," the trunnion axis is parallel to the CM y-axis. Mirror rotation about the trunnion axis then moves the LOS in the CM x,z plane only. When the trunnion rotation angle is at "zero," the LOS points along the shaft axis. The trunnion axis can be elevated from zero to about 50 degrees. Thus, rotating the shaft and elevating the trunnion allows the crew to acquire any target within a 100-deg cone (Figure 7.1-3).<sup>\*</sup> The shaft angle and trunnion angle then specify the direction of the LOS with respect to the optical unit assembly.

#### 7.1.2 IMU Orientation

The CMC's task of establishing and maintaining an inertial-attitude reference can now be stated in terms of the coordinate systems defined above. There are two basic problems to be solved by the alignment programs: (a) determine the stable member's axes relative to the Basic-reference Coordinate System, i.e., determine the current REFSMMAT; and (b) determine the stable member's orientation relative to a desired inertial orientation (preferred or nominal). Since the stable member will slowly drift away from the orientation stored in REFSMMAT, item (b) also includes the problem of determining the current stable-member orientation relative to the orientation stored in REFSMMAT. Once the stable member's orientation is known relative to the desired orientation, it can be driven into the desired orientation.

The technique used by the CMC to determine the current REFSMMAT is as follows:

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<sup>\*</sup>Spacecraft structure or an attached vehicle further restricts the cone of acquisition. For example, ablative material on the CM exterior reduces the cone of acquisition to about 85 deg.



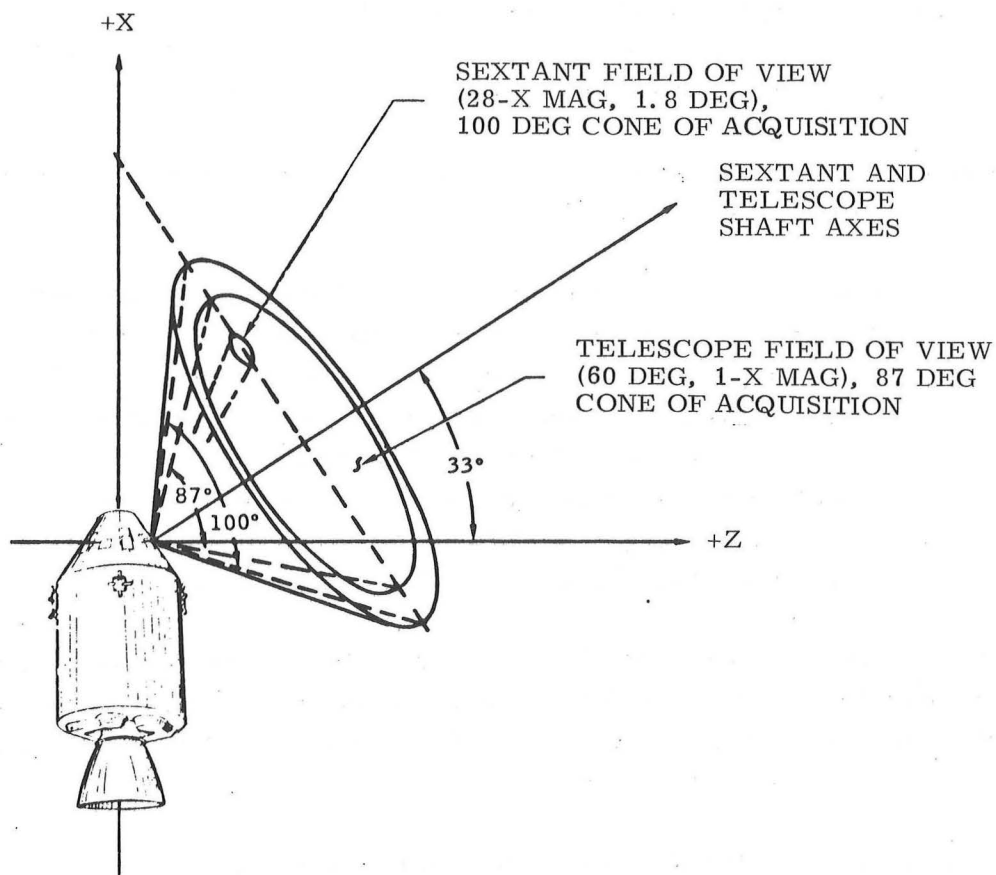


Figure 7.1-3. CM Optics Field of Coverage

- a. Use the CM optics, the ATM sun sensor, or the ATM star tracker to measure an LOS to two celestial bodies in navigation-base coordinates. Transform the measured vectors to stable-member coordinates using the gimbal angles to relate navigation-base coordinates to stable-member coordinates.
- b. Obtain the basic-reference coordinates for the same two celestial bodies from storage, calculation, or astronaut DSKY entry.
- c. Use the difference between the stable-member coordinates and the basic-reference coordinates to calculate and store REFSMMAT.

An extension of this technique is used to determine the stable member's orientation relative to a desired inertial orientation:

- a. As before, perform two LOS measurements in navigation-base coordinates and transform them to stable-member coordinates.
- b. Obtain the basic-reference coordinates for the same two targets.
- c. Convert the targets' basic-reference coordinates to vectors expressed in terms of the desired stable-member coordinates.
- d. Use the difference between the present and desired stable-member coordinates of the targets to calculate the angles required to drive the stable-member into alignment with the desired orientation.

The REFSMMAT is computed at liftoff and then changed by execution of P52 during the rendezvous phase. When the IMU is powered up for docked operations or undocking the stored REFSMMAT will be valid for a known set of angles which the crew can coarse align to using V41N20.

In the event of an unanticipated loss of alignment P51 or P53 may be used to establish a valid REFSMMAT.

In accomplishing the steps listed above, all alignment programs have in common the following operation, Step c above: given two vectors, each expressed in two coordinate systems, compute the coordinate axes of one system expressed in terms of the other coordinate system. Consider P51 as an example and refer to Figure 7.1-4. The unit vectors  $A'$  and  $B'$  in Figure 7.1-4a represent lines of sight to two celestial bodies measured in the stable -member coordinate system  $x', y', z'$ ;  $A$  and  $B$  in Figure 7.1-4b represent the same two lines of sight as known in basic-reference coordinates  $x, y, z$ . To compute REFSMMAT, the problem is to first find  $x', y', z'$  in terms of the unprimed coordinate system (Figure 7.1-4c).

This is accomplished by defining two new sets of orthogonal vectors, one in primed coordinates and one in unprimed coordinates, as follows (Figure 7.1-4d and e):

$$\begin{aligned}\underline{u}'_1 &= \underline{A}' \\ \underline{u}'_2 &= \text{unit}(\underline{A}' \times \underline{B}') \\ \underline{u}'_3 &= \underline{u}'_1 \times \underline{u}'_2,\end{aligned}$$

and

$$\begin{aligned}\underline{u}_1 &= \underline{A} \\ \underline{u}_2 &= \text{unit}(\underline{A} \times \underline{B}) \\ \underline{u}_3 &= \underline{u}_1 \times \underline{u}_2.\end{aligned}$$

The  $\underline{x}'$  unit coordinate vector can now be constructed in unprimed coordinates as a vector sum of its components along  $\underline{u}_1$ ,  $\underline{u}_2$ , and  $\underline{u}_3$ :

$$\begin{aligned}\underline{x}' \text{ (in unprimed coordinates)} &= (\underline{x}' \cdot \underline{u}'_1) \underline{u}_1 + (\underline{x}' \cdot \underline{u}'_2) \underline{u}_2 \\ &\quad + (\underline{x}' \cdot \underline{u}'_3) \underline{u}_3 \\ &= u'_{1x'} \underline{u}_1 + u'_{2x'} \underline{u}_2 + u'_{3x'} \underline{u}_3,\end{aligned}$$

where  $u'_{1x'}$ ,  $u'_{2x'}$ ,  $u'_{3x'}$ , represent the components of  $\underline{u}'_1$ ,  $\underline{u}'_2$ , and  $\underline{u}'_3$ , respectively, along the  $x'$  axis. Similarly, for the  $y'$  and  $z'$  axes,

$$\underline{y}' = u'_{1y'} \underline{u}_1 + u'_{2y'} \underline{u}_2 + u'_{3y'} \underline{u}_3, \text{ and}$$

$$\underline{z}' = u'_{1z'} \underline{u}_1 + u'_{2z'} \underline{u}_2 + u'_{3z'} \underline{u}_3.$$

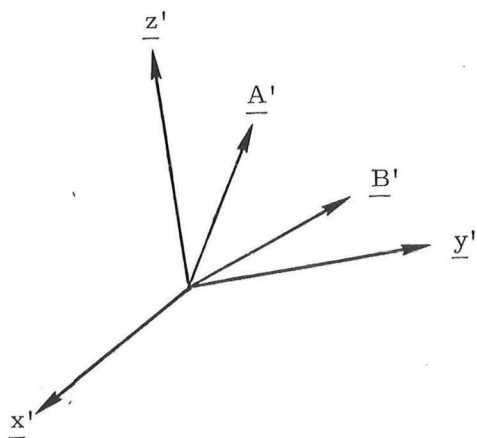
By definition, REFSMMAT is the matrix which transforms a vector from basic-reference coordinates to stable-member coordinates. Therefore,

$$\text{REFSMMAT} = \begin{bmatrix} \underline{x}'^T \\ \underline{y}'^T \\ \underline{z}'^T \end{bmatrix}.$$

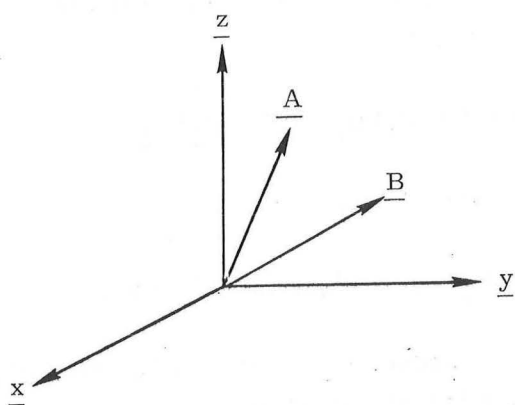
A CMC routine called AXISGEN carries out the above calculations. In P51 and P53, the inputs to AXISGEN are the four line-of-sight vectors: two are in stable-member coordinates and two are in basic-reference coordinates.\* Two lines of sight are measured in sextant-base or ATM coordinates, then transformed into

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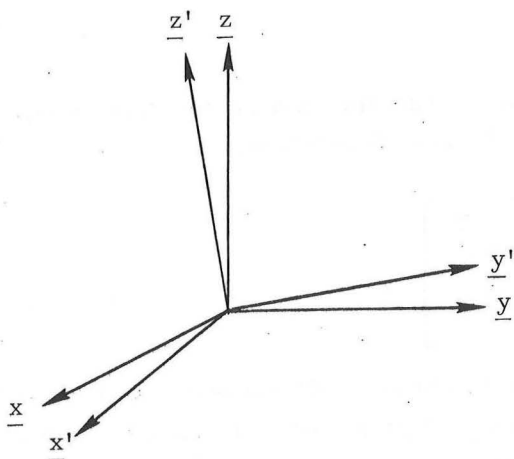
\* In P50 and P55, AXISGEN can have other inputs. Refer to the appropriate program descriptions.



a. Vectors A and B described in primed coordinate system.

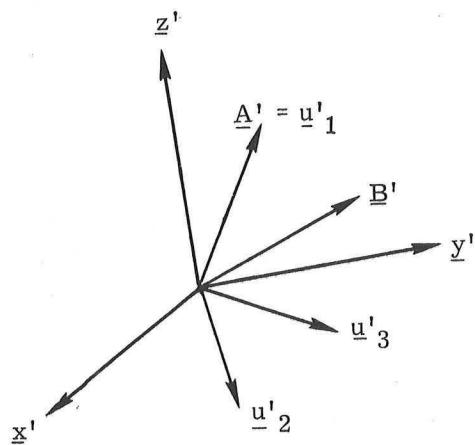


b. Vectors A and B described in unprimed coordinate system.

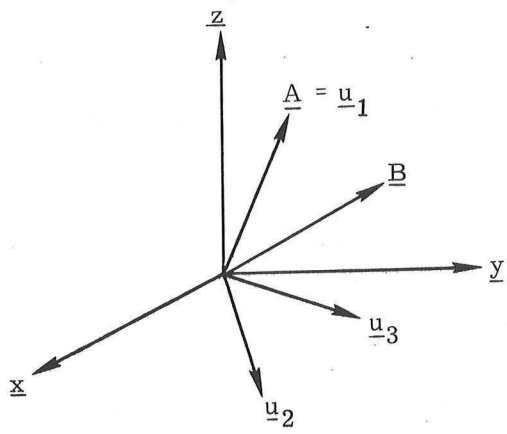


c. Primed coordinate system described in unprimed coordinate system.

Figure 7. 1-4. Coordinate Axes Generator (Sheet 1 of 2)



d. Orthonormal vectors generated from  $\underline{A'}$  and  $\underline{B'}$ ; primed axes are resolved into their components along  $\underline{u'_1}$ ,  $\underline{u'_2}$ ,  $\underline{u'_3}$ .



e. Orthonormal vectors generated from  $\underline{A}$  and  $\underline{B}$ ; primed axes are constructed in unprimed coordinates from their components along  $\underline{u_1}$ ,  $\underline{u_2}$ ,  $\underline{u_3}$ .

Figure 7. 1-4. Coordinate Axes Generator (Sheet 2 of 2)

navigation-base coordinates, and finally, using the IMU gimbal angles, transformed into stable-member coordinates suitable for AXISGEN input. The other two lines of sight are obtained in basic-reference coordinates from stored knowledge of the celestial bodies' inertial coordinates. The output of AXISGEN is used as REFSMMAT.

In P52 and P54, the CMC must compute the desired orientation of the stable-member axes with respect to the present Stable-member Coordinate System. In this case, the inputs to AXISGEN are two vectors describing the LOS to two celestial bodies in present stable-member coordinates and two vectors describing the same LOS in desired stable-member coordinates. Figure 7.1-5 shows the processing of the four LOS vectors before AXISGEN input. If the target is a star, its basic-reference vector is obtained directly from CMC memory. If the target is the sun or earth, the CMC calculates its basic-reference vector. The astronaut must load the basic-reference vector for all other celestial bodies via the DSKY.

The general sequence of computer and ISS operations during the realignment programs is as follows (refer to Figure 7.1-6):

- a. The astronaut selects a desired inertial orientation for the stable member.
- b. The CMC calculates the gimbal angles corresponding to the desired stable-member orientation.
- c. If the desired gimbal angles are satisfactory to the astronaut, the computer coarse aligns the stable member to the desired gimbal angles.
- d. The astronaut takes sightings on two celestial bodies to enable the CMC to precisely determine the difference between the present and desired inertial orientations and to compute the required torquing angles.
- e. The computer torques the stable member into fine alignment with the computed orientation.

Three REFSMMATs are used by the CSM during a normal mission. The stable-member orientations that they describe are chosen to provide the most convenient orientation for the flight director attitude indicator (FDAI). The stable-member orientations are described here:

- a. Launch -pad orientation (launch through orbit insertion) --- at launch the FDAI will display Roll =  $90^{\circ}$  + flight azimuth, Pitch =  $90^{\circ}$ , Yaw =  $0^{\circ}$ .
- b. Rendezvous REFSMMAT --- at TPI the FDAI will display the following approximate attitude: Roll =  $0^{\circ}$ , Pitch =  $28^{\circ}$ , Yaw =  $0^{\circ}$ .
- c. Deorbit REFSMMAT --- at SPS deorbit ignition the FDAI will display Roll =  $0^{\circ}$ , Pitch =  $180^{\circ}$ , Yaw =  $0^{\circ}$ .

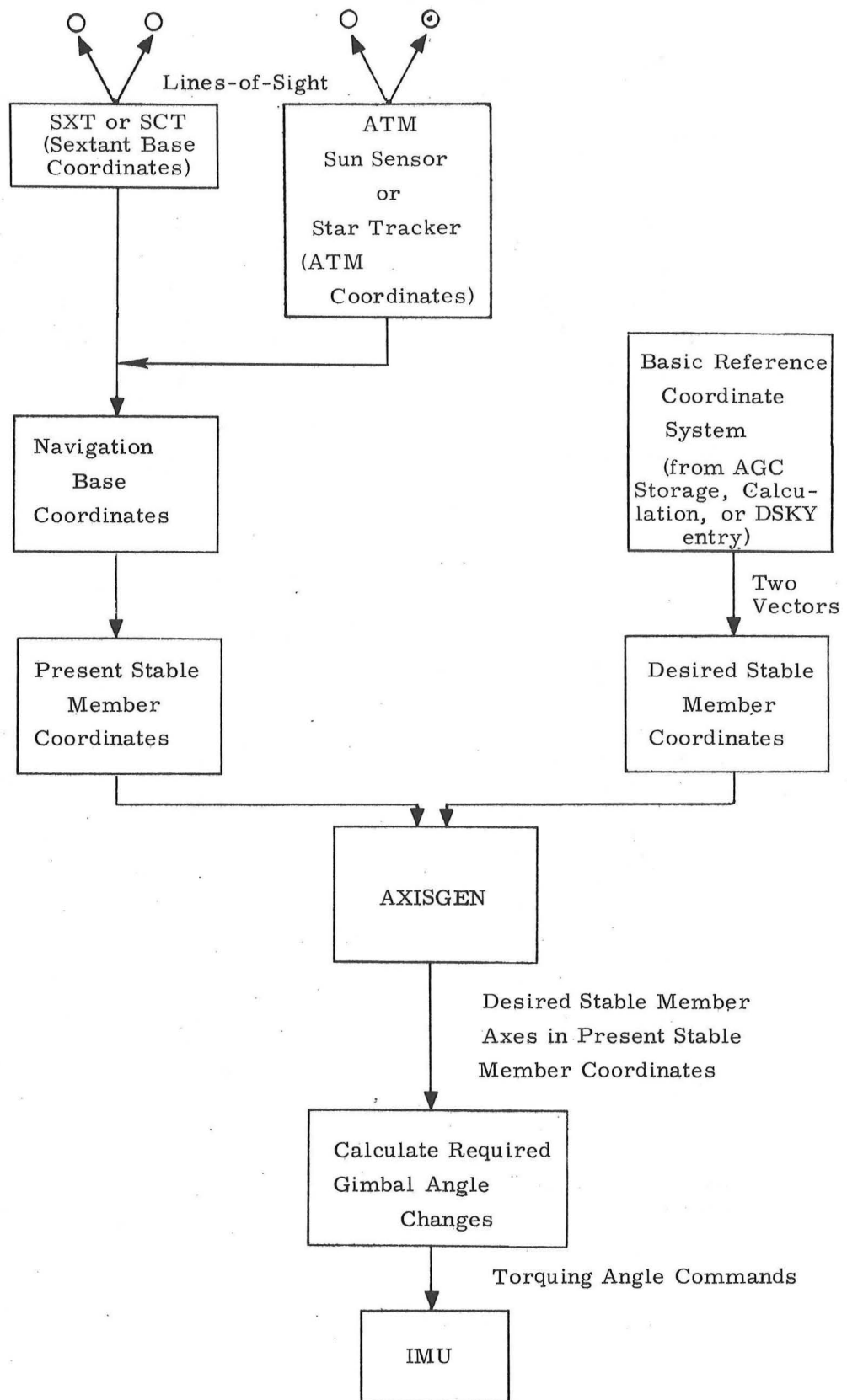
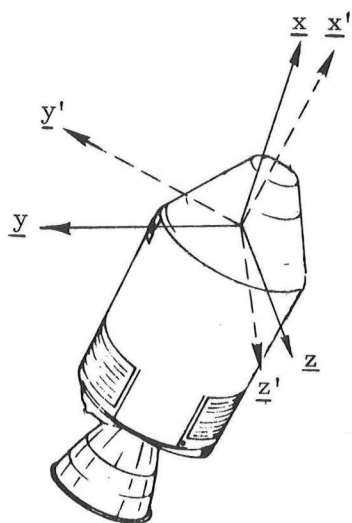
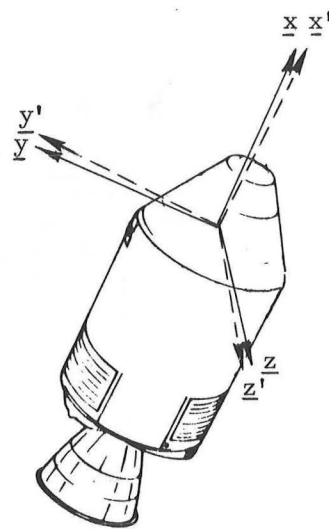


Figure 7. 1-5. AXISGEN Inputs for Realignment Program



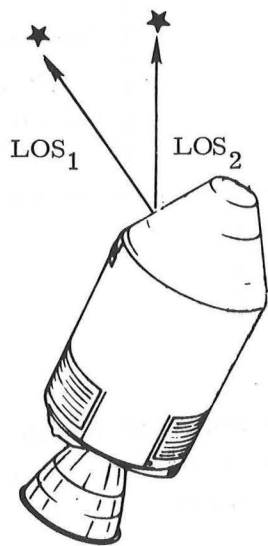
a. Calculate desired stable member orientation



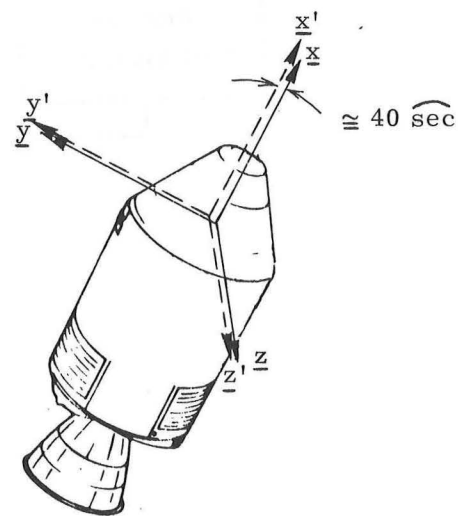
b. Coarse align stable member

———— Present Stable Member Axes

- - - - - Desired Stable Member Axes



c. Take celestial body sightings



d. Fine align stable member



## 7.2 P50, ATM ORIENTATION DETERMINATION PROGRAM

The ATM Orientation Determination Program (P50) computes and stores the orientation of the ATM Sensor Coordinate System with respect to the Navigation-base Coordinate System. This information is needed when the CSM is docked to the workshop and the astronaut uses sighting data from the ATM optics to perform IMU orientation determination (P51 or P53) or IMU realignment (P52 or P54). ATM-orientation information is also used by the ATM Star Tracker Gimbal Angle Program (P55) to compute the gimbal angles required by the ATM star tracker to point at a designated celestial body.

### 7.2.1 Options

The orientation of the ATM sensor coordinate system is represented in the CMC by two vectors that define the y- and z-axes of this system in navigation-base coordinates. Before launch, the expected normal values of these two vectors are loaded into erasable memory. In flight, the stored ATM orientation can be partially or completely updated by a suitable selection of one of three options available in P50.

#### 7.2.1.1 Option 1: ATM Orientation Determination Using ATM Sun Sensor

Option 1 provides a partial update of the ATM sensor orientation by determining the current orientation of the ATM sensor +z-axis with respect to the Navigation-base Coordinate System. Option 1 calculations are as follows:

- a. The CMC must have a valid REFSMMAT in storage and the ATM must be in the solar inertial attitude. In solar inertial attitude, the sun sensor and, therefore, the ATM sensor +z-axis are pointing at the sun.
- b. When the astronaut is satisfied that the ATM is in solar inertial attitude, he depresses the MARK button to record the current time and IMU gimbal angles.
- c. The CMC computes the unit LOS vector to the sun with respect to basic-reference coordinates; this vector is parallel to the ATM sensor +z-axis when in solar inertial attitude. The CMC then converts the ATM sensor z-axis to navigation-base coordinates by using REFSMMAT and the current gimbal angles. The computer saves this new value for the ATM sensor z-axis in addition to the previously stored y- and z-axes.
- d. P50 partially updates the ATM sensor y-axis by using the routine AXISGEN to construct a new y-vector that is perpendicular to the new

z-axis and is in the plane containing the new z-axis and old y-axis.

- e. Using the partially updated ATM sensor axes, P50 computes and displays a set of docking angles that describe the orientation of the ATM sensor coordinates with respect to navigation-base coordinates.
- f. If the astronaut is satisfied with the display, he commands the CMC to replace the previously-stored ATM sensor axes with the new axes. If he is not satisfied, he can overwrite one or more of the displayed angles, and the CMC will compute new ATM sensor axes based on the crew-supplied angles. In Options 1 and 2, the computed  $\alpha_{\text{ATM}}$  is usually more accurate than the docking ring scale indication, because it is independent of structural mounting errors.

#### 7.2.1.2 Option 2: ATM Orientation Determination Using ATM Sun Sensor and Star Tracker

Option 2 provides a complete update of all ATM sensor axes by using both ATM sun sensor and star tracker. Option 2 operates as follows:

- a. The CMC must have a valid REFSMMAT, the ATM must be in solar inertial attitude, and the star tracker must be locked onto a celestial body.
- b. When the sun and another celestial body have been acquired by the ATM sensors, the astronaut depresses the MARK button to record IMU gimbal angles and time. The astronaut writes down the star-tracker gimbal angles and celestial-body identification for later CMC entry.
- c. The CMC updates the ATM sensor z-axis in the same way as in Option 1.
- d. P50 uses the routine AXISGEN to update the ATM sensor y-axis. The inputs to AXISGEN are the stored celestial-body LOS vectors in navigation-base coordinates and the measured celestial body vectors in ATM coordinates. The outputs of AXISGEN are the ATM sensor x-, y-, and z-axis vectors in navigation-base coordinates, including the ATM z-axis already obtained in step c.
- e. Using the completely updated ATM axes, P50 computes a set of pseudo gimbal angles and displays the docking angles as in Option 1.
- f. The astronaut can store or replace the computed axes as in Option 1.

#### 7.2.1.3 Option 3: ATM Orientation Using Independent Docking Angle Data

The astronaut selects Option 3 when he wants to update the stored ATM sensor axes using data from the docking ring scale or from a message voiced to him. No

celestial-body sightings are taken. Option 3 can also be selected if the astronaut only wants the CMC to compute and display the docking angle values corresponding to the currently-stored values of the ATM sensor axes. Option 3 operates as follows:

- a. The CMC computes and displays the docking angles corresponding to the stored ATM sensor axes.
- b. The astronaut can approve the displayed values or load new angles, if he desires. If he loads new angles, the stored ATM sensor axes will be replaced by the new values.

#### 7.2.2 Procedures

P50 DSKY procedures are as follows (refer to Figure 7.9-1 for functional flow diagrams of P50/R53):

1. Start the ATM Orientation Determination Program (P50) by keying VERB 37 ENTR 50 ENTR. Respond to flashing display of option code requesting "Please select ATM orientation-determination option":

##### FL VERB 04 NOUN 06

R1	00012	Request specify option
R2	0000x	Option Code (preloaded 00001)
R3	Blank	

Option codes in R2 are as follows:

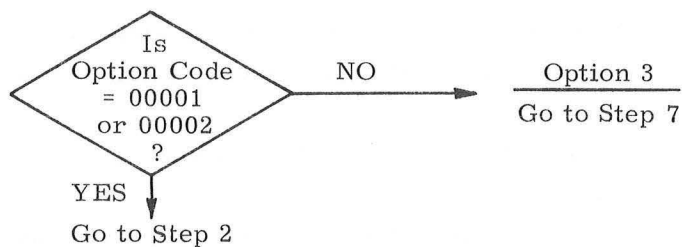
00001 — ATM Sun Sensor (requires valid REFSMMAT and ATM in solar inertial attitude before a mark is taken);

00002 — ATM Sun Sensor and ATM Star Tracker (requires valid REFSMMAT, ATM in solar inertial attitude, and Star Tracker locked onto identified celestial body).

00003 — ATM angles from independent source (no REFSMMAT or attitude requirements).

If displayed option code is not desired, key VERB 22 ENTR and load desired code.

To approve displayed code, key PRO.



Possible ALARM

PROG Alarm 00210 (IMU off). To perform P50 Option 3, reselect program and load 00003 into NOUN 06 (R2).

PROG Alarm 00220 (REFSMMAT invalid). To perform P50 Option 3, reselect program and load 00003 into NOUN 06 (R2).

2. Respond to flashing display requesting mark:

FL VERB 51 (R53)

R1 Blank

R2 Blank

R3 Blank

NOTE 1.—NOUN and R1 are not cleared when display is recycled by MARK REJ response to FL VERB 50 NOUN 25 (R1 = 00016).

NOTE 2.—FL VERB 51 does not appear if IMU is off or if REFSMMAT is invalid. In this case, the CMC turns on the PROG alarm light, stores alarm code 00210 (IMU off) or 00220 (REFSMMAT invalid), and terminates P50. Reselect P50 and load Option 3 in Step 1.

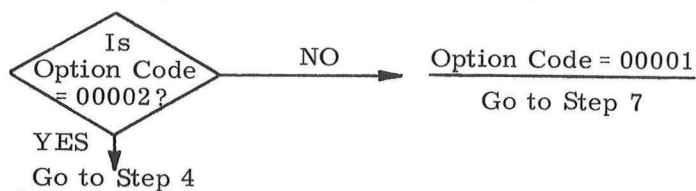
Before a mark, ascertain that the ATM is in solar inertial attitude and, if Option 2, that the star tracker is locked onto a celestial body. When the sighting is satisfactorily accomplished, depress the MARK button and, if Option 2, record the star-tracker gimbal angles at mark time.

3. After one mark is completed, respond to flashing request to "Please perform terminate mark sequence":

FL VERB 50 NOUN 25 (R53)

R1 00016 Checklist  
R2 Blank  
R3 Blank

- . To terminate marking, key PRO.
- . To reject mark, key MARK REJ and return to Step 2.



4. Respond to flashing request to load optics code and celestial body code:

FL VERB 01 NOUN 71 (R53)

R1 00CDE  
R2 Blank  
R3 Blank

where "C" is code for source of sighting data:

0 = CSM optics  
1 = sun sensor  
2 = star tracker

and "DE" is the celestial body code:

00<sub>g</sub> = any planet  
01<sub>g</sub>-45<sub>g</sub> = star from celestial-body list  
46<sub>g</sub> = sun  
47<sub>g</sub> = earth

NOTE.—Appropriate loading of R1 is 002xx, where xx = 00<sub>8</sub>–45<sub>8</sub>. OPR ERR occurs if C = 1 and DE ≠ 46<sub>8</sub> or if DE ≠ 00<sub>8</sub>–47<sub>8</sub>.

- . To load new values, key VERB 21 ENTR and load desired CDE in R1.
- . To accept displayed values, key PRO.

5. Respond to flashing request for star-tracker angles recorded in Step 2:

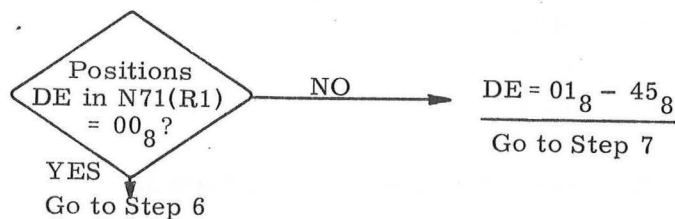
FL VERB 06 NOUN 14 (R53)

R1 ±xxxxx. arc-min star tracker azimuth ( $\psi_3$ )  
 R2 ±xxxxx. arc-min star tracker elevation ( $\psi_1$ )  
 R3 Blank

- . Key VERB 24 ENTR, and load star-tracker angles that were recorded at time of mark.
- . PRO

Possible OPR ERR

If either azimuth or elevation is less than -10800 or greater than +10800 arc-min, key RSET and reload Noun 14.



6. Respond to flashing planet position-vector components:

FL VERB 06 NOUN 88

R1 ±.xxxxx XPL  
 R2 ±.xxxxx YPL  
 R3 ±.xxxxx ZPL

- . Key VERB 25 ENTR and load x,y,z components of planet position vector.
- . PRO

7. Respond to flashing display requesting approval of docking angles describing ATM coordinates with respect to navigation-base coordinates:

FL VERB 06 NOUN 23

R1     $\pm xxx.xx$     deg  $\alpha_{ATM}$   
R2     $\pm xxx.xx$     deg  $\beta_{ATM}$   
R3     $\pm xxx.xx$     deg  $\gamma_{ATM}$

- . If displayed angles are not satisfactory (e.g., Option 3), key VERB 25 ENTR and load desired value(s).
- . To accept the displayed angles, key PRO.
- . To exit P50 without updating the stored ATM axes, key VERB 34 ENTR.

8. Respond to flashing display, "Please select new program":

FL VERB 37 (R00).

- . Key xx ENTR

### 7.3 ' P51, IMU ORIENTATION DETERMINATION PROGRAM

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. It does this as follows:

- a. Assuming that the IMU is operating, two marks are made on identified celestial bodies and, using the gimbal angles and the known relationship between the mark source and the Navigation Base, the mark lines of sight are transformed into the Stable Member Coordinate System.
- b. From storage, calculation, or DSKY entry, the lines of sight to the two bodies in the Basic Reference Coordinate System are obtained.
- c. Using these two pairs of vectors as input to the routine AXISGEN (paragraph 7.1.2), the orientation of the Stable Member in Basic Reference Coordinates is determined and stored as REFSMMAT.

This program is the same as that used in Apollo except that two additional sighting data sources are available when the CSM is docked with the OWS. These are the ATM Acquisition Sun Sensor (ATM SS) and the ATM Star Tracker (ST). These sources can be used when the transformation relating the CSM Navigation Base and the ATM coordinate system is known. This transformation is computed by the ATM Orientation Determination Program (P50) (subsection 7.2).

For the undocked configuration, the crew can, upon P51 entry, acquire identifiable celestial bodies by maneuvering the optics or the spacecraft until the body is in the field of view, while monitoring the FDAI ball to avoid gimbal lock. The crew can coarse align the IMU to (0,0,0) gimbal angles if desired. The astronaut performs the marks by centering the body in the field of view and keying MARK.

If the ATM SS is being used as a mark data source, the mark is made when the OWS is in solar inertial attitude, and the mark body is the sun. If the ATM ST is used, the mark is made when the tracker is locked onto the body, and the tracker gimbal angles are recorded at the instant of marking for later DSKY entry.

7.3.1 Options: None.

7.3.2 Procedures

P51 DSKY procedures are as follows (refer to Figure 7.9-2 for functional flow diagrams of P51):



1. Start the IMU Orientation Determination Program (P51) by keying VERB 37 ENTR 51 ENTR.

Possible ALARM

PROG Alarm 00210 (IMU Off). To perform P51, turn on IMU and, after a 15-minute warmup period, reselect P51 as above.

2. Respond to flashing request to "Please perform celestial body acquisition":

FL VERB 50 NOUN 25

R1 00015 Checklist  
R2 Blank  
R3 Blank

Maneuver the vehicle, using the RHC, to place the CSM pitch axis in a preferred direction, if desired, or to place celestial bodies within the SCT field of view. Monitor impending gimbal lock via the FDAI ball. If necessary or desired, key ENTR to coarse align the IMU to (0,0,0) gimbal angles, and observe:

VERB 41 NOUN 22

R1 +00000 OGA  
R2 +00000 IGA  
R3 +00000 MGA

and NO ATT light until coarse align is complete and FL VERB 50 NOUN 25 R1 00015 reappears.

Possible ALARM

PROG Alarm 00217 (Bad return from stall routines). If alarm code 00211 (Coarse align error - greater than 2 degrees) accompanies the 00217 alarm, key RSET and continue. If there is no 00211 alarm, then either the IMU has been caged or the ISS Warning light has been turned on. Follow checklist procedures.

When desired maneuvers are complete key PRO.

3. Respond to flashing display requesting mark:

FL VERB 51 (R53)

R1 Blank  
R2 Blank  
R3 Blank

NOTE.—NOUN and R1 are not blank if display is invoked by MARK REJ response to FL VERB 50 NOUN 25 R1 00016 at Step 4 below.

- a. Mark using CSM optics: set OPT MODE switch to MAN, center celestial body in field of view, and key MARK.
  - b. Mark using ATM sun sensor: ensure that ATM is in solar inertial attitude, and key MARK.
  - c. Mark using ATM star tracker: ensure that star tracker is locked onto the desired celestial body, and key MARK. Record star tracker gimbal angles at the instant of mark.
4. Respond to flashing display "Please terminate mark sequence":

FL VERB 50 NOUN 25 (R53)

R1 00016  
R2 Blank  
R3 Blank

- . To reject mark, key MARK REJ, and return to Step 3.
- . To accept mark, key PRO.

5. Respond to flashing display of optics and celestial body codes:

FL VERB 01 NOUN 71 (R53)

R1 00CDE  
R2 Blank  
R3 Blank

Where "C" indicates device used to obtain mark at Step 3 as follows:

0 = CSM optics  
1 = sun sensor  
2 = star tracker

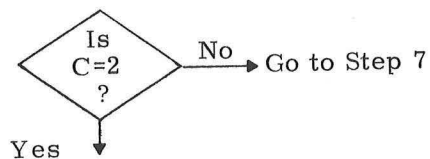
and "DE" indicates celestial body marked on as follows:

$00_8$  = planet  
 $01_8 - 45_8$  = star from AGC catalog  
 $46_8$  = sun (Mandatory if  $C = 1$ )  
 $47_8$  = earth

To load new data, key VERB 21 ENTR 00CDE ENTR. Key PRO when R1 is correct.

Possible OPR ERR

1. If DE not  $00_8 - 47_8$   
If  $C = 1$  and DE not  $46_8$   
Key RSET and repeat Step 5.



6. Respond to flashing request to load star tracker gimbal angles recorded at Step 3:

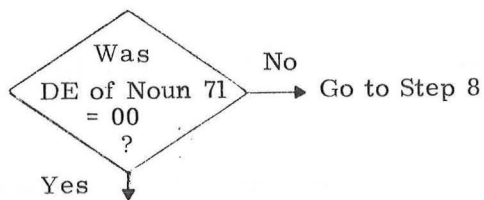
FL VERB 06 NOUN 14 (R53)

R1 ±xxxxx. arc-min star tracker azimuth ( $\psi_3$ )  
R2 ±xxxxx. arc-min star tracker elevation ( $\psi_1$ )  
R3 Blank

Key VERB 24 ENTR and load recorded star tracker gimbal angles. Key PRO.

Possible OPR ERR

If either azimuth or elevation is less than -10800 or greater than +10800 arc-min, key RSET and reload NOUN 14.



7. Respond to flashing request to load position vector components of SXT/SCT or ATM star tracker target:

FL VERB 06 NOUN 88

R1	±.xxxxxx	XPL
R2	±.xxxxxx	YPL
R3	±.xxxxxx	ZPL

Where XPL, YPL, and ZPL are components of the position vector of the body marked on.

Key VERB 25 ENTR and load vector components obtained from table. Key PRO when correct.

8. If this is the first mark, repeat Steps 3 through 7 above for second mark. Otherwise, go to Step 9.

9. Respond to flashing display of sighting mark data:

FL VERB 06 NOUN 05 (R54)

R1    +xxx.xx    Sighting angle difference  
R2    +xxx.xx    Sighting angle  
R3    Blank

If sighting angle difference (R1) is unacceptable considering the sources of the marks, or if sighting angle (R2) is not satisfactory (recommended bandwidth is between 25 and 155 degrees), key VERB 32 ENTR to recycle P51 to Step 2 above.

If both R1 and R2 are satisfactory, key PRO.

10. Respond to flashing display "Please select new program":

FL VERB 37 (R00)

Key    xx    ENTR

#### 7.4. P52, IMU REALIGN PROGRAM

The IMU Realign Program (P52) is used during free fall to realign the IMU either to its presently assumed orientation in the basic reference coordinate system or to a new such orientation. P52 accomplishes this in the following way:

- a. Assuming that the IMU is operating, that its inertial orientation, except for drift, is known (REFSMMAT is valid), and orientation, except for drift, is known (REFSMMAT is valid), and that the new desired orientation has been stored, two marks are made on identified celestial bodies. These mark lines of sight are transformed into present stable member coordinates using the gimbal angles and the known relationship between the mark source and the Navigation Base.

NOTE - P52 may be used to align to a stored REFSMMAT even though the present orientation is not known. Large gyro torquing angles (Noun 93) may result.

- b. The lines of sight to the same two bodies in the Basic Reference Coordinate System are obtained from storage, from calculations, or from DSKY entry. These are transformed into desired stable member coordinates.
- c. Using these two pairs of lines of sight vectors, the routine AXISGEN (paragraph 7.1.2) determines the orientation of the desired orientation with respect to the present orientation.
- d. The AXISGEN result is converted to gyro torquing angles which will drive the stable member from present to desired orientation.

This program is identical to P52 for Apollo, except for the availability, when the CSM is docked with the OWS, of two additional sources of sighting data. These are the ATM sun sensor and the ATM star tracker, which may be used whenever the transformation relating the CSM Nav Base and the ATM coordinate system (matrix NBOA) is known. This matrix is calculated by the ATM Orientation Determination Program (P50) (Subsection 7.2).

Additionally, P52 is called twice automatically during the MINKEY plane-change sequence: before and after the plane-change burn. Before the burn, P52 torques the IMU  $45^{\circ}$  about its z-axis in such a direction as to relieve the gimbal lock constraint. After the burn, P52 restores the IMU orientation existing before the first, pre-burn torquing.

At the beginning of non-MINKEY P52, the crew must select which of the following three stable member orientations is desired:

<u>Option</u>	<u>Code</u>	<u>Use</u>
Preferred	1	For alignment with respect to the targeted thrust vector, or with uplinked desired stable member orientation.
Nominal	2	For alignment with respect to local vertical at some crew-specified time.
REFSMMAT	3	For realignment to the presently assumed orientation. Eliminates uncompensated drift.

For preferred and nominal realignments, P52 displays gimbal angles at the new IMU orientation to assist the crew in determining that middle gimbal angle at the new IMU orientation will be satisfactory (less than 70 degrees).

The IMU can be initially aligned to the desired orientation either by coarse aligning or by pulse-torquing the gyros without coarse alignment. The normal procedure is to use the Coarse Align Routine, which will calculate the IMU gimbal angles for the new orientation and, if any one or more gimbal angles differs from its present value by more than one degree, the IMU is coarse-aligned by driving the gimbals to their desired values. Following this, the residual gimbal errors are trimmed by gyro torquing. Any CSM attitude changes during the coarse alignment phase will be reflected in misalignment of the IMU at termination of this procedure. Such misalignment will have the following effects:

1. If large, improper operation of the star selection routine.
2. Improper operation of the Auto Optics Positioning Routine (R52), resulting in difficulty in visual acquisition of the star. (SXT FOV is  $0.9^{\circ}$  half-cone angle).
3. Large gyro torquing angles required during the Gyro Torquing Routine (R55).

The alternative procedure of pulse torquing the IMU to the desired orientation does not require maintenance of a constant attitude, but does require considerable time (approximately 1.8 seconds per degree of the sum of the three angles to be torqued).

To perform CSM optical sightings when the CSM is not docked with the OWS, the crew must maneuver to an attitude permitting celestial body acquisition. The crew may select the bodies or, alternately, the program may be allowed to select them. In either case, the Auto Optics Positioning Routine (R52) may be used as an acquisition aid to position the optics toward the body.

#### 7.4.1 Options

The astronaut has the option of realigning the stable member to an orientation defined in one of three ways.

##### 7.4.1.1 Option 1: Preferred

Option 1 provides for realignment of the IMU from the inertial orientation described by REFSMMAT to a new inertial orientation calculated externally to P52. This external source may be the ground, in which case the new orientation must be provided via uplink. The external source may also be the Thrusting Programs, P40 and P41, which calculate a preferred IMU orientation as a function of a targeted thrust vector.

##### 7.4.1.2 Option 2: Nominal

In option 2, the desired IMU orientation is a function of the local vertical at some astronaut-specified time. In this option, the desired orientation is calculated by program P52 itself, and stored as the preferred orientation. Having performed this calculation, P52 continues as in option 1.

##### 7.4.1.3 Option 3: REFSMMAT

In option 3, REFSMMAT itself is treated by P52 as the new desired orientation.

#### 7.4.2 Procedures

##### 7.4.2.1 Crew-selected P52 (Non-MINKEY)

DSKY procedures for crew-selected (non-MINKEY) P52 follow below (refer to Figure 7.9-3 for functional flow diagrams of P52). DSKY procedures for MINKEY P52 are at paragraph 7.4.2.2.

1. Start the IMU Realign Program (P52) by keying VERB 37 ENTR 52 ENTR.



Possible ALARMS

PROG Alarm 00210 (IMU Off). To perform P52, turn on IMU, wait 15 minutes for warmup, select P51 to determine IMU orientation, and reselect P52 as above.

PROG Alarm 00220 (IMU Not Aligned). To perform P52, select P51 to determine IMU orientation, and then reselect P52 as above or set the following flags in order to perform P52 option 3.

REFSMFLG (FLAGWRD3, bit 13)

IMUOPBIT (IMODES30, bit 9)

2. Respond to flashing display of option code requesting "Please select IMU orientation":

FL VERB 04 NOUN 06

R1	00001	Request specify option
R2	0000x	Option code (Preloaded 00001 if
R3	Blank	Preferred Attitude Flag is set.
		Otherwise preloaded 00003).

Option codes in R2 are as follows:

00001 — Align to stored preferred orientation

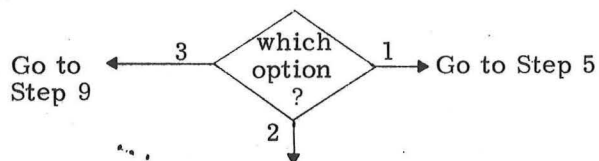
00002 — Align to local vertical at time to be specified

00003 — Align to REFSMMAT

If displayed option is not desired, key VERB 22 ENTR and load desired option code.

When option is correct, key PRO.

3.



4. Respond to flashing display of time of local vertical to be aligned to:

FL VERB 06 NOUN 34

R1 +xxxxx. (hrs)

R2 +000xx. (min)

R3 +0xx.xx (sec)

Initially, R1, R2, and R3 are set to zero. If it is desired to align to local vertical at the present time, key PRO. If the local vertical is to be that for some other time than the present, key VERB 25 ENTR and load the desired time. When the correct time is present in the DSKY, key PRO.

Possible ALARM

PROG Alarm 00401 (Desired gimbal angles yield gimbal lock). At the present vehicle attitude, coarse-aligning of the IMU to the desired orientation will result in a middle gimbal angle greater than +60 degrees or less than -60 degrees.

5. Respond to flashing display of gimbal angles resulting from coarse alignment to new orientation:

FL VERB 06 NOUN 22

R1 +xxx.xx OGA

R2 +xxx.xx IGA

R3. +xxx.xx MGA

If the final middle gimbal angle is unsatisfactory, either:

- a. Maneuver the vehicle, using the RHC, to obtain a more suitable MGA. Key VERB 32 ENTR to recycle to VERB 06 NOUN 22 which will display the final gimbal angles at the new attitude; or
- b. Key VERB 34 ENTR to exit P52.

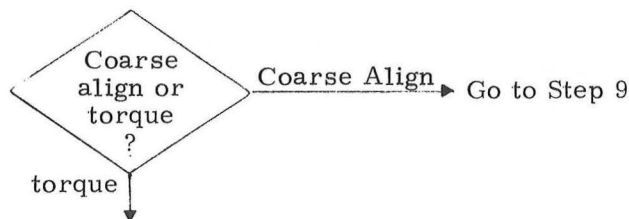
If the final gimbal angles are satisfactory, key PRO.

6. Respond to flashing display "Please perform normal or gyro torque coarse align":

FL VERB 50 NOUN 25

R1 00013  
R2 Blank  
R3 Blank

If normal coarse alignment of the IMU followed by trimming residual gimbal angles via pulse-torquing is desired, key PRO. Otherwise, if pulse torquing of the IMU is desired (considering the amounts to be torqued at 0.55 deg/sec), key ENTR.



7. Observe:

VERB 16 NOUN 20

R1 +xxx.xx OGA  
R2 +xxx.xx IGA  
R3 +xxx.xx MGA

Monitor display to ensure that IMU will not be torqued into gimbal lock. If necessary, maneuver to avoid gimbal lock. NOUN 20 will remain for approximately 1.8 x (total of 3 torquing angles) seconds.

8. Respond to flashing display "Please perform fine align":

FL VERB 50 NOUN 25

R1 00014  
R2 Blank  
R3 Blank

If it is desired to continue P52 through the fine-align phase, key PRO. Otherwise, key ENTR to exit P52 to routine R00. In this event, the IMU will have been pulse-torqued into compliance with REFSMMAT insofar as the CMC program is able to compute that compliance without celestial observations.

9. Respond to flashing display "Please perform star acquisition":

FL VERB 50 NOUN 25

R1 00015

R2 Blank

R3 Blank

If ATM Star Tracker, or ATM Sun Sensor are to be used in marking, key ENTR to bypass automatic star selection by the CMC and continue at step 10. Otherwise, if CMC assistance in star acquisition is desired, key PRO. Optics mode switch should be switched to CMC.

Possible ALARM

PROG Alarm 00405 (Two stars not available). If further CMC assistance in star selection is wanted, maneuver the vehicle and key VERB 32 ENTR to recycle to Step 9. If no further assistance is required, key PRO and maneuver to acquire stars in the SXT/SCT field of view manually.

10. Respond to flashing display of celestial body code and mark source code:

FL VERB 01 NOUN 70

R1 00CDE

R2 Blank

R3 Blank

Where "C" indicates device used to obtain mark as follows:

0 = CSM optics

1 = sun sensor

2 = star tracker

and "DE" indicates celestial body marked upon, as follows:

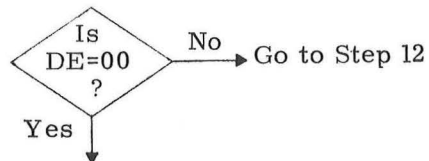
00<sub>8</sub> = planet  
01<sub>8</sub> - 45<sub>8</sub> = star from CMC catalog  
46<sub>8</sub> = sun (mandatory if "C" = 1)  
47<sub>8</sub> = earth

To load new data, key VERB 21 ENTR 00CDE ENTR. Key PRO when R1 contains desired data.

NOTE:—This display is for auto optics positioning purposes only, and may be simply bypassed by keying PRO when it appears. R1 must, however, contain a legal (if irrelevant) star code, or OPR ERR will appear (see below).

Possible OPR ERR

1. If DE not 00<sub>8</sub> - 47<sub>8</sub>
2. If C = 1 and DE not 46<sub>8</sub>  
Key RSET and repeat step 10.



11. Respond to flashing display of position vector of celestial body to be marked on:

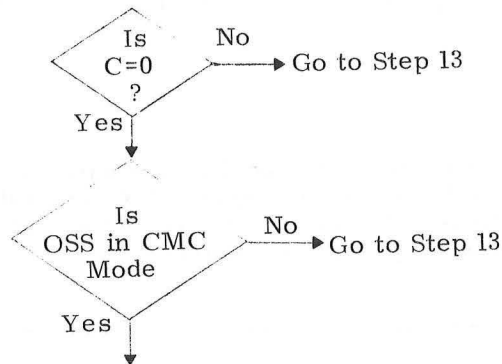
FL VERB 06 NOUN 88

R1 ±.xxxxx XPL  
R2 ±.yyyyy YPL  
R3 ±.zzzzz ZPL

where XPL, YPL, and ZPL are proportional position vector components of the celestial body to be marked on. To load new data, key VERB 25 ENTR

and load vector components, which may be any proportional set. Unit vectors are, however, recommended. Key PRO when correct.

This display, too, is for auto optics positioning purposes only and may be bypassed by keying PRO when it appears, if auto optics positioning is not to be used.



#### Possible ALARM

Prog Alarm 00404 (Trunnion angle greater than  $90^{\circ}$ ). Maneuver vehicle until optics can acquire the body. Key PRO.

12. Observe display of desired shaft and trunnion angles:

#### VERB 06 NOUN 92 (R52)

R1    ±xxx.xx    desired shaft angle in 0.01 deg.  
R2    +xx.xxx    desired trunnion angle in 0.001 deg.

At this time, R52 drives the optics to the desired shaft and trunnion angles. If, however, the desired trunnion angle is greater than about 50 degrees, R52 will drive the shaft to the proper value, but will drive the trunnion to approximately 50 degrees. Noun 92 will show approximately 50 degrees in this circumstance. Maneuver the vehicle so that desired trunnion angle is less than 50 degrees. When the celestial body appears in the optics field of view, switch the Optics Mode Switch to MANUAL.

13. Respond to flashing display requesting mark:

FL VERB 51 (R53)

R1 Blank  
R2 Blank  
R3 Blank

NOTE.—NOUN and R1 are not blank if display is invoked by a MARK REJ response to FL VERB 50 NOUN 25 R1 00016 at Step 14 below.

- a. Mark using CSM SXT/SCT: with Optics Mode Switch in MANUAL position, center celestial body in the optics field of view and key MARK;
- b. Mark using ATM Sun Sensor: ensure that ATM is in solar inertial attitude, and key MARK;
- c. Mark using ATM Star Tracker: ensure that Star Tracker is locked onto celestial body, and key MARK. Record Star Tracker gimbal angles at instant of MARK for DSKY entry at Step 16 below.

14. Respond to flashing display "Please terminate mark sequence":

FL VERB 50 NOUN 25 (R53)

R1 00016  
R2 Blank  
R3 Blank

- . To reject mark, key MARK REJ and return to Step 13;
- . To accept mark, key PRO.

15. Respond to flashing display of celestial body code and mark source code:

FL VERB 01 NOUN 71 (R53)

R1 00CDE  
R2 Blank  
R3 Blank

NOTE.—This display will be correct if Noun 70 was correctly loaded at Step 10.

Where "C" indicates device used to obtain mark as follows:

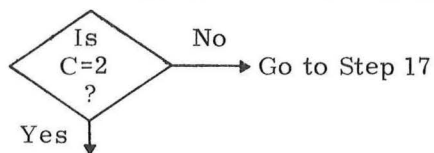
0 = CSM optics  
1 = sun sensor  
2 = star tracker

and "DE" indicates celestial body marked upon, as follows:

$00_8$  = planet  
 $01_8 - 45_8$  = star from CMC catalog  
 $46_8$  = sun (mandatory if "C" = 1)  
 $47_8$  = earth

Possible OPR ERR

1. If DE not  $00_8 - 47_8$
2. If C = 1 and DE not  $46_8$   
Key RSET and repeat Step 15.



16. Respond to flashing display of star tracker gimbal angles recorded at Step 13:

FL VERB 06 NOUN 14 (R53)

R1 ±xxxxx. arc-min star tracker azimuth ( $\psi_3$ )  
R2 ±xxxxx. arc-min star tracker elevation ( $\psi_1$ )  
R3 Blank

Key VERB 24 ENTR and load Star Tracker azimuth and elevation angles recorded at Step 13.

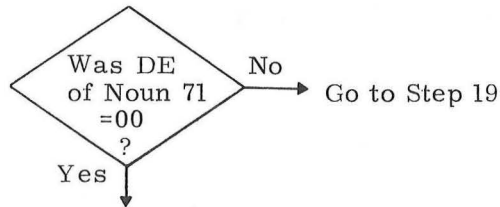


Possible OPR ERR

If either azimuth or elevation is less than -10800 or greater than +10800 arc-min,  
key RSET and repeat Step 16.

When R1 and R2 are correct, key PRO.

17.



18. Respond to flashing display of position vector components for celestial body marked at Step 13:

FL VERB 06 NOUN 88

R1	±xxxxx.	XPL
R2	±xxxxx.	YPL
R3	±xxxxx.	ZPL

Where XPL, YPL, and ZPL are the position vector components of the celestial body marked upon.

NOTE.—Noun 88 will contain correct values at this point if it was loaded with correct values at Step 11.

Key VERB 25 ENTR and load a proportional set of vector components; unit vectors are, however, recommended. Key PRO when correct.

19. Repeat Steps 10 through 18 above for the second mark.

20. Respond to flashing display of sighting mark data:

FL VERB 06 NOUN 05 (R54)

R1    +xxx.xx    Sighting angle difference  
R2    +xxx.xx    Sighting angle

If sighting angle difference (R1) is unacceptable considering the source of the marks, or if sighting angle (R2) is not satisfactory (recommended bandwidth is between 25 and 155 degrees), key VERB 32 ENTR and continue at Step 22. Otherwise, if R1 and R2 are satisfactory, key PRO.

21. Respond to flashing display of gyro torquing angles

FL VERB 06 NOUN 93 (R55)

R1    ±xx.xxx    X gyro  
R2    ±xx.xxx    Y gyro  
R3    ±xx.xxx    Z gyro

Where X gyro, Y gyro, and Z gyro are the angles through which the Stable Member must be torqued in order for it to have the desired inertial orientation.

If the gyro torquing angles are unacceptable, key VERB 32 ENTR to bypass torquing the Stable Member. If the angles are acceptable, key PRO to torque the Stable Member into the desired inertial orientation.

NOTE.—In spite of the gyro trim performed at Step 6, it is still possible that Noun 93 will display unacceptable torquing angles, although Noun 05 indicated satisfactory marking. This could occur, for example, when Navi has been used as one of the mark bodies. (See SKYLARK Anomaly No. 3 describing the CMC star catalogue error in Navi's position.) In this situation, in fact, Noun 05 would deceptively indicate good marking in a geometrically bad case, and vice versa. As another example, vehicle rotation during coarse alignment at step 6 will cause large values of Noun 93 corresponding to the amount of rotation.

22. Respond to flashing request to "Please perform fine align":

FL VERB 50 NOUN 25

R1 00014

R2 Blank

R3 Blank

If either Noun 05 or Noun 93 was unsatisfactory, key PRO to recycle P52 to Step 9 above. If a third star check is desired, also key PRO. If none of the above apply, and it is desired to terminate P52, key ENTR.

Respond to flashing display "Please select new program":

FL VERB 37 (R00)

Key xx ENTR to select program Pxx.

7.4.2.2 Automatically selected P52 (MINKEY)

DSKY procedures for automatically selected P52 during MINKEY planechange sequence are as follows (refer to Figure 7.9-3 for functional flow diagrams of P52):

1. Observe PROG 52.

#### Possible ALARMS

If either of these alarms occurs, the MINKEY Plane Change sequence will be terminated and FL VERB 37 will be observed.

PROG Alarm 00210 (IMU Off). Turn on IMU, wait 15 minutes for warmup, select P51 to determine IMU orientation, and key VERB 37 ENTR 38 ENTR to re-select the MINKEY Plane Change sequence.

PROG Alarm 00220 (IMU Not Aligned). Perform P51 and reselect MINKEY Plane Change sequence.

2. Respond to flashing display of gimbal angles at out-of-plane alignment:

FL VERB 06 NOUN 22

R1 +xxx.xx OGA  
R2 +xxx.xx IGA  
R3 +xxx.xx MGA

If the middle gimbal angle is unsatisfactory, either:

- a. Maneuver the vehicle to provide a more suitable middle gimbal angle. Key VERB 32 ENTR to recycle VERB 06 NOUN 22, which will then display the gimbal angles for the out-of-plane alignment at the new vehicle attitude, or:
- b. Key VERB 34 ENTR to exit the MINKEY plane-change sequence.

If the middle gimbal angle is satisfactory, key PRO.

3. Respond to flashing display "Please perform pulse-torquing for plane-change":

FL VERB 50 NOUN 25

R1 00020  
R2 Blank  
R3 Blank

If pulse-torquing is desired, key PRO. If pulse torquing is not to be done, and this is the first (pre-burn) MINKEY P52, key ENTR and continue at step 5.

Possible ALARM

PROG Alarm 00402 (ENTR response not allowed). This can occur only during the second (post-burn) MINKEY P52, and only if:

- a. The first out-of-plane torquing was performed, and
- b. The response to VERB 50 NOUN 25 R1 00020 is ENTR.

Key PRO on reappearance of VERB 50 NOUN 25 R1 00020. If IMU was torqued out of plane, it must be returned.

4. Observed display of present gimbal angles during the approximately 82 seconds required to torque 45 degrees:

VERB 16 NOUN 20

R1	+xxx,xx	OGA
R2	+xxx,xx	IGA
R3	+xxx,xx	MGA

5. Exit P52. If this is the first P52 in the MINKEY plane-change sequence, observe PROG 40 or 41 (depending on the magnitude of the plane-change burn). If the second, respond to flashing display "Please select new program":

FL VERB 37 (R00)

Key xx ENTR to select Pxx.

## 7.5 P53, BACKUP IMU ORIENTATION DETERMINATION PROGRAM

The Backup IMU Orientation Determination Program (P53) is used during free fall —when the CSM Optical subsystem has malfunctioned—to determine the orientation of the IMU stable member with respect to the Basic Reference Coordinate System. Either the SCT/SXT with manual readout of the TPAC or the COAS is used. This program would also be used in the event of a failed MARK button. The program flow is similar to that of P51.

P53 for SKYLAB is identical to APOLLO P53 with the exception that two additional sighting data sources are available when the CSM is docked with the OWS. These are the ATM Acquisition Sun Sensor (ATM SS) and the ATM Star Tracker (ATM ST). These sources can be used whenever the transformation relating the CSM Navigation Base and the ATM coordinate system (matrix NBOA) is known. This transformation is calculated by the ATM Orientation Determination Program (P50) (subsection 7.2).

When the CSM is not docked, the astronaut may, at the start of P53, maneuver the spacecraft to place the pitch axis in a preferred direction, while monitoring the FDAI ball to avoid gimbal lock. He can also coarse align the IMU to (0,0,0) gimbal angles if desired.

The astronaut performs the marking by using the RHC to center the COAS or SCT/SXT field of view on the body and keying ENTR. If the ATM SS is being used as a mark data source, the mark is made when the ATM is in solar inertial attitude and the mark body is the sun. If the ATM Star Tracker is used, the astronaut ensures that the tracker is locked onto the body and records the tracker gimbal angles at the time of marking for later DSKY entry.

### 7.5.1 Options: None.

### 7.5.2 Procedures:

P53 DSKY procedures are as follows (refer to Figure 7.9-4 for functional flow diagrams of P53):

1. Start the Backup IMU Orientation Program (P53) by keying VERB 37 ENTR 53 ENTR.

Possible ALARM

PROG Alarm 00210 (IMU Off). To perform P53, turn on IMU, wait 15 minutes for warmup, and reselect P53 as above.

2. Respond to flashing request "Please perform celestial body acquisition":

FL VERB 50 NOUN 25

R1 00015 Checklist  
R2 Blank  
R3 Blank

Maneuver the vehicle, using the RHC, to place the CSM pitch axis in a preferred direction, if desired, or to place celestial bodies near the line of sight. Monitor impending gimbal lock with the FDAI ball. If necessary or desired, key ENTR to coarse align the IMU to (0,0,0) gimbal angles, and observe:

VERB 41 NOUN 22

R1 +00000 OGA  
R2 +00000 IGA  
R3 +00000 MGA

and NO ATT light until coarse align is complete and FL VERB 50 NOUN 25 R1 00015 reappears.

Possible ALARM

PROG Alarm 00217 (bad return from stall routines). If alarm code 00211 (Coarse align error greater than two degrees) accompanies the 00217 alarm, key RSET and continue. If there is no accompanying 00211 alarm then either the IMU has been caged or the ISS warning light is on. Follow checklist procedures.

When desired maneuvers are complete, key PRO.

3. Respond to flashing display of alternate LOS coordinates:

FL VERB 06 NOUN 94 (R56)

R1    ±xxx.xx    Equivalent optics shaft angle  
R2    +xx.xxx    Equivalent optics trunnion angle  
R3    Blank

If ATM mark data source is not to be used for this mark, key VERB 24 ENTR and load equivalent optics shaft and trunnion angles. Key PRO when correct. If ATM source is to be used, key PRO; this display is not relevant.

4. Respond to flashing display "Please mark":

FL VERB 53 (R56)

R1    Blank  
R2    Blank  
R3    Blank

NOTE.—NOUN and R1 are not blank if this display is the result of an ENTR response at Step 5 below.

- a. Mark using SCT/SXT or COAS; use RHC to center celestial body in field of view and key ENTR.
- b. Mark using ATM sun sensor; ensure that ATM is in solar inertial attitude and key ENTR.
- c. Mark using ATM star tracker; ensure that star tracker is locked onto the desired celestial body, key ENTR and record the star tracker azimuth and elevation gimbal angles at the time of keying ENTR.

5. Respond to flashing display "Please terminate mark sequence":

FL VERB 50 NOUN 25 (R56)

R1    00016  
R2    Blank  
R3    Blank

- . To reject mark, key ENTR, and return to Step 4.
- . To accept mark, key PRO.



6. Respond to flashing display of optics and celestial body codes:

FL VERB 01 NOUN 71 (R56)

R1 00CDE

R2 Blank

R3 Blank

Where "C" indicates device used to obtain mark at Step 4 as follows:

0 = CSM alternate LOS

1 = sun sensor

2 = star tracker

and "DE" indicates celestial body marked on as follows:

$00_8$  = planet

$01_8 - 45_8$  = star from AGC catalog

$46_8$  = sun (Mandatory if  $C = 1$ )

$47_8$  = earth

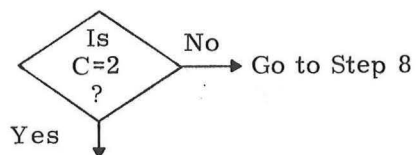
To load new data, key VERB 21 ENTR 00CDE ENTR. Key PRO when R1 is correct.

Possible OPR ERR

1. If DE not  $00_8 - 47_8$

2. If  $C = 1$  and DE not  $46_8$

Key RSET and repeat Step 5.



7. Respond to flashing display of star tracker gimbal angles recorded at Step 3:

FL VERB 06 NOUN 14 (R56)

R1 ±xxxxx. arc-min star tracker azimuth ( $\psi_3$ )

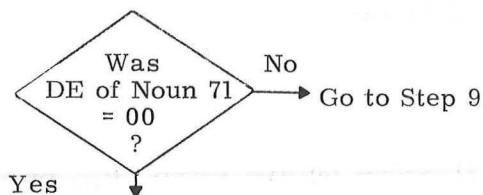
R2 ±xxxxx. arc-min star tracker elevation ( $\psi_1$ )

R3 Blank

Key VERB 24 ENTR and load recorded star tracker gimbal angles. Key PRO.

Possible OPR ERR

If either azimuth or elevation is less than -10800 or greater than +10800 arc-min., key RSET and repeat Step 7.



8. Respond to flashing display of position vector components of alternate LOS or ATM star tracker target:

FL VERB 06 NOUN 88

R1 ±.xxxxx XPL

R2 ±.xxxxx YPL

R3 ±.xxxxx ZPL

where XPL, YPL, and ZPL are components of the position vector of the body marked on.

Key VERB 25 ENTR and load vector components obtained from table. Key PRO when correct.

9. If this is the first mark, repeat Steps 3 through 8 above for second mark. Otherwise, go to Step 10.
10. Respond to flashing display of sighting mark data:

FL VERB 06 NOUN 05 (R54)

R1	+xxx.xx	Sighting angle difference
R2	+xxx.xx	Sighting angle
R3	Blank	

If sighting angle difference (R1) is unacceptable considering the sources of the marks, or if sighting angle (R2) is not satisfactory (recommended bandwidth is between 25 and 155 degrees), key VERB 32 ENTR to recycle P53 to Step 2 above.

If both R1 and R2 are satisfactory, key PRO.

11. Respond to flashing display "Please select new program":

FL VERB 37 (R00)

Key    xx    ENTR

## 7.6 P54, BACKUP IMU REALIGN PROGRAM

The Backup IMU Realign Program (P54) is used during free fall—when the CSM Optical subsystem has malfunctioned—to realign the IMU either to its presently assumed orientation in the basic reference coordinate system or to a new such orientation. Either the SCT/SXT with manual readout of the TPAC or the COAS is used. This program would also be used in the event of a failed MARK button. The logic of P54 parallels that of the IMU Realign Program (P52) of Subsection 7.4).

This program is identical to APOLLO P54, with the exception that, when the CSM is docked with the OWS, two additional sources of sighting data are available. These are the ATM sun sensor and the ATM star tracker, which can be used whenever the transformation relating the CSM Nav Base and the ATM coordinate system (matrix NBOA) is known. This matrix is calculated by the ATM Orientation Determination Program (P50) (subsection 7.2).

At the beginning of P54, the crew must select which of the following three stable member orientations is desired:

<u>Option</u>	<u>Code</u>	<u>Use</u>
Preferred	1	For alignment with respect to the targeted thrust vector, or with uplinked desired stable member orientation.
Nominal	2	For alignment with respect to local vertical at some crew-specified time.
REFSMMAT	3	For realignment to the presently assumed orientation. Eliminates uncompensated drift.

For preferred and nominal realignments, P54 displays gimbal angles at the new IMU orientation to assist the crew in determining that middle gimbal angle at the new IMU orientation will be satisfactory (less than 70 degrees).

The IMU can be initially aligned to the desired orientation either by coarse aligning or by pulse-torquing the gyros without coarse alignment. The normal procedure is to use the Coarse Align Routine, which will calculate the IMU gimbal angles for the new orientation and, if any one or more gimbal angles differs from its present value by more than one degree, the IMU is coarse-aligned by driving the gimbals to their desired values. Following this, the residual gimbal errors are trimmed

by gyro torquing. Any CSM attitude changes during the coarse alignment phase will be reflected in misalignment of the IMU at termination of this procedure, and large gyro torquing angles will be observed during the Gyro Torquing Routine (R55).

The alternative procedure of pulse torquing the IMU to the desired orientation does not require maintenance of a constant attitude, but does require considerable time (approximately 1.8 seconds per degree of the sum of the three angles to be torqued).

#### 7.6.1 Options

The astronaut has the option of aligning the stable member to an orientation defined in one of three ways.

##### 7.6.1.1 Option 1: Preferred

Option 1 provides for realignment of the IMU from the inertial orientation described by REFSMMAT to a new inertial orientation calculated externally to P54. This external source may be the ground, in which case the new orientation must be provided via uplink. The external source may also be the thrusting programs, P40 and P41, which calculate a preferred IMU orientation as a function of a targeted thrust vector.

##### 7.6.1.2 Option 2: Nominal

In option 2, the desired IMU orientation is a function of the local vertical at some astronaut-specified time. In this option, the desired orientation is calculated by program P54 itself, and stored as the preferred orientation. Having performed this calculation, P54 continues as in option 1.

##### 7.6.1.3 Option 3: REFSMMAT

In option 3, REFSMMAT itself is treated by P54 as the new desired orientation.

#### 7.6.2 Procedures

DSKY procedures for P54 are as follows (refer to Figure 7.9-5 for functional flow diagrams of P54):

1. Start the Backup IMU Realign Program (P54) by keying VERB 37 ENTR 54 ENTR.

Possible ALARMS

PROG Alarm 00210 (IMU off). To perform P54, turn on IMU, wait 15 minutes for warmup, select P53 to determine IMU orientation, and reselect P54 as above.

PROG Alarm 00220 (IMU not aligned). To perform P54, select P53 to determine IMU orientation, and then reselect P54 as above, or set the following flags to perform a P54 option 3:

REFSMFLG (FLAGWRD3, Bit 13)

IMUOPBIT (IMODES30, Bit 9)

2. Respond to flashing display of option code for assumed orientation:

FL VERB 04 NOUN 06

R1	00001	Request specify option
R2	0000x	Option code (Preloaded 00001 if
R3	Blank	Preferred Attitude Flag is set.
		Otherwise preloaded 00003).

Option codes in R2 are as follows:

00001 — Align to stored preferred orientation

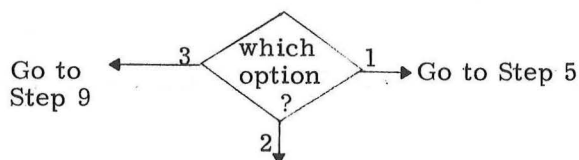
00002 — Align to local vertical at time to be specified

00003 — Align to REFSMMAT

If displayed option is not desired, key VERB 22 ENTR and load desired option code.

When option is correct, key PRO.

- 3.



4. Respond to flashing display of time of local vertical to be aligned to:

FL VERB 06 NOUN 34

R1 +xxxxx. (hrs)  
R2 +000xx. (min)  
R3 +0xx,xx (sec)

Initially, R1, R2, and R3 are set to zero. If it is desired to align to local vertical at the present time, key PRO. If the local vertical is to be that for some time other than the present, key VERB 25 ENTR and load the desired time. When the correct time is present in the DSKY, key PRO.

Possible ALARM

PROG Alarm 00401 (Desired gimbal angles yield gimbal lock). At the present vehicle attitude, coarse-aligning of the IMU to the desired orientation will result in a middle gimbal angle greater than +60 degrees or less than -60 degrees.

5. Respond to flashing display of gimbal angles resulting from coarse alignment to new orientation:

FL VERB 06 NOUN 22

R1 +xxx,xx OGA  
R2 +xxx,xx IGA  
R3 +xxx,xx MGA

If the final middle gimbal angle is unsatisfactory, either:

- a. Maneuver the vehicle, using the RHC, to obtain a more suitable MGA. Key VERB 32 ENTR to recycle to VERB 06 NOUN 22 which will display the final gimbal angles at the new attitude; or
- b. Key VERB 34 ENTR to exit P54.

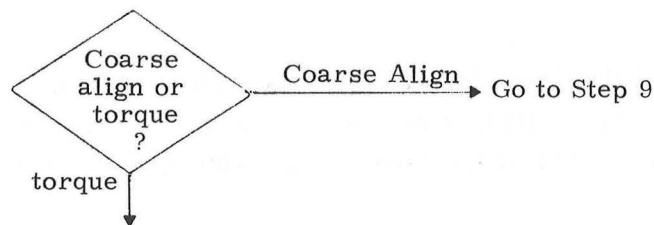
If the final gimbal angles are satisfactory, key PRO.

6. Respond to flashing display "Please perform normal or gyro torque coarse align":

FL VERB 50 NOUN 25

R1 00013  
R2 Blank  
R3 Blank

If normal coarse alignment of the IMU followed by trimming residual gimbal angles via pulse-torquing is desired, key PRO. Otherwise, if pulse torquing of the IMU is desired (considering the amounts to be torqued at 0.55 deg/sec), key ENTR.



7. Observe:

VERB 16 NOUN 20

R1 +xxx.xx OGA  
R2 +xxx.xx IGA  
R3 +xxx.xx MGA

Monitor display to ensure that IMU will not be torqued into gimbal lock. If necessary, maneuver to avoid gimbal lock. NOUN 20 will remain for approximately 1.8 x (total of 3 torquing angles) seconds.

8. Respond to flashing display "Please perform fine align":

FL VERB 50 NOUN 25

R1 00014  
R2 Blank  
R3 Blank



If it is desired to continue P54 through the fine-align phase, key PRO. Otherwise, key ENTR to exit P54 to routine R00. In this event, the IMU will have been pulse-torqued into agreement with REFSMMAT insofar as the CMC program is able to compute that agreement without celestial observations.

9. Respond to flashing display "Please perform star acquisition":

FL VERB 50 NOUN 25

R1 00015  
R2 Blank  
R3 Blank

If ATM Star Tracker or ATM Sun Sensor is to be used in marking, key ENTR to bypass automatic star selection by the CMC and continue at Step 10. Otherwise, if CMC assistance in star acquisition is desired, key PRO. Optics mode switch should be switched to CMC, if CSM SXT/SCT is to be used and can be driven by the CMC.

Possible ALARM

PROG Alarm 00405 (Two stars not available). If further CMC assistance in star selection is wanted, maneuver the vehicle and key VERB 32 ENTR to recycle to Step 9. If no further assistance is required, key PRO and maneuver to acquire stars in the SXT/SCT field of view manually.

10. Respond to flashing request to load celestial body code and mark source code:

FL VERB 01 NOUN 70

R1 00CDE  
R2 Blank  
R3 Blank

Where "C" indicates device used to obtain mark as follows:

0 = CSM alternate LOS  
1 = sun sensor  
2 = star tracker

and "DE" indicates celestial body marked upon, as follows:

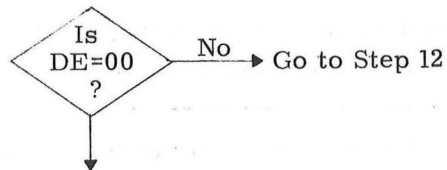
00<sub>8</sub> = planet  
01<sub>8</sub> - 45<sub>8</sub> = star from CMC catalog  
46<sub>8</sub> = sun (mandatory if "C" = 1)  
47<sub>8</sub> = earth

To load new data, key VERB 21 ENTR 00CDE ENTR. Key PRO when R1 contains desired data.

NOTE.—This display is for auto optics positioning purposes only, and may be simply bypassed by keying PRO when it appears. R1 must, however, contain a legal (if irrelevant) star code, or OPR ERR will appear. (See below.)

Possible OPR ERR

1. If DE not 00<sub>8</sub>-47<sub>8</sub>
2. If C = 1 and DE not 46<sub>8</sub>  
Key RSET and repeat step 10.



11. Respond to flashing display of position vector of celestial body to be marked on:

FL VERB 06 NOUN 88

R1    ±.xxxxx    XPL  
R2    ±.yyyyy    YPL  
R3    ±.zzzzz    ZPL

where XPL, YPL, and ZPL are proportional position vector components of the celestial body to be marked on. To load new data, key VERB 25 ENTR and load vector components, which may be any proportional set. Unit vectors are, however, recommended. Key PRO when correct.

This display, too, is for auto optics positioning purposes only and may be bypassed by keying PRO when it appears.

12. Monitor display of alternate line of sight coordinates:

VERB 06 NOUN 94 (R56)

R1    ±xxx.xx    shaft offset in .01 deg.  
R2    +xx.xxx    trunnion offset in .001 deg.

The nominal COAS offsets are: shaft=0, trunnion=+57.470 degrees. If these values are not present in Noun 94, or if other offsets are in use, key VERB 24 ENTR and load the correct values. If the source of this mark is to be either of the ATM devices, this display is irrelevant. When data in R1 and R2 are correct, key PRO.

13. Respond to flashing display requesting mark:

FL VERB 53 (R56)

R1    Blank  
R2    Blank  
R3    Blank

NOTE,—NOUN and R1 are not blank if display is invoked by an ENTR response to FL VERB 50 NOUN 25 R1 00016 at Step 14 below.

- a. Mark using CSM alternate LOS: maneuver vehicle using RHC to center the celestial body in the field of view and key ENTR
- b. Mark using ATM Sun Sensor: ensure that ATM is in solar-inertial attitude, and key ENTR;
- c. Mark using ATM Star Tracker: ensure that Star Tracker is locked onto celestial body, and key ENTR. Record Star Tracker gimbal angles at time of mark for DSKY entry at Step 16 below.

14. Respond to flashing display "Please terminate mark sequence":

FL VERB 50 NOUN 25 (R56)

R1 00016  
R2 Blank  
R3 Blank

- . To reject mark, key ENTR and return to Step 13;
- . To accept mark, key PRO.

15. Respond to flashing display of celestial body code and mark source code:

FL VERB 01 NOUN 71 (R56)

R1 00CDE  
R2 Blank  
R3 Blank

NOTE.—This display will be correct if Noun 70 was correctly loaded at Step 10.

Where "C" indicates device used to obtain mark as follows:

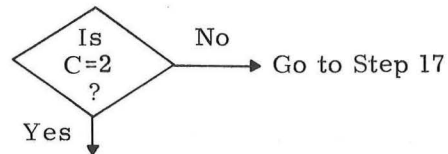
0 = CSM alternate LOS  
1 = sun sensor  
2 = star tracker

and "DE" indicates celestial body marked upon, as follows:

00<sub>8</sub> = planet  
01<sub>8</sub> - 45<sub>8</sub> = star from CMC catalog  
46<sub>8</sub> = sun (mandatory if "C" = 1)  
47<sub>8</sub> = earth

Possible OPR ERR

1. If DE not  $00_8 - 47_8$
2. If C = 1 and DE not  $46_8$   
Key RSET and repeat Step 15.



16. Respond to flashing display of Star Tracker gimbal angles recorded at Step 13:

FL VERB 06 NOUN 14 (R56)

R1  $\pm$ xxxxx. arc-min star tracker azimuth ( $\psi_3$ )  
R2  $\pm$ xxxxx. arc-min star tracker elevation ( $\psi_1$ )  
R3 Blank

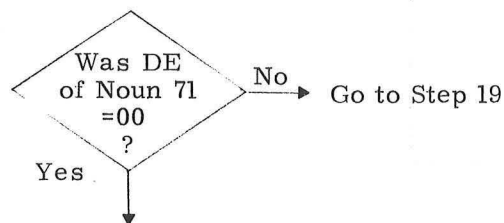
Key VERB 24 ENTR and load Star Tracker azimuth and elevation angles recorded at Step 13.

Possible OPR ERR

If either azimuth or elevation is less than -10800 or greater than +10800.  
Key RSET and repeat Step 16.

When R1 and R2 are correct, key PRO.

17.



18. Respond to flashing display of position vector components for celestial body marked at Step 13:

FL VERB 06 NOUN 88

R1	±xxxxx.	XPL
R2	±xxxxx.	YPL
R3	±xxxxx.	ZPL

Where XPL, YPL, and ZPL are the position vector components of the celestial body marked upon.

NOTE.—This display will contain correct values at this point if it was loaded with correct values at Step 11.

Key VERB 25 ENTR and load a proportional set of vector components; unit vectors are, however, recommended. Key PRO when correct.

NOTE.—Noun 88 will contain correct values at this point if it was loaded with correct values at Step 11.

19. Repeat Steps 10 through 18 above for the second mark.

20. Respond to flashing display of sighting mark data:

FL VERB 06 NOUN 05 (R54)

R1	+xxx.xx	Sighting angle difference
R2	+xxx.xx	Sighting angle

If sighting angle difference (R1) is unacceptable considering the source of the marks, or if sighting angle (R2) is not between 25 and 155 degrees, key VERB 32 ENTR and continue at Step 22. Otherwise, if R1 and R2 are satisfactory, key PRO.

21. Respond to flashing display of gyro torquing angles

FL VERB 06 NOUN 93 (R55)

R1    ±xx.xxx    X gyro  
R2    ±xx.xxx    Y gyro  
R3    ±xx.xxx    Z gyro

Where X gyro, Y gyro, and Z gyro are the angles through which the Stable Member must be torqued in order for it to have the desired inertial orientation.

If the gyro torquing angles are unacceptable, key VERB 32 ENTR to bypass torquing the Stable Member. If the angles are acceptable, key PRO to torque the Stable Member into the desired inertial orientation.

NOTE.—In spite of the gyro trim performed at Step 6, it is still possible that Noun 93 will display unacceptable torquing angles, although Noun 05 indicated satisfactory marking. This could occur, for example, when Navi has been used as one of the mark bodies. (See SKYLARK Anomaly No. 3 describing the CMC star catalogue error in Navi's position.) In this situation, in fact, Noun 05 would deceptively indicate good marking in a geometrically bad case, and vice versa. As another example, vehicle rotation during coarse alignment at Step 6 will cause large values of Noun 93 corresponding to the amount of rotation.

22. Respond to flashing request to "Please perform fine align":

FL VERB 50 NOUN 25

R1    00014  
R2    Blank  
R3    Blank

If either Noun 05 or Noun 93 was unsatisfactory, key PRO to recycle P54 to Step 9 above. If a third star check is desired, also key PRO. If none of the above apply, and it is desired to terminate P54, key ENTR.

Respond to flashing display "Please select new Program":

FL VERB 37 (R00)

Key xx ENTR to select program Pxx.



## 7.7 P55, ATM STAR TRACKER GIMBAL ANGLE PROGRAM

The ATM Star Tracker Gimbal Angle Program (P55) is used to compute and display the gimbal angles for pointing the ATM star tracker at a designated celestial body. The primary use of P55 output is input, in the event of star-tracker failure, for the ATM digital computer. The ATM computer requires this input (specifically, the star-tracker outer gimbal angle, corresponding to azimuth) to complement sun-sensor data when determining the inertial orientation of the ATM.

The secondary use of P55 output is to aid the crew in acquiring star-tracker targets. In this instance the star tracker is fully operational, but the crew needs the gimbal angles corresponding to azimuth and elevation in order to manually acquire a designated body within the star-tracker field of view, preparatory to initiating the tracking function.

To satisfy both uses, P55 gimbal-angle data are displayed in two forms: (1) octal display of azimuth, for input to the ATM computer; (2) decimal display of azimuth and elevation, for manual positioning the star tracker to acquire a designated target.

### 7.7.1 Options

P55 has two options for computing the desired star-tracker gimbal angles. Both options assume that the astronaut has performed the ATM Orientation Determination Program (P50) to determine the attitude of the ATM sensor coordinate system with respect to the CSM.

#### 7.7.1.1 Option 1: Star Tracker Gimbal Angle Determination Using Aligned IMU

Option 1 requires a valid REFSMMAT and requests the astronaut to supply an identification code corresponding to the desired celestial body. When the astronaut identifies the celestial body, the CMC computes the desired gimbal angles as follows:

- a. The CMC obtains the target LOS vector in basic-reference coordinates and uses REFSMMAT and the CSM-ATM relative orientation to compute the LOS vector in ATM sensor coordinates.
- b. The ATM LOS vector is resolved into components along the ATM sensor axes to yield the star-tracker azimuth and elevation gimbal angles ( $\psi_3$  and  $\psi_1$ , respectively).
- c. The gimbal angles are displayed and tested to see if they are within the star tracker's mechanical limits. If not, the CMC issues an alarm to

the crew. The astronaut can also display  $\psi_3$  in a format suitable for loading into the ATM computer.

- d. If the astronaut is not satisfied with the angles, he can recycle P55 and select another celestial body for gimbal-angle computation.

#### 7.7.1.2 Option 2: Star Tracker Gimbal Angle Determination Using CSM Optics

Option 2 requires the ATM to be in solar-inertial attitude; it does not require a valid REFSMMAT and does not require the IMU to be on. In this option, P55 calculates the star-tracker gimbal angles as follows:

- a. The astronaut uses the SXT or SCT to perform a sighting on one celestial body. (Sun and earth are not suitable because of geometry and nearness respectively.)
- b. The CMC uses the CSM optics angles and CSM-ATM relative orientation to compute the sun's and celestial-body's LOS vector in ATM sensor coordinates.
- c. The CMC computes the sun's and celestial body's LOS vectors in basic-reference coordinates.
- d. The two LOS vectors in ATM sensor coordinates and in basic-reference coordinates are used as inputs to routine AXISGEN to compute the ATM sensor orientation in basic-reference coordinates.
- e. The astronaut identifies the celestial body to be acquired by the star tracker, and the CMC uses the ATM sensor basic-reference orientation to compute the target LOS in ATM sensor coordinates.
- f. The CMC computes and displays the star-tracker gimbal angles as described in steps b through d, Option 1. Option 2 assumes that the ATM inertial orientation will remain fixed from the time of the CSM optics sighting until the crew uses the star-tracker gimbal angles.

#### 7.7.2 Procedures

P50 DSKY procedures are as follows (refer to Figure 7.9-6 for functional flow diagrams of P50/R53):

1. Start the ATM Star Tracker Gimbal Angle Program (P55) by keying VERB 37 ENTR 55 ENTR on the DSKY. Observe flashing display of option code requesting "Please specify P55 option":

FL VERB 04 NOUN 06

R1 00013 Request specify option  
R2 0000x Option Code (preloaded 00001)  
R3 Blank

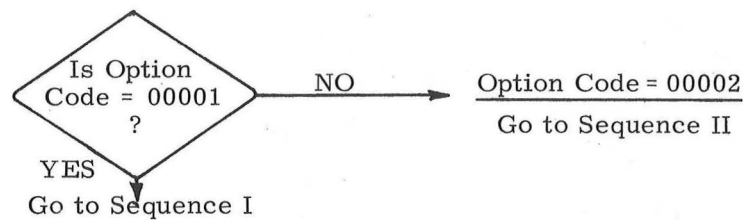
Option codes are as follows:

00001 — Celestial body and IMU orientation (requires valid REFSMMAT)

00002 — Optics mark and ATM solar inertial attitude

If displayed option code is not desired, key VERB 22 ENTR and load desired code.

PRO



I. Option 1 (NOUN 06, R2, =00001; R1 = 00013)

Possible ALARM

PROG Alarm 00210 (IMU off). To perform P55 Option 2, reselect program and load 00002 into NOUN 06 (R2).

PROG Alarm 00220 (REFSMMAT invalid). To perform P55 (Option 2), reselect program and load 00002 into NOUN 06 (R2).

2. Respond to flashing display, "Please load celestial-body code for star-tracker target":

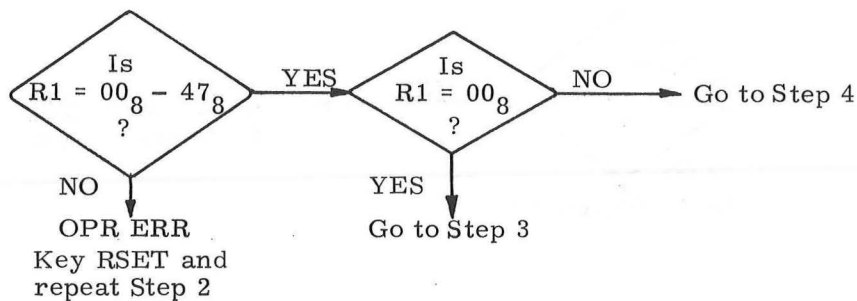
FL VERB 01 NOUN 70

R1 000xx Celestial-body code  
R2 Blank  
R3 Blank

where xx = 00<sub>8</sub> designates planet option  
xx = 01<sub>8</sub>-45<sub>8</sub> designates star from celestial-body list.

NOTE.—Sun (xx = 46<sub>8</sub>) or earth (xx = 47<sub>8</sub>) are not used as star-tracker targets—because of brightness and nearness respectively.

- . If NOUN 70 values are incorrect, key VERB 21 ENTR and load desired code into R1.
- . PRO



3. Respond to flashing display requesting crew to load position-vector components of star-tracker target.

FL VERB 06 NOUN 88

R1 ±.xxxxx XPL  
R2 ±.xxxxx YPL  
R3 ±.xxxxx ZPL

where XPL, YPL, and ZPL are components of the position vector of the star-tracker target.

- . Obtain from tables and load (VERB 25 ENTR) vector components for star-tracker target.
- . PRO

4. Respond to flashing display requesting approval of CMC-computed star-tracker angles:

FL VERB 06 NOUN 14

R1    ±xxxxx.    arc-min star tracker azimuth ( $\psi_3$ )  
R2    ±xxxxx.    arc-min star tracker elevation ( $\psi_1$ )  
R3    Blank

NOTE.—Option 1 requires that the ATM inertial orientation remain fixed between computation and use of  $\psi_3, \psi_1$ .

Possible ALARM

PROG Alarm Code 00107- Computed star-tracker angles for selected star exceed mechanical limits of star tracker- (azimuth =  $\pm 87$  degrees, elevation =  $\pm 40$  degrees). Clear alarm by keying RSET; then recycle (VERB 32 ENTR) to Step 2 and select a suitable star-tracker target.

- . Record data for use—if required—in manually acquiring star-tracker target.
  - . To recycle to Step 2, key VERB 32 ENTR.
  - . To terminate P55, key VERB 34 ENTR.
  - . To proceed to Step 5, key PRO.
5. Respond to flashing display of star-tracker azimuth (octal):

FL VERB 04 NOUN 19

R1    0SABC    Octal value of star-tracker  
R2    00DE0    azimuth in arc minutes  
R3    Blank

where    S = 0 denotes "+"

          S = 1 denotes "-"

          ABCDE = |octal azimuth|

- . Record data for loading into ATM computer.
- . To recycle to Step 2, key VERB 32 ENTR.
- . To exit P55, key PRO.

6. Respond to flashing display, "Please select new program":

FL VERB 37 (R00)

Key xx ENTR

II. Option 2 (NOUN 06, R2, = 00002; R1 = 00013)

2. Respond to flashing display requesting mark on celestial body.

FL VERB 51 (R53)

R1 Blank

R2 Blank

R3 Blank

NOTE 1. -NOUN and R1 are not cleared if display is recycled by MARK REJ response to FL VERB 50 NOUN 25 (R1 = 00016).

- . Before marking, ensure that ATM is in solar inertial attitude.
- . Set OPT MODE switch to MAN.
- . Center target in optics; depress the MARK button.

NOTE 2. -Option 2 requires that the inertial orientation of the ATM remain fixed from the time of optics mark until the star-tracker angles are used.

3. Respond to flashing display, "Please terminate mark sequence":

FL VERB 50 NOUN 25 (R53)

R1 00016 Checklist

R2 Blank

R3 Blank

- . To reject mark, key MARK REJ and return to Step 2.
- . To accept mark, key PRO.

4. Respond to flashing request to load optics code and celestial body code:

FL VERB 01 NOUN 71 (R53)

R1 00CDE  
R2 Blank  
R3 Blank

where

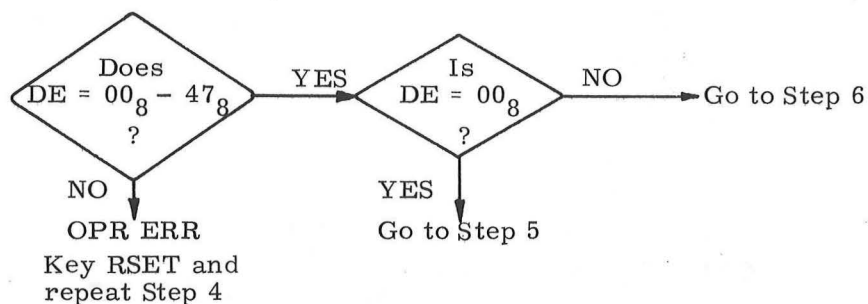
C = 0 designates CSM SXT or SCT.

DE =  $xx_8$  designates celestial body marked on in Step 2:

$00_8$  = planet

$01_8-47_8$  = target from celestial-body list.

- . To load new data, key VERB 21 ENTR and load R1 positions CDE.
- . PRO



5. Respond to flashing request to load position vector components of optics target:

FL VERB 06 NOUN 88

R1  $\pm.xxxxx$  XPL  
R2  $\pm.xxxxx$  YPL  
R3  $\pm.xxxxx$  ZPL

where XPL, YPL, and ZPL are components of the position vector for the target marked on.

- Obtain from tables and load (VERB 25 ENTR) vector components of target body.
- PRO

6. Respond to flashing request to load identification code for star-tracker target:

FL VERB 01 NOUN 70

R1 000xx Celestial-body code  
 R2 Blank  
 R3 Blank

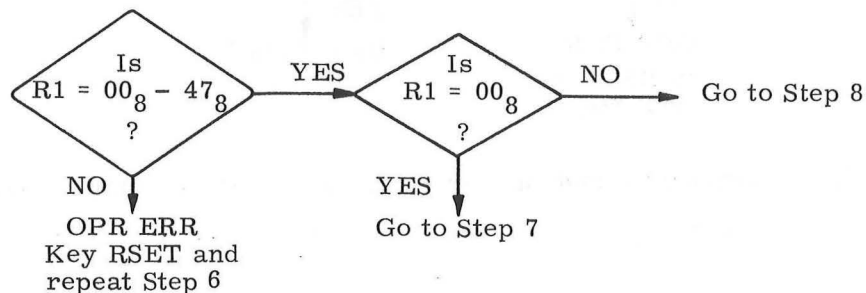
where

xx = 00<sub>8</sub> designates planet option

xx = 01<sub>8</sub>-45<sub>8</sub> designates star from celestial-body list.

NOTE.—Sun (xx = 46<sub>8</sub>) or earth (xx = 47<sub>8</sub>) are not used as star-tracker targets—because of brightness or nearness respectively.

- If NOUN 70 values are incorrect, key VERB 21 ENTR and load desired code into R1.
- PRO



7. Respond to flashing request to load position vector components of star-tracker target:

FL VERB 06 NOUN 88

R1 ±.xxxxx XPL  
 R2 ±.xxxxx YPL  
 R3 ±.xxxxx ZPL



where XPL, YPL, and ZPL are components of the position vector of the star-tracker target.

- . Obtain from tables and load (VERB 25 ENTR) vector components of star-tracker target.
- . PRO

8. Respond to flashing display of CMC-computed star-tracker angles:

FL VERB 06 NOUN 14

R1 ±xxxxx. arc-min star tracker aximuth ( $\psi_3$ )  
R2 ±xxxxx. arc-min star tracker elevation ( $\psi_1$ )  
R3 Blank

Possible ALARM

PROG Alarm Code 00107 - Computed star-tracker angles for selected star exceed mechanical limits of star tracker - (azimuth =  $\pm 87$  degrees, elevation =  $\pm 40$  degrees). Clear alarm by keying RSET; then recycle (VERB 32 ENTR) to Step 6 and select a suitable star-tracker target.

- . Record data for use—if required—in manually acquiring star-tracker target.
- . To recycle to Step 6, key VERB 32 ENTR.
- . To terminate P55, key VERB 34 ENTR.
- . If octal display of star-tracker outer-gimbal angle (azimuth) is desired, key PRO and proceed to Step 9.

9. Respond to flashing display of star-tracker azimuth (octal):

FL VERB 04 NOUN 19

R1 0SABC Octal value of star-tracker  
R2 00DE0 azimuth in arc- min  
R3 Blank

where S = 0 denotes "+"

S = 1 denotes "-"

ABCDE = |octal azimuth|

- . Record data for loading into ATM computer.
- . To recycle to Step 6, key VERB 32 ENTR.
- . To exit P55, key PRO.

10. Respond to flashing display, "Please select new program":

FL VERB 37 (R00)

- . Key xx ENTR

## 7.8 EXTENDED VERBS FOR IMU AND OPTICS

The extended verbs discussed here are separate routines designed to accomplish relatively simple tasks, i. e., to control the alignment of the stable member and optics. Table 7.8-I 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. This verb can be used to align the gimbals to zero (or any other value) when the ISS is in the coarse align mode and in gimbal lock. 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. 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) 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 do not provide a means of determining the stable member's inertial orientation.

The Zero ICDU extended verb (VERB 40) is used to synchronize the ISS CDU counters and the CDU counters in the CMC. VERB 40 turns off the NO ATT light and switches the ISS to fine-align mode. This extended verb cannot be used during gimbal lock. (See VERB 41 NOUN 20).

TABLE 7.8-I. IMU and Optics Extended Verb DSKY Activity.

VERB	Identification	Purpose	Remarks
V41 N20	Coarse align ISS extended verb	Coarse align stable member to gimbal angles specified by astronaut	<p>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.</p> <p>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.</p>
V42	Fine align ISS extended verb	Pulse torque stable member through angles indicated by astronaut	<p>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.</p>
V41 N91	Coarse align OSS extended verb	Align optics shaft and trunnion to angles specified by astronaut.	<p>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.</p>
V40	Zero ICDU extended verb.	Ensure synchronization between ISS CDU counters and CDU counters in CMC. Terminates IMU coarse align mode and enters IMU fine align mode.	<p>Astronaut keys in V40 ENTR. CMC enters CDU Zero Mode, turns off NO ATT light, clears ISS CDU read counters, and enters ISS fine align mode.</p>

## 7.9 FUNCTIONAL FLOW DIAGRAMS

This subsection contains functional flow diagrams for SKYLARK alignment programs described in earlier subsections.

Figure 7.9-1. ATM Orientation Determination Program, P50.

Figure 7.9-2. IMU Orientation Determination Program, P51.

Figure 7.9-3. IMU Realign Program, P52.

Figure 7.9-4. Backup IMU Orientation Determination  
Program, P53.

Figure 7.9-5. Backup IMU Realign Program, P54.

Figure 7.9-6. ATM Star Tracker Gimbal Angle Program, P55.

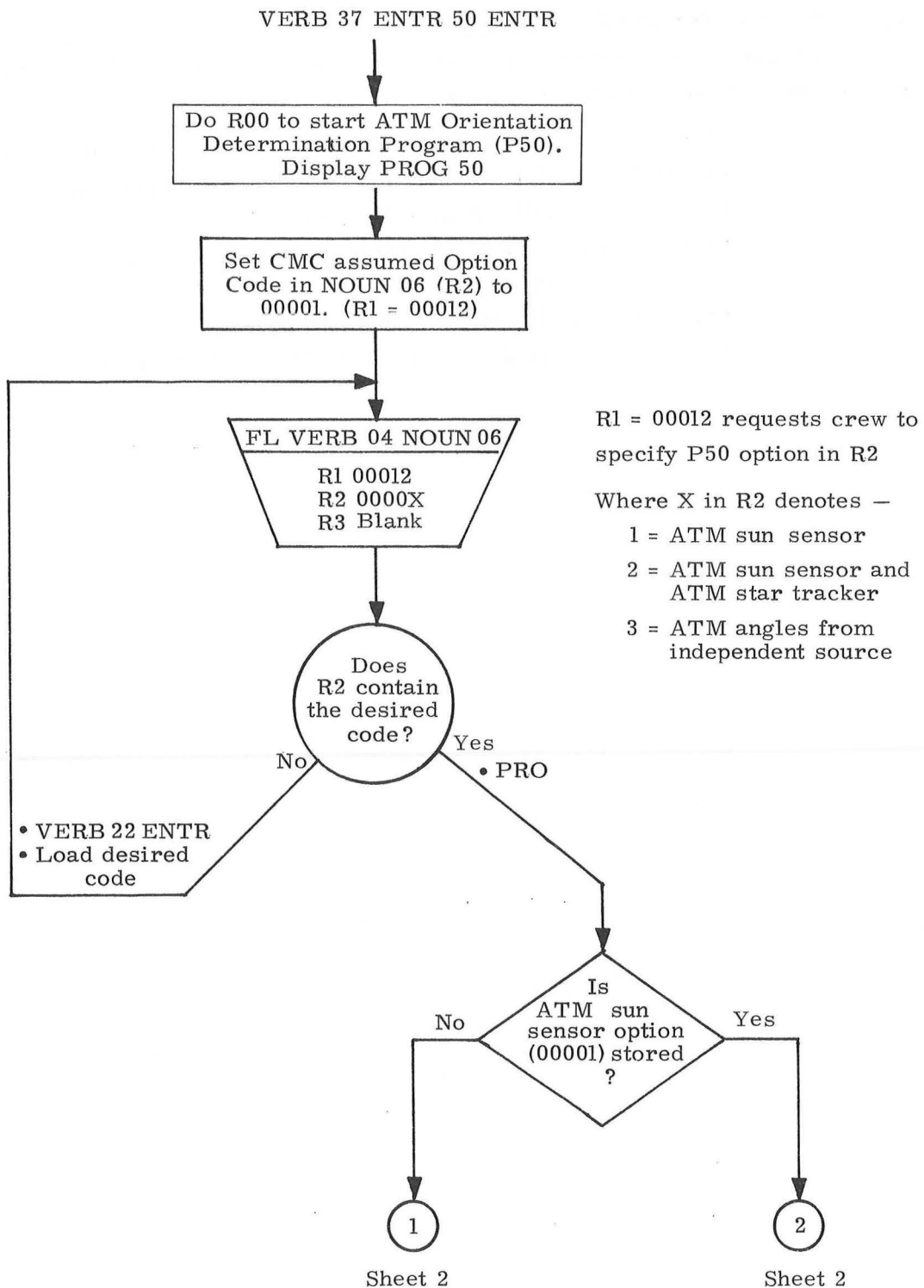


Figure 7.9-1. ATM Orientation Determination Program (P50)  
(Sheet 1 of 7)

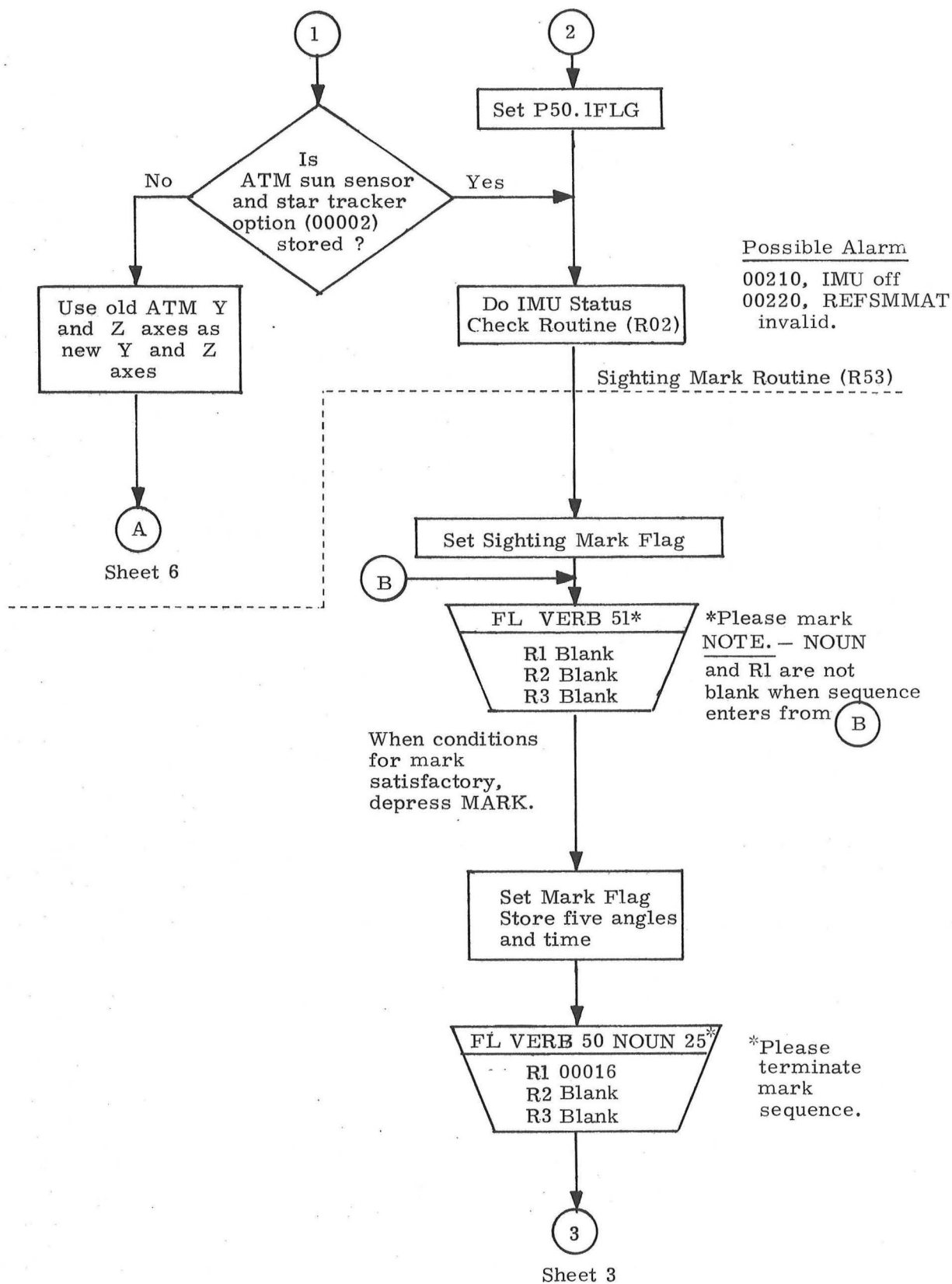


Figure 7.9-1. ATM Orientation Determination Program (P50)

(Sheet 2 of 7)

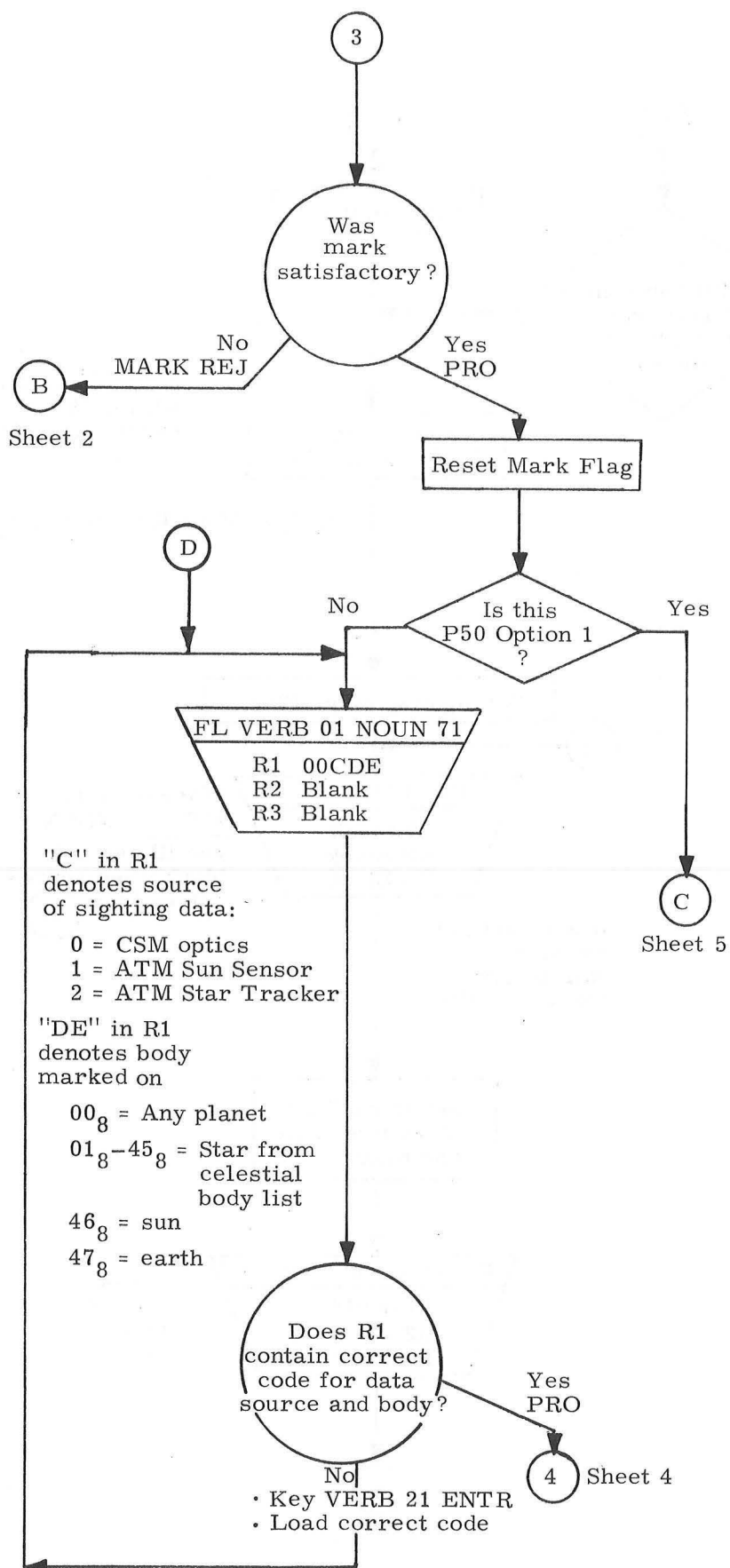


Figure 7. 9-1. ATM Orientation Determination Program (P50)

(Sheet 3 of 7)



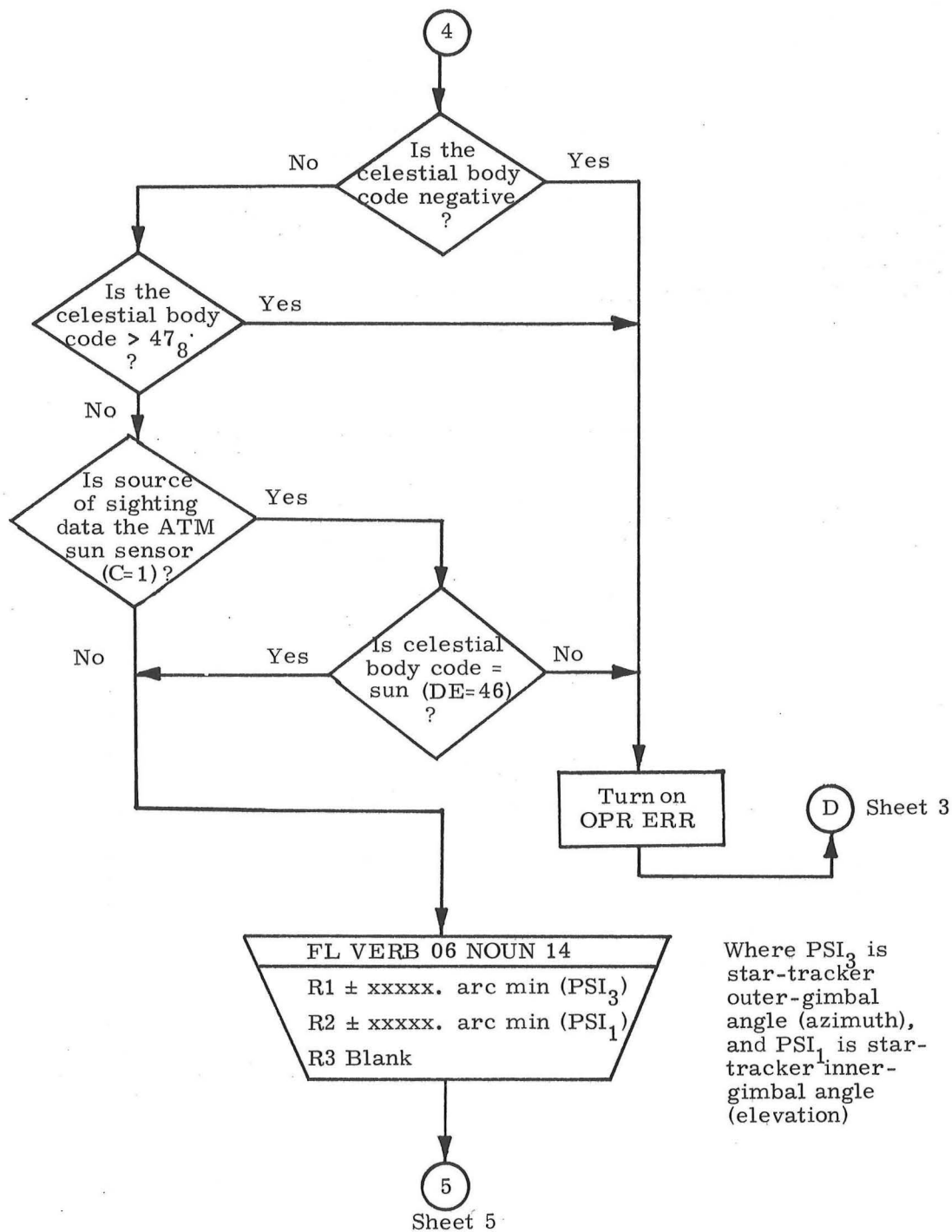
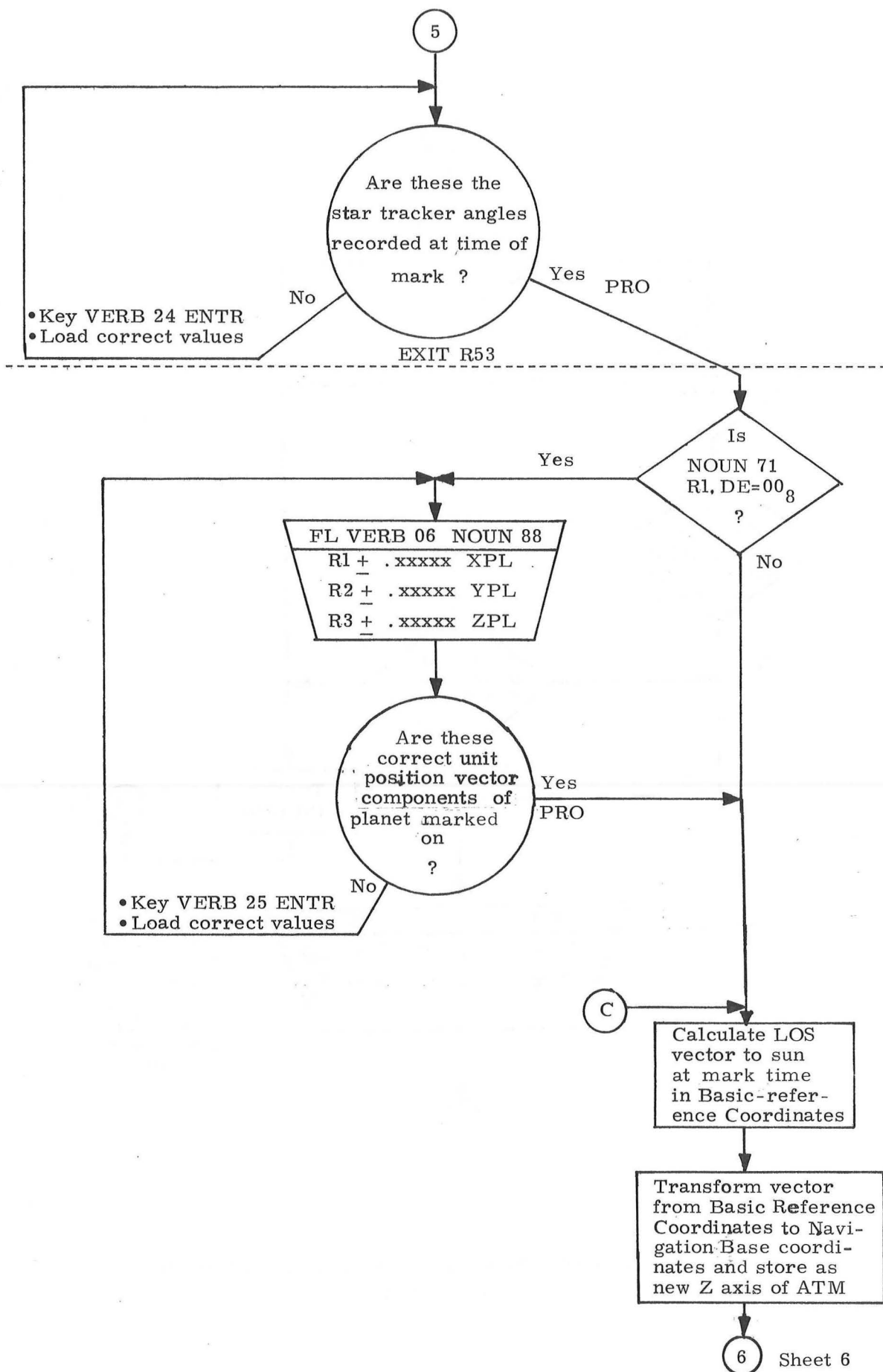


Figure 7.9-1. ATM Orientation Determination Program (P50)  
(Sheet 4 of 7)



Sheet 6

Figure 7.9-1. ATM Orientation Determination Program (P50)

(Sheet 5 of 7)

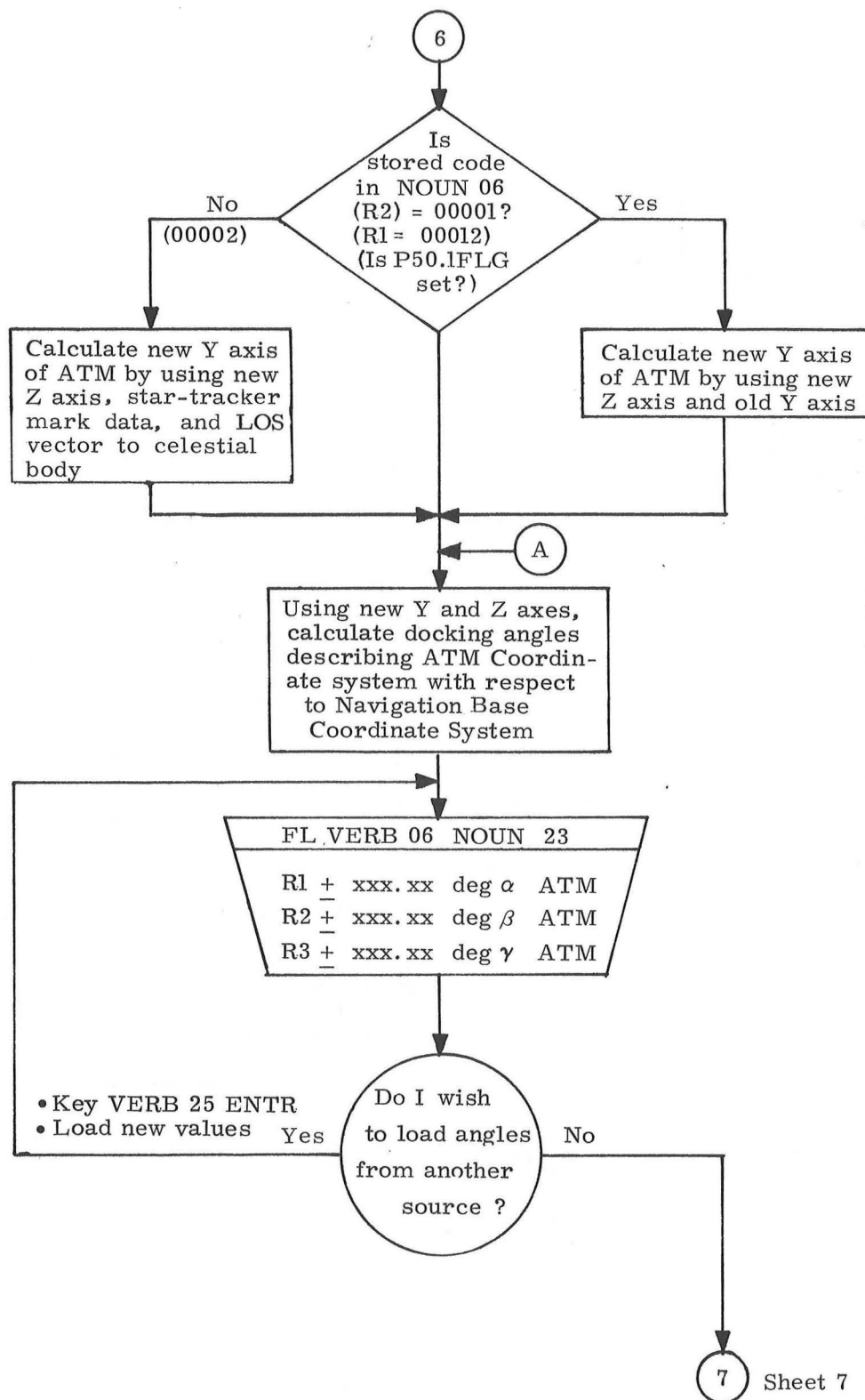


Figure 7.9-1. ATM Orientation Determination Program (P50)  
(Sheet 6 of 7)

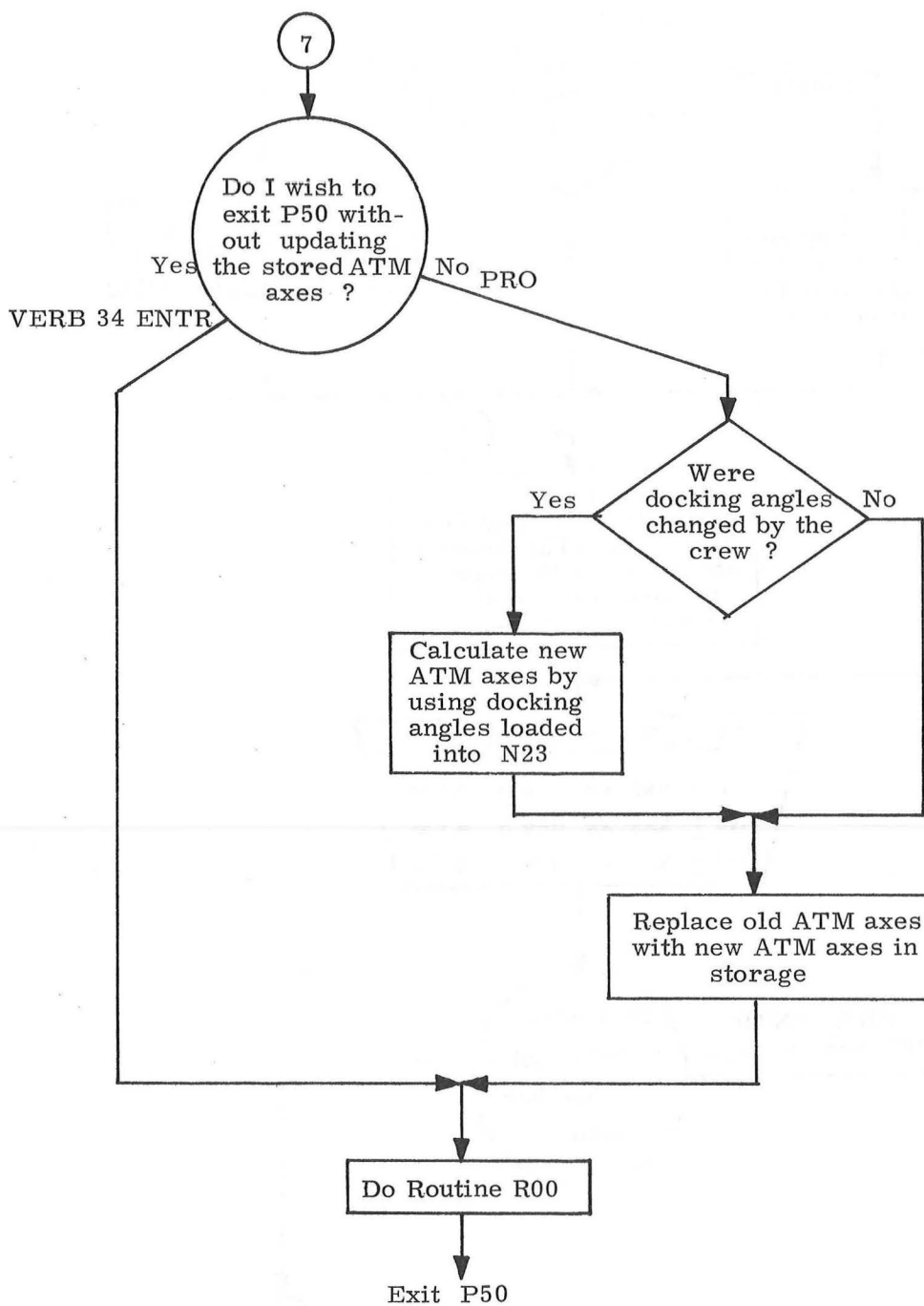


Figure 7.9-1. ATM Orientation Determination Program (P50)  
(Sheet 7 of 7)

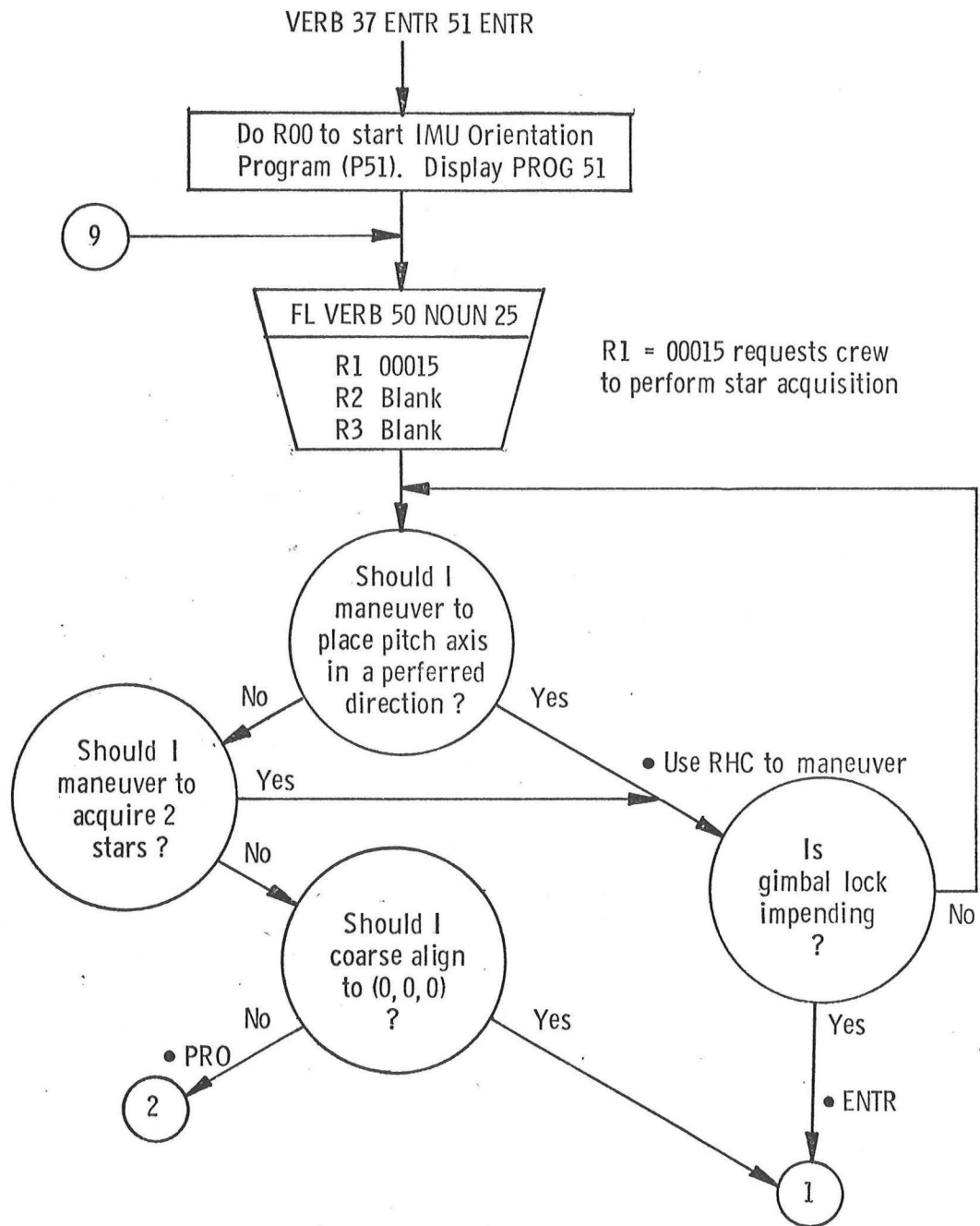


Figure 7.9. -2. IMU Orientation Determination Program (P51)  
(Sheet 1 of 5)

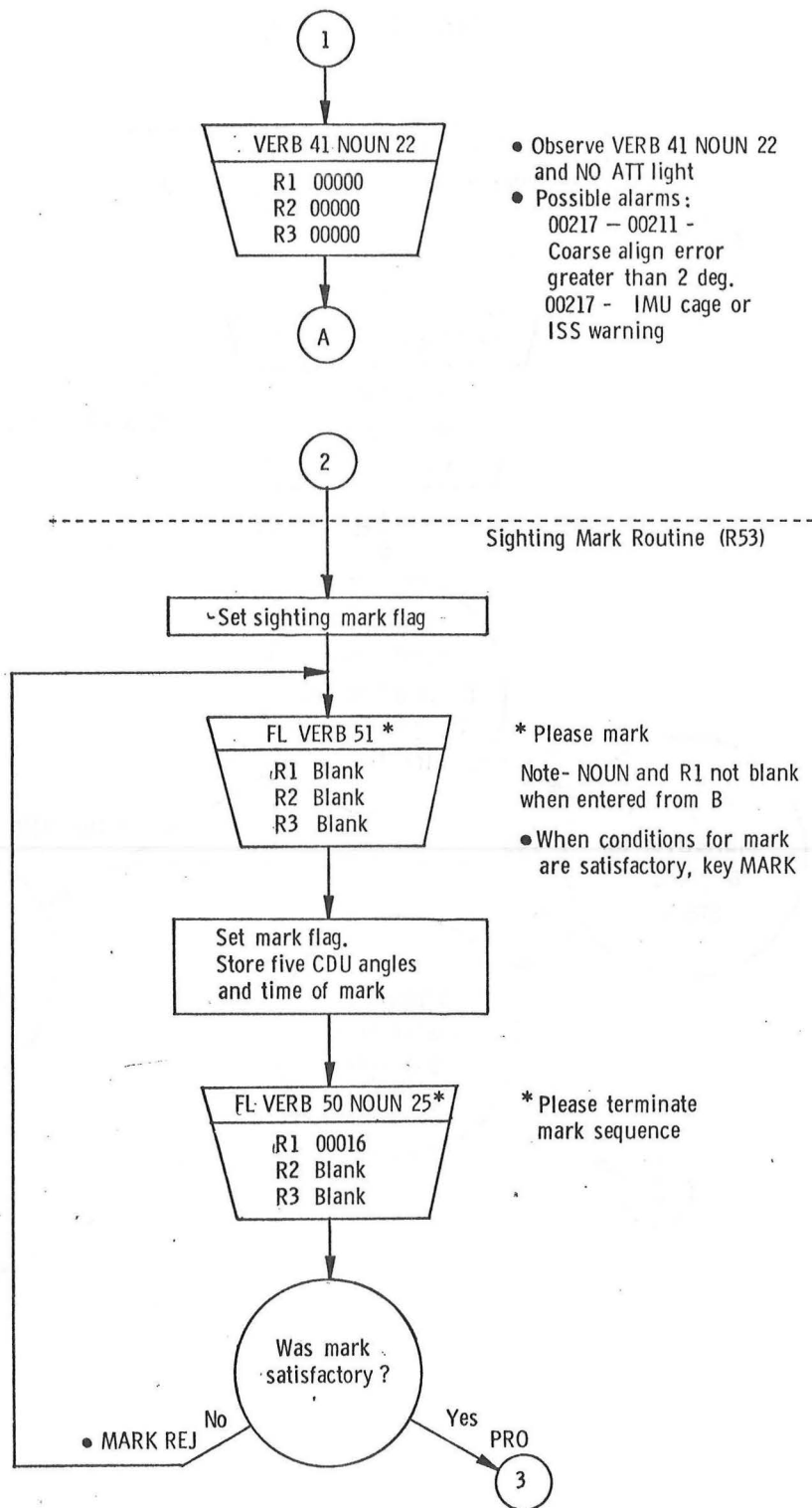


Figure 7.9-2. IMU Orientation Determination Program (P51)  
(Sheet 2 of 5)

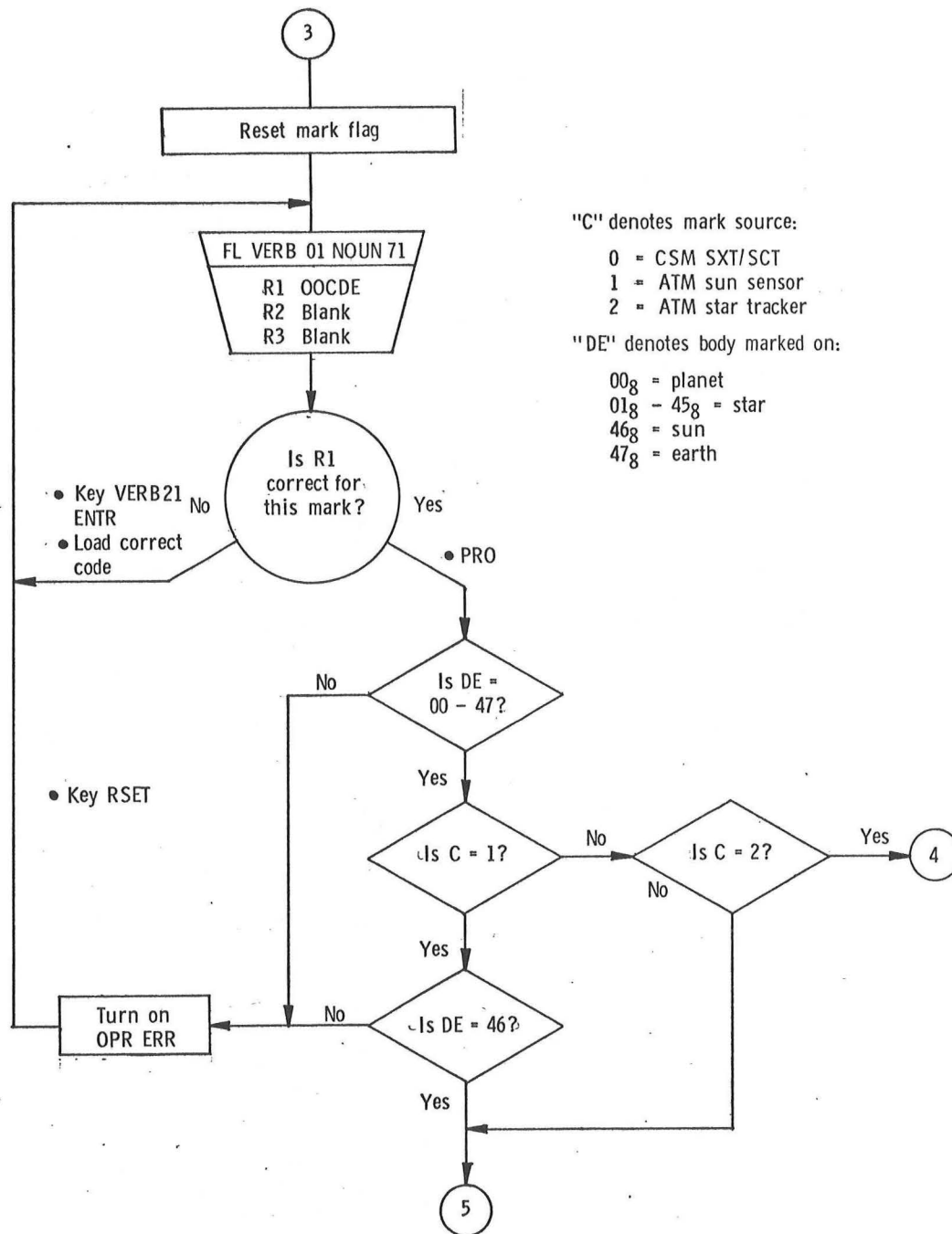


Figure 7.9-2. IMU Orientation Determination Program (P51)  
 (Sheet 3 of 5)

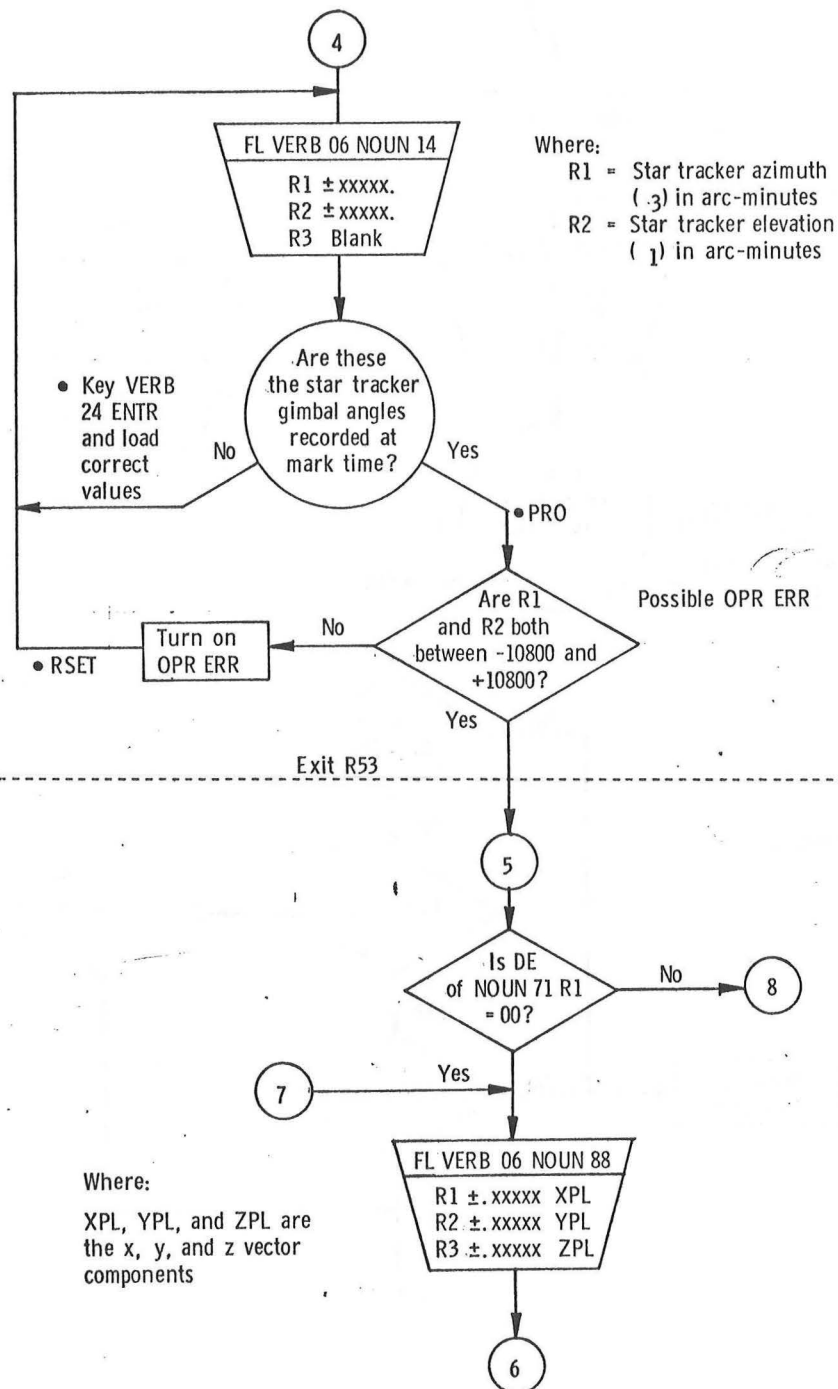


Figure 7.9-2. IMU Orientation Determination Program (P51)  
(Sheet 4 of 5)



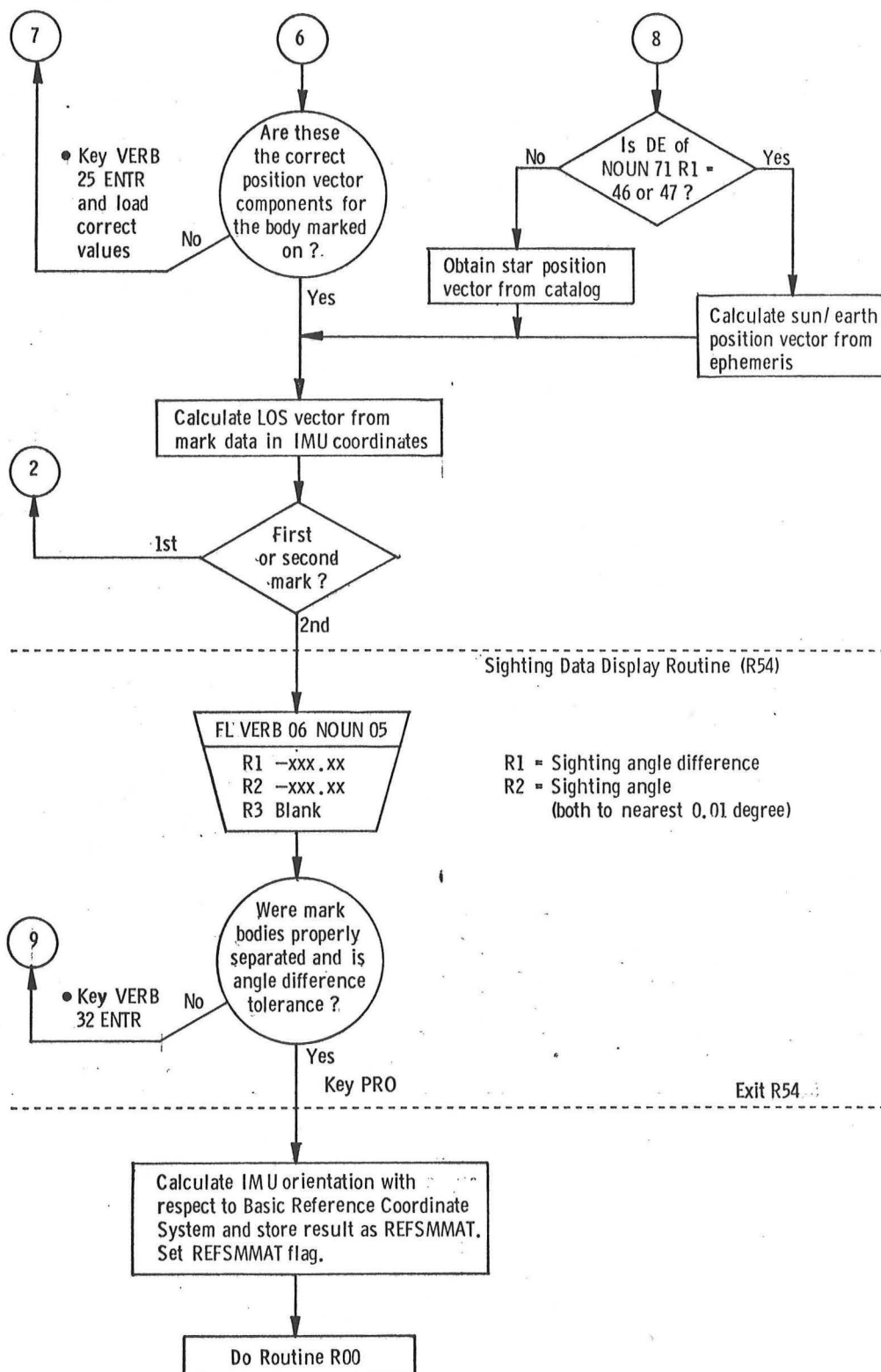


Figure 7.9-2. IMU Orientation Determination Program (P51)  
(Sheet 5 of 5)

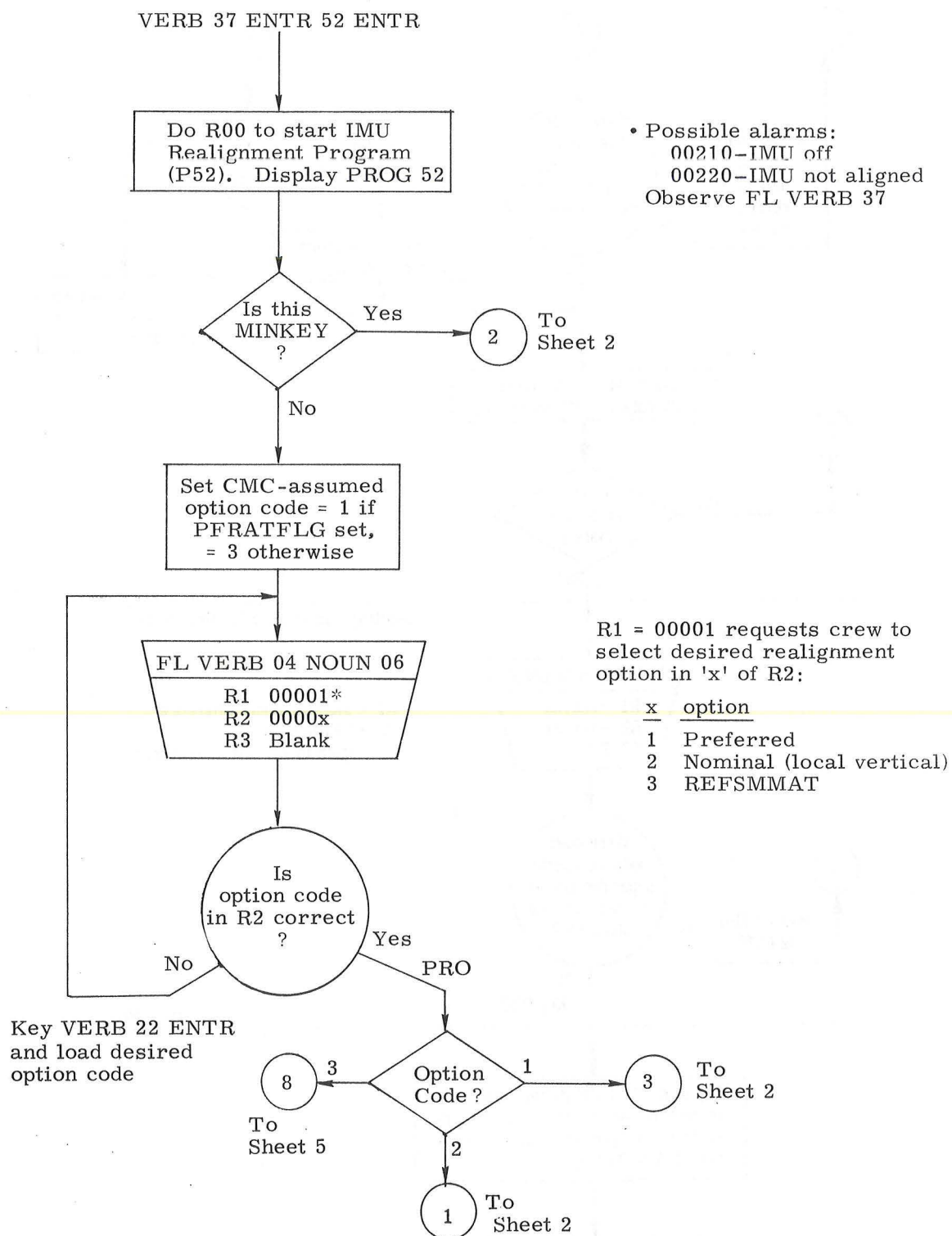


Figure 7.9-3. IMU Realign Program (P52)  
(Sheet 1 of 12)

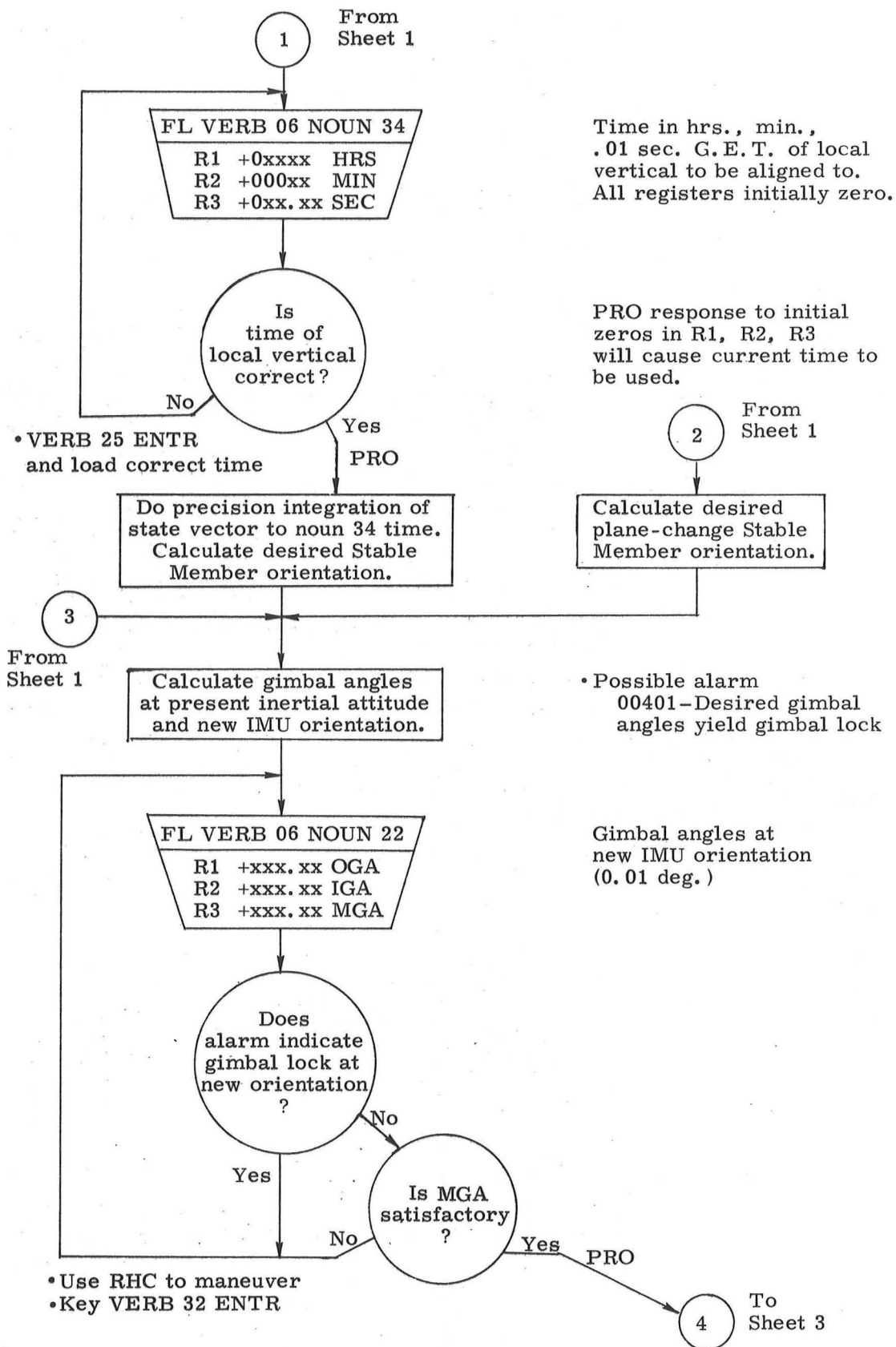


Figure 7.9-3. IMU Realign Program (P52)  
(Sheet 2 of 12)

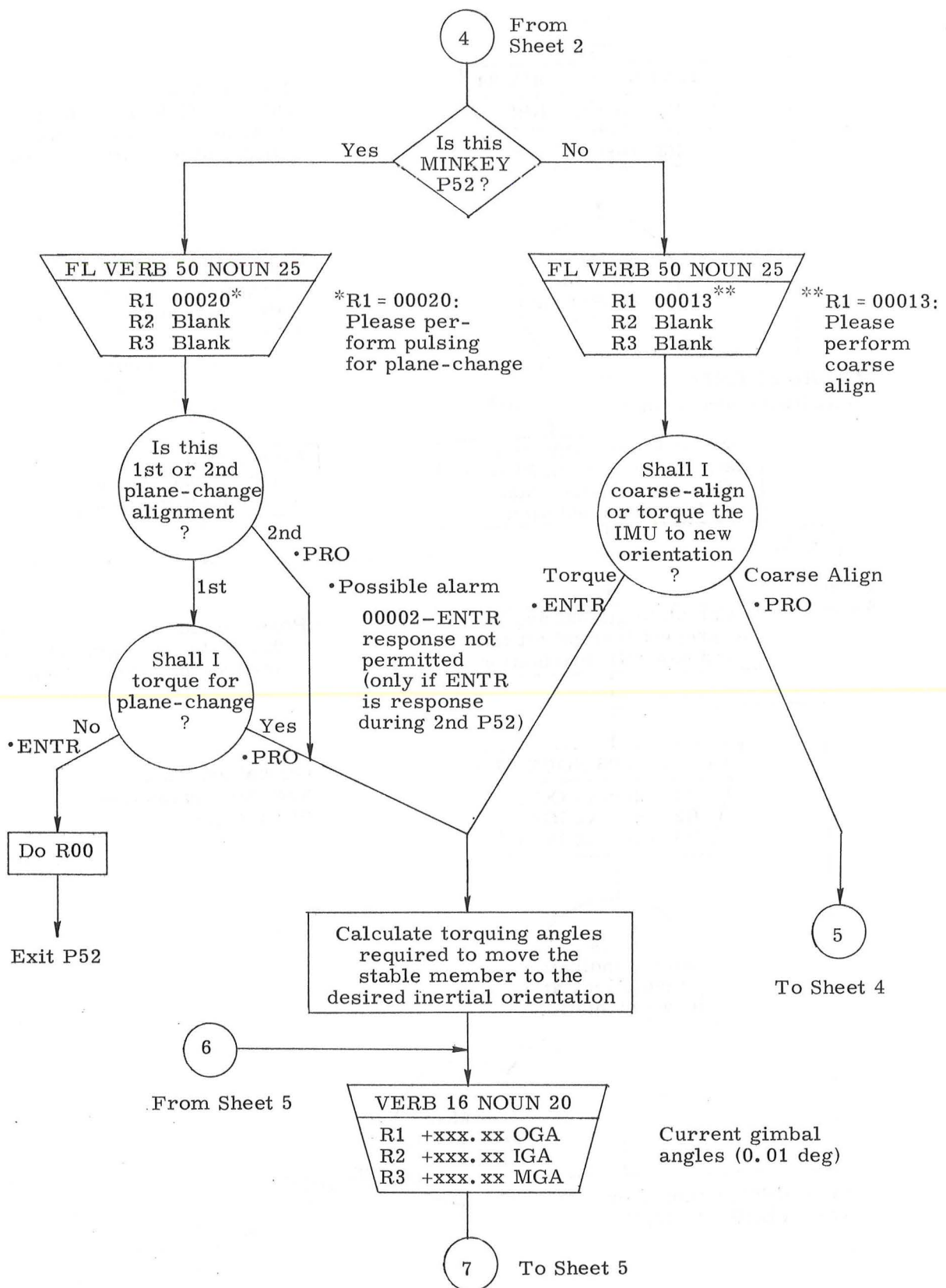
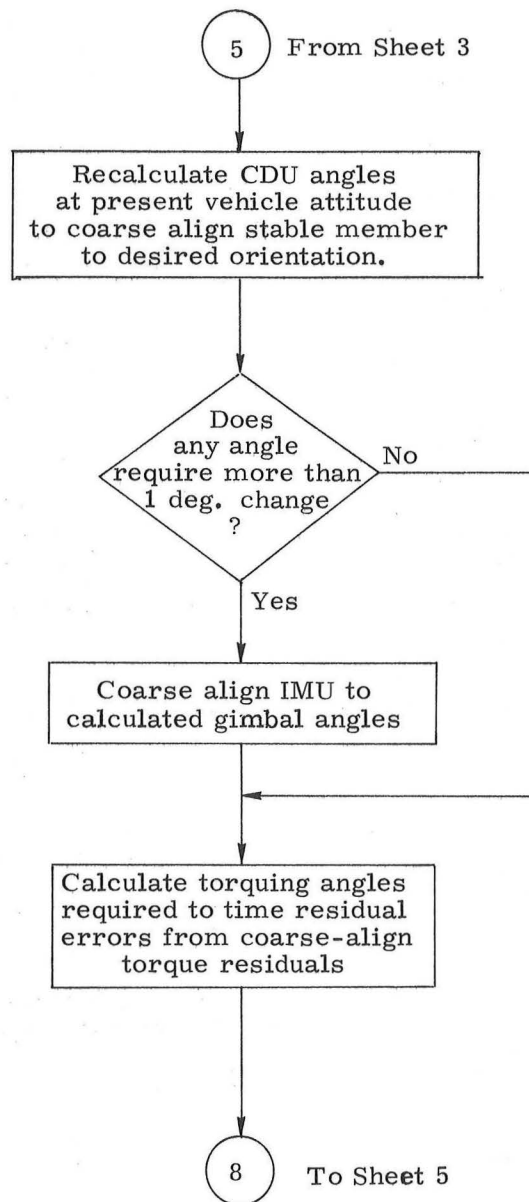


Figure 7.9-3. IMU Realign Program (P52)  
(Sheet 3 of 12)



• Possible alarm

00401—Desired gimbal angles yield gimbal lock. Will not occur if vehicle attitude has not been changed since Noun 22 (sheet 2)

• Possible alarm

00217—Bad return from stall

- Maintain attitude during coarse alignment

Figure 7.9-3. IMU Realign Program (P52)  
(Sheet 4 of 12)

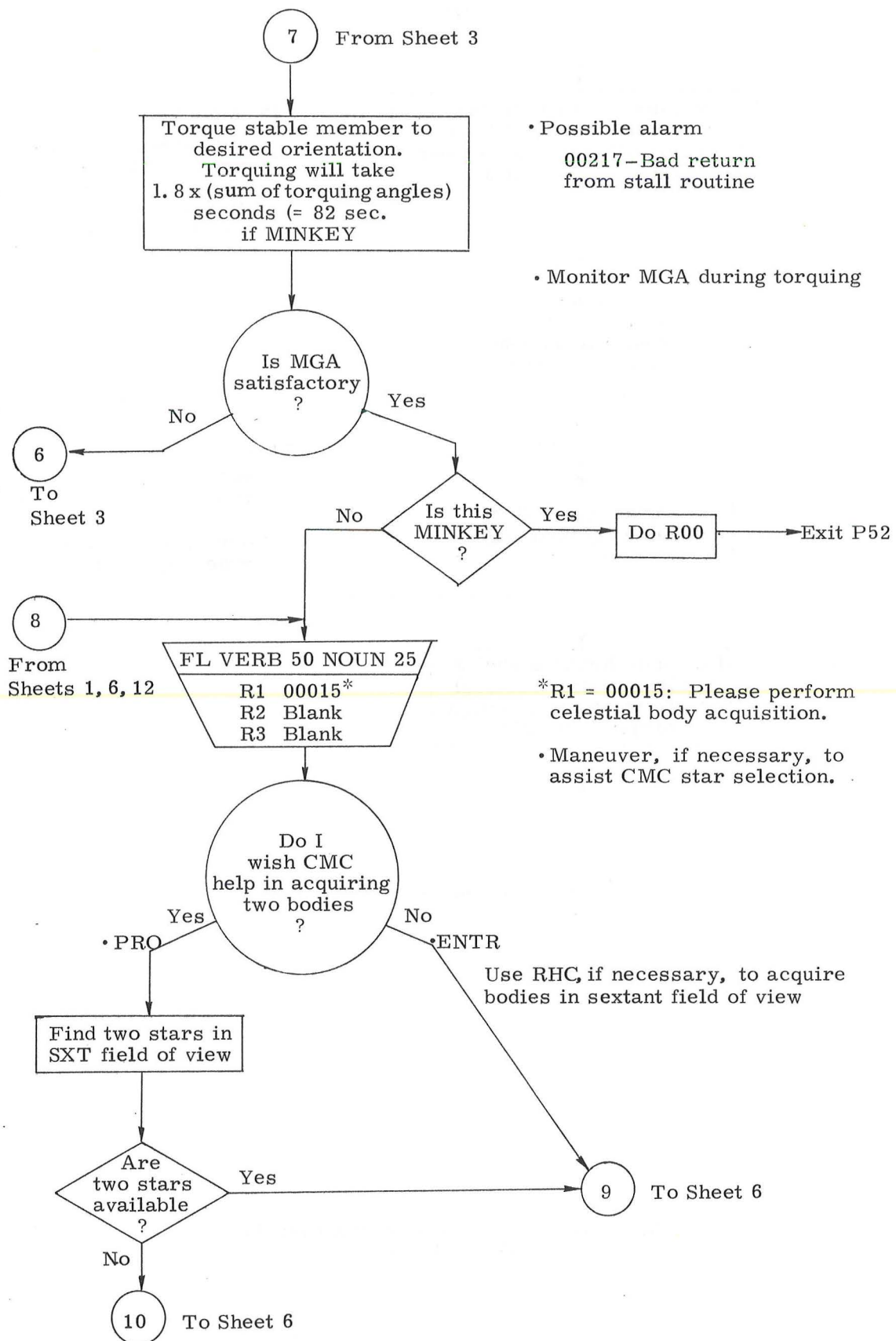


Figure 7.9-3. IMU Realign Program (P52)  
(Sheet 5 of 12)

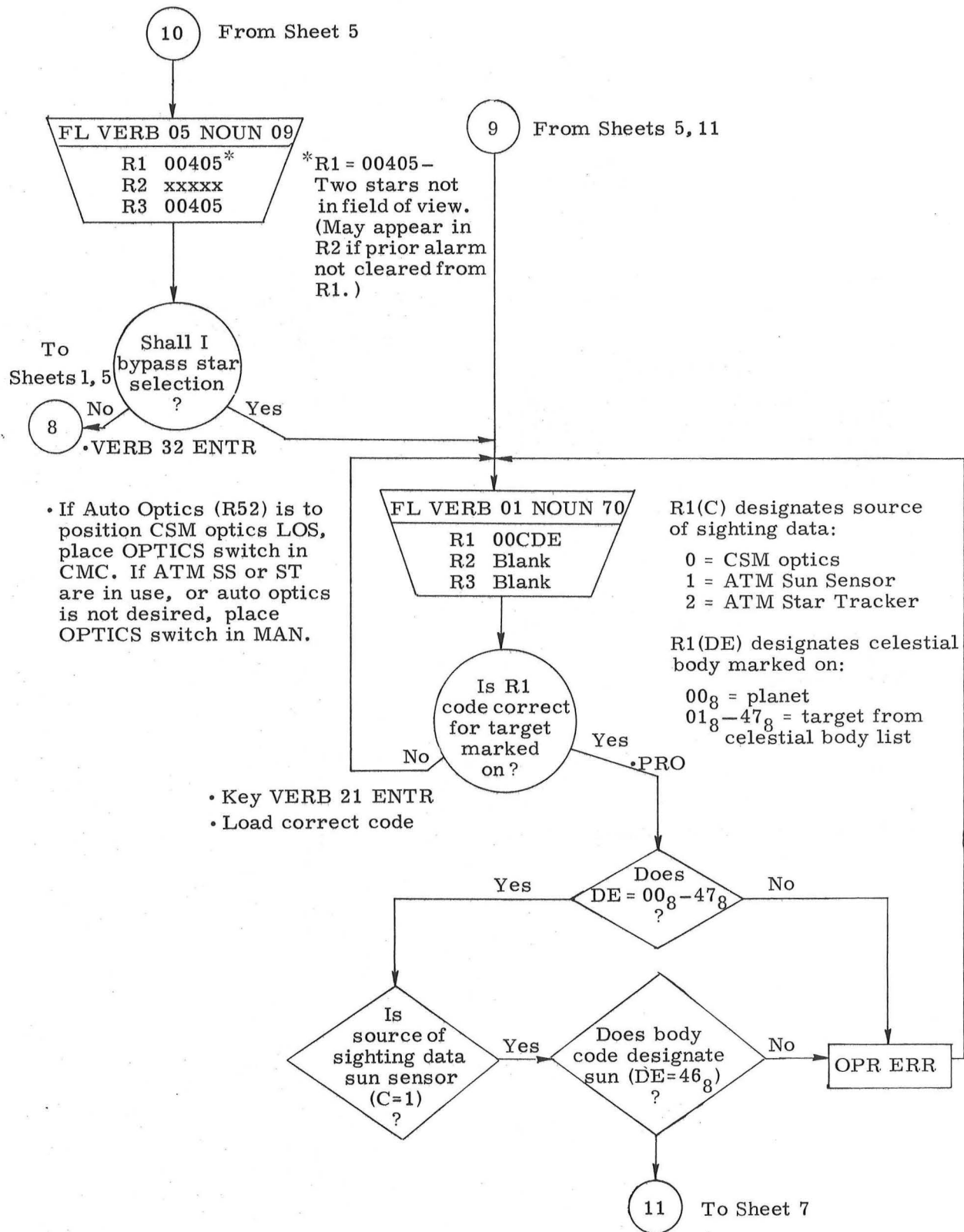


Figure 7.9-3. IMU Realign Program (P52)  
(Sheet 6 of 12)

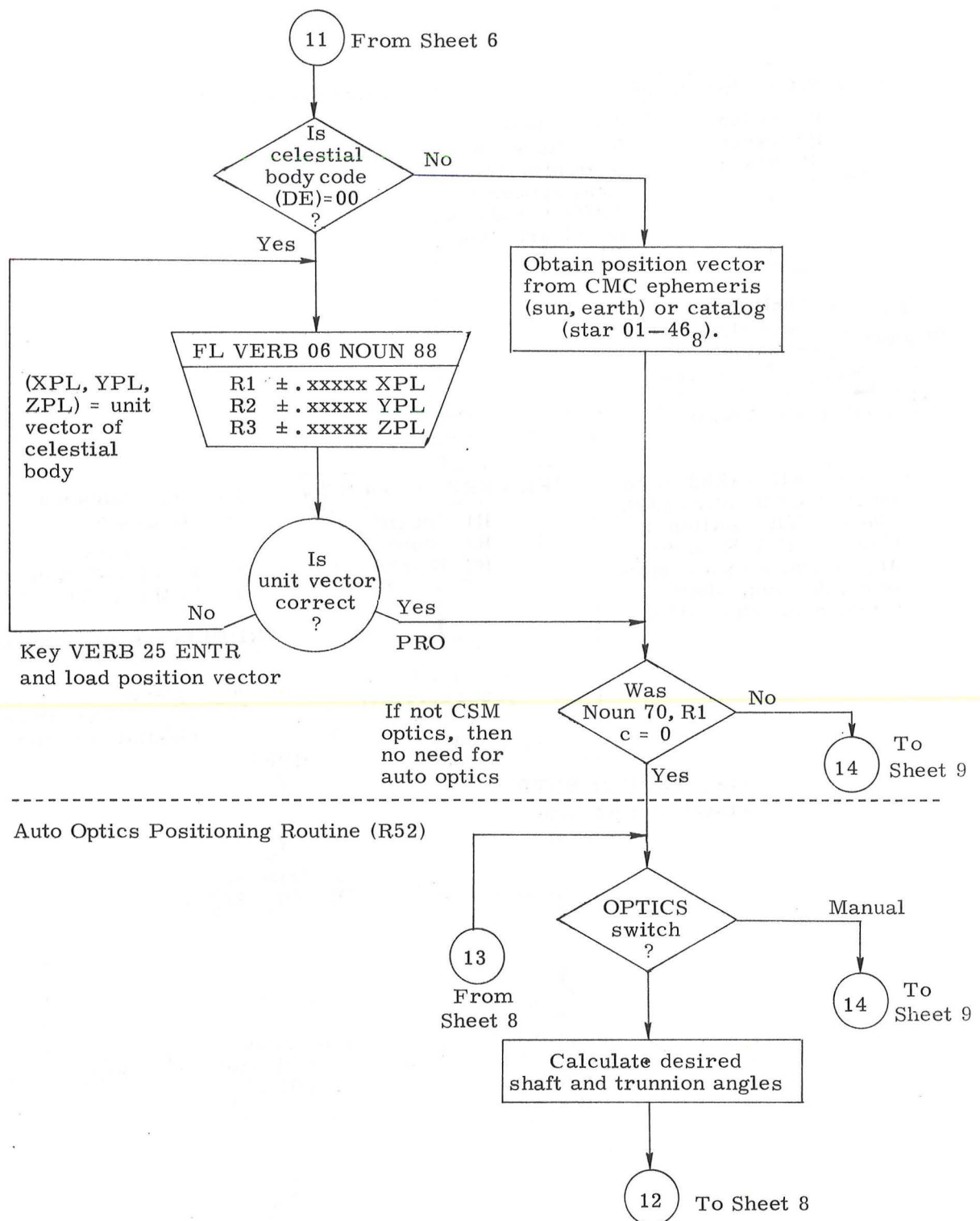


Figure 7.9-3. IMU Realign Program (P52)  
(Sheet 7 of 12)



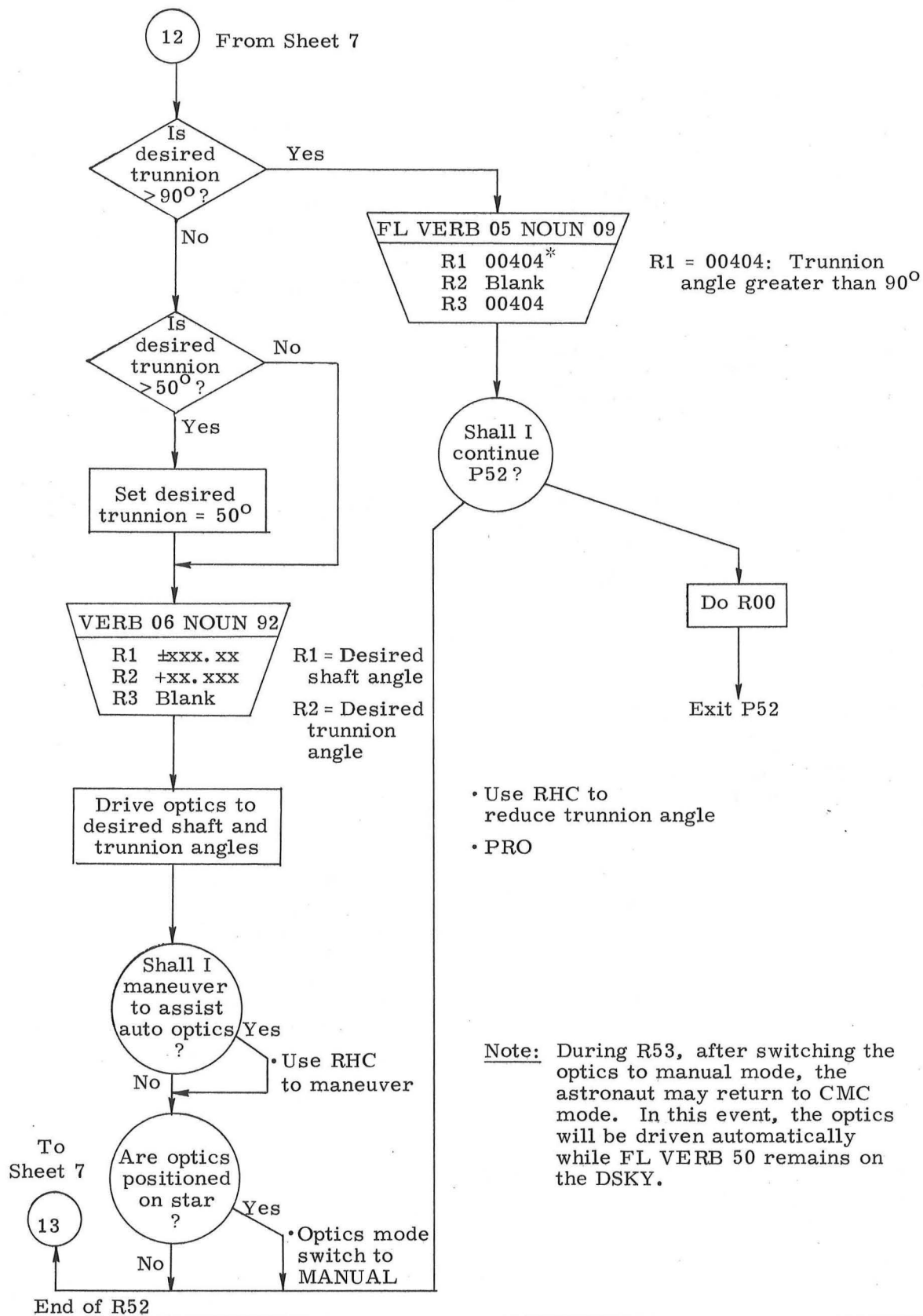


Figure 7.9-3. IMU Realign Program (P52)  
(Sheet of 8 of 12)

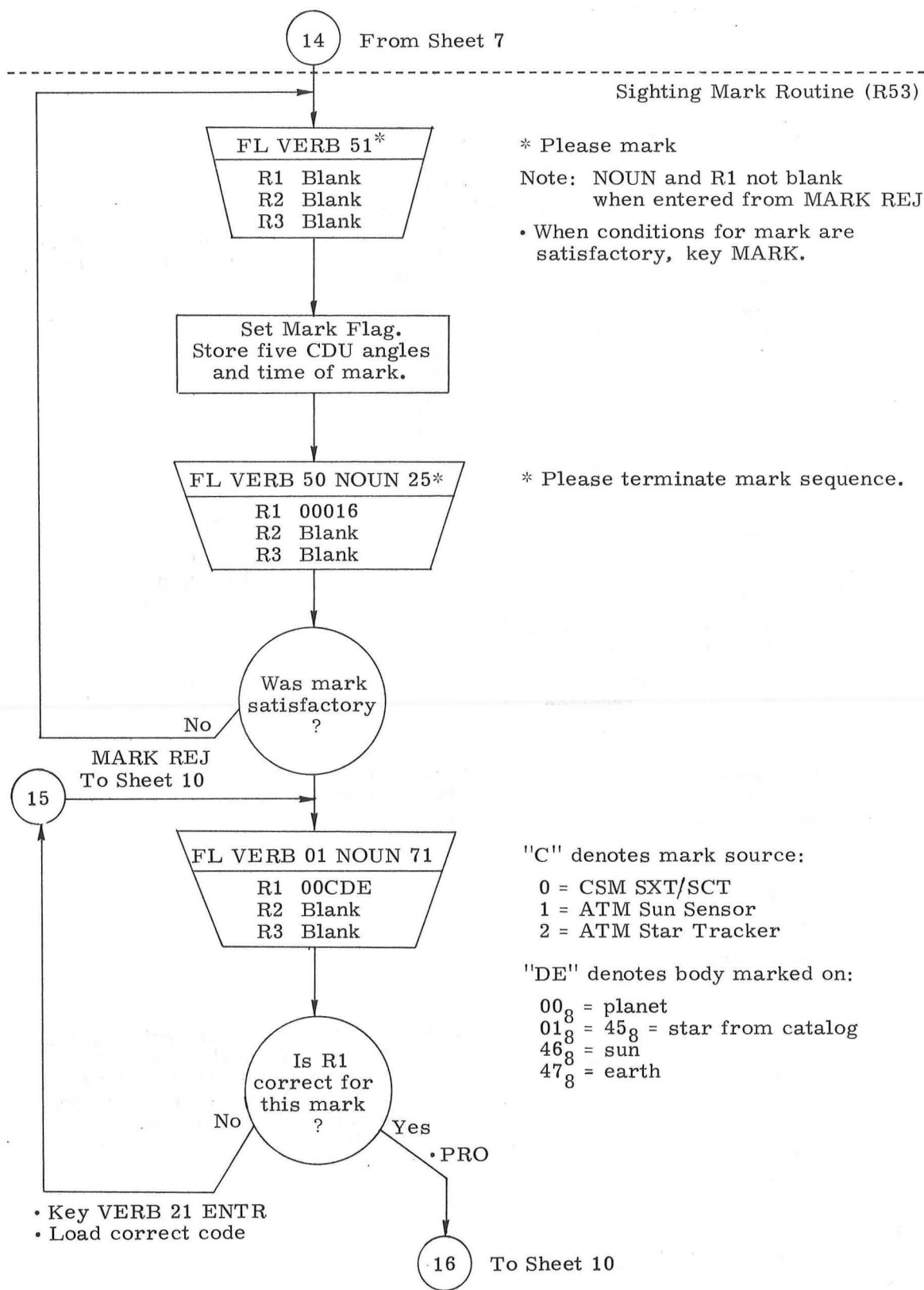


Figure 7.9-3, IMU Realign Program (P52)  
(Sheet 9 of 12)

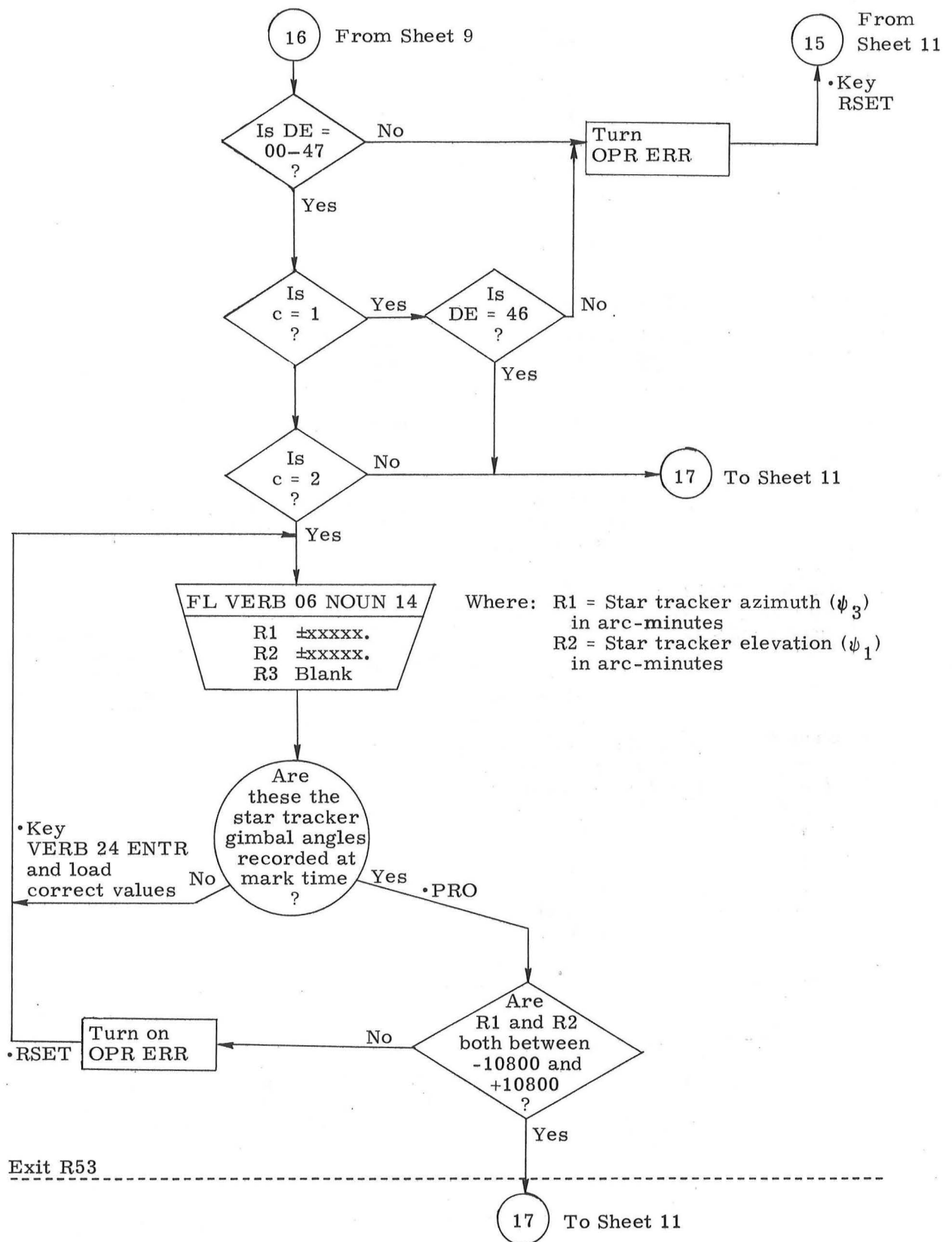


Figure 7.9-3. IMU Realign Program (P52)  
(Sheet 10 of 12)

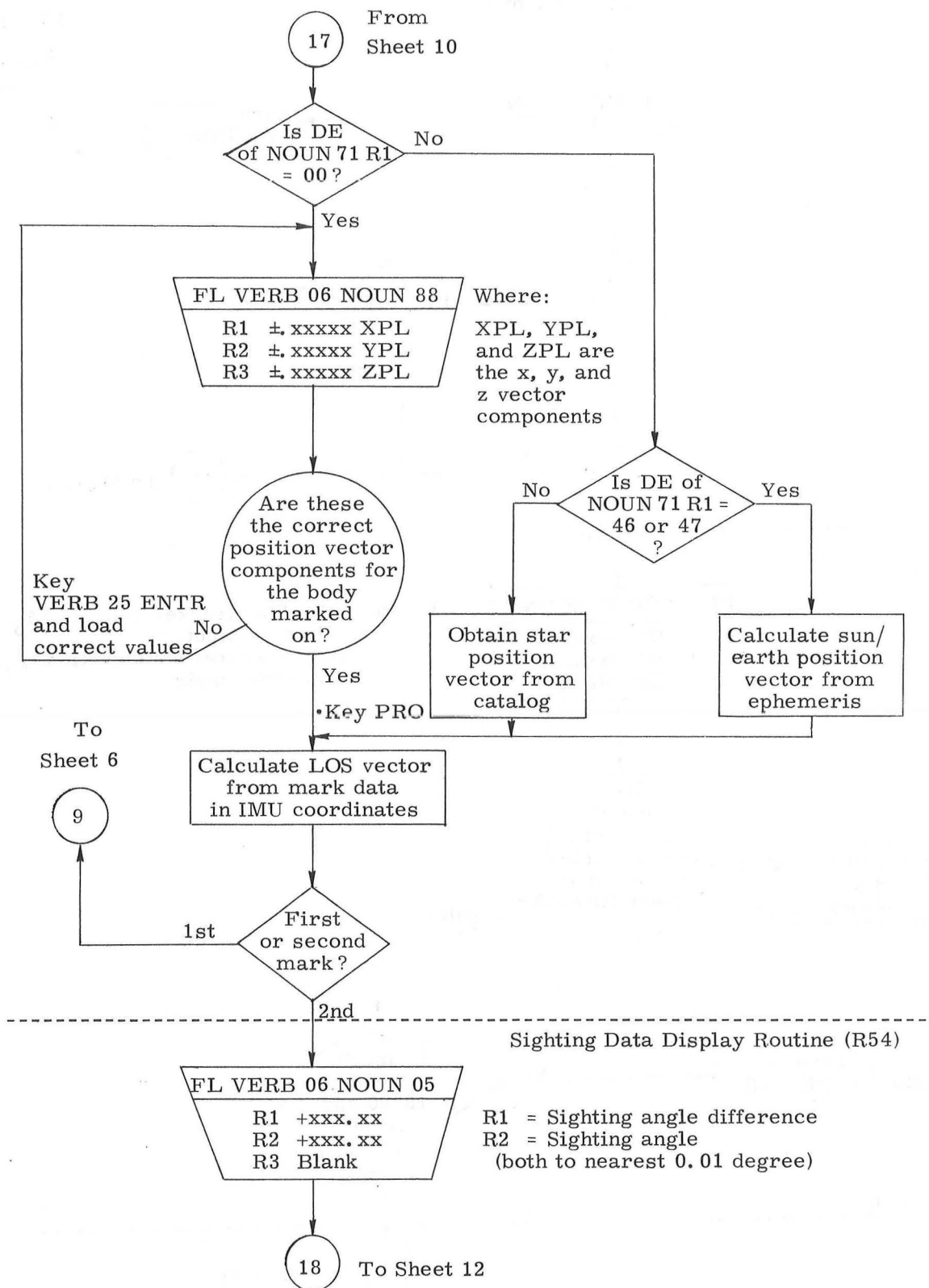


Figure 7.9-3, IMU Realign Program (P52)  
(Sheet 11 Of 12)

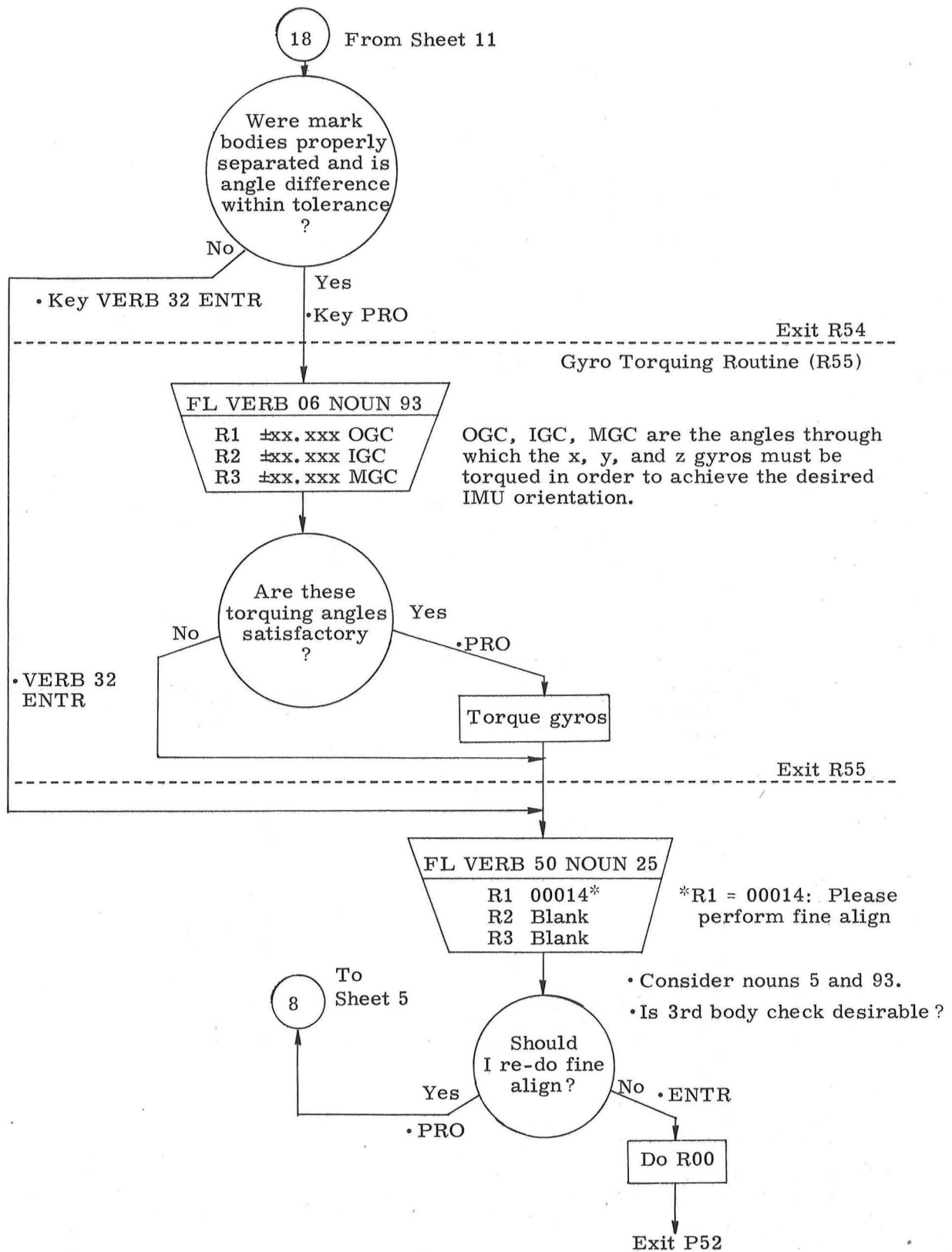


Figure 7.9-3. IMU Realign Program (P52)  
(Sheet 12 of 12)

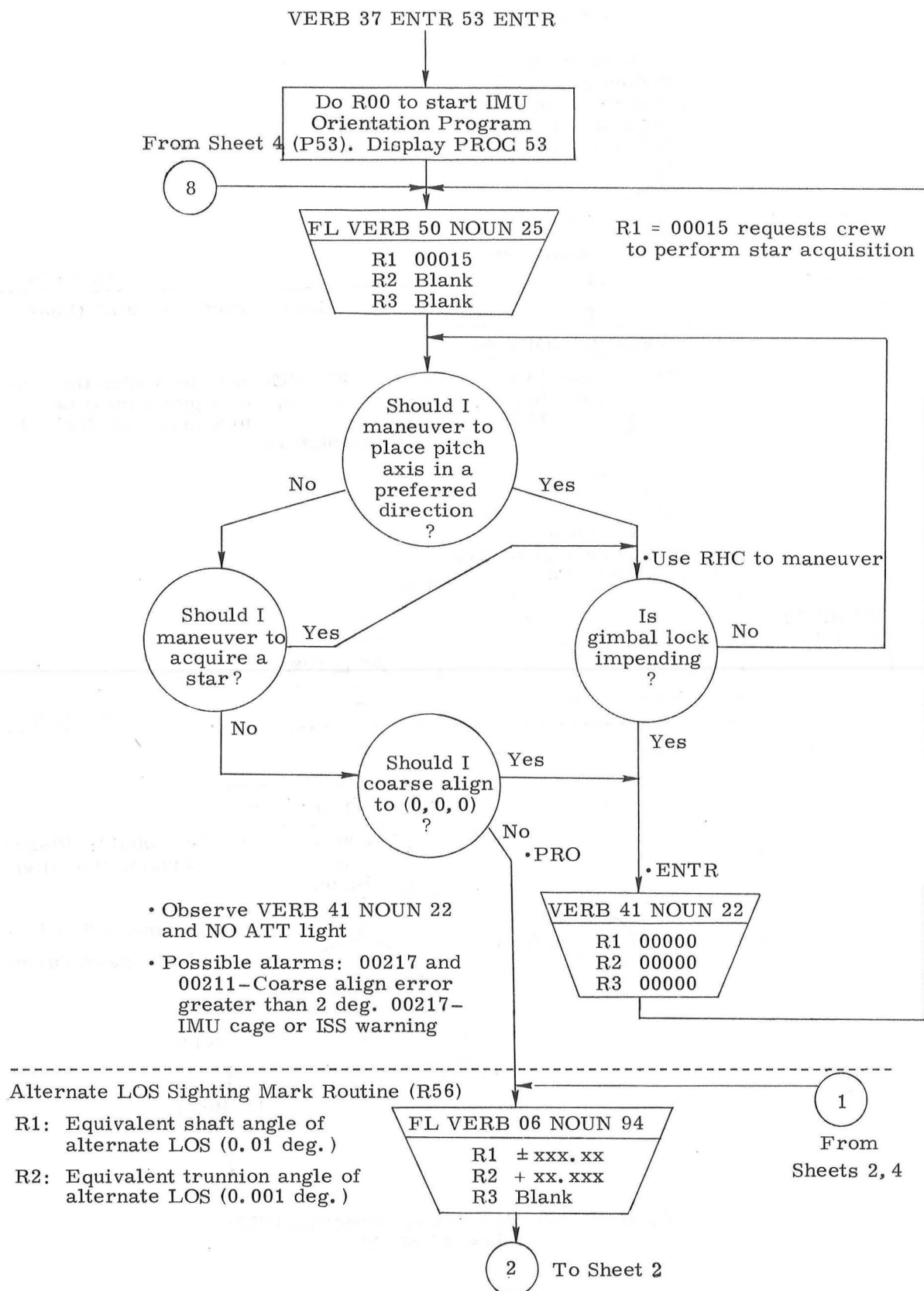


Figure 7.9-4. Backup IMU Orientation Program (P53)  
(Sheet 1 of 4)

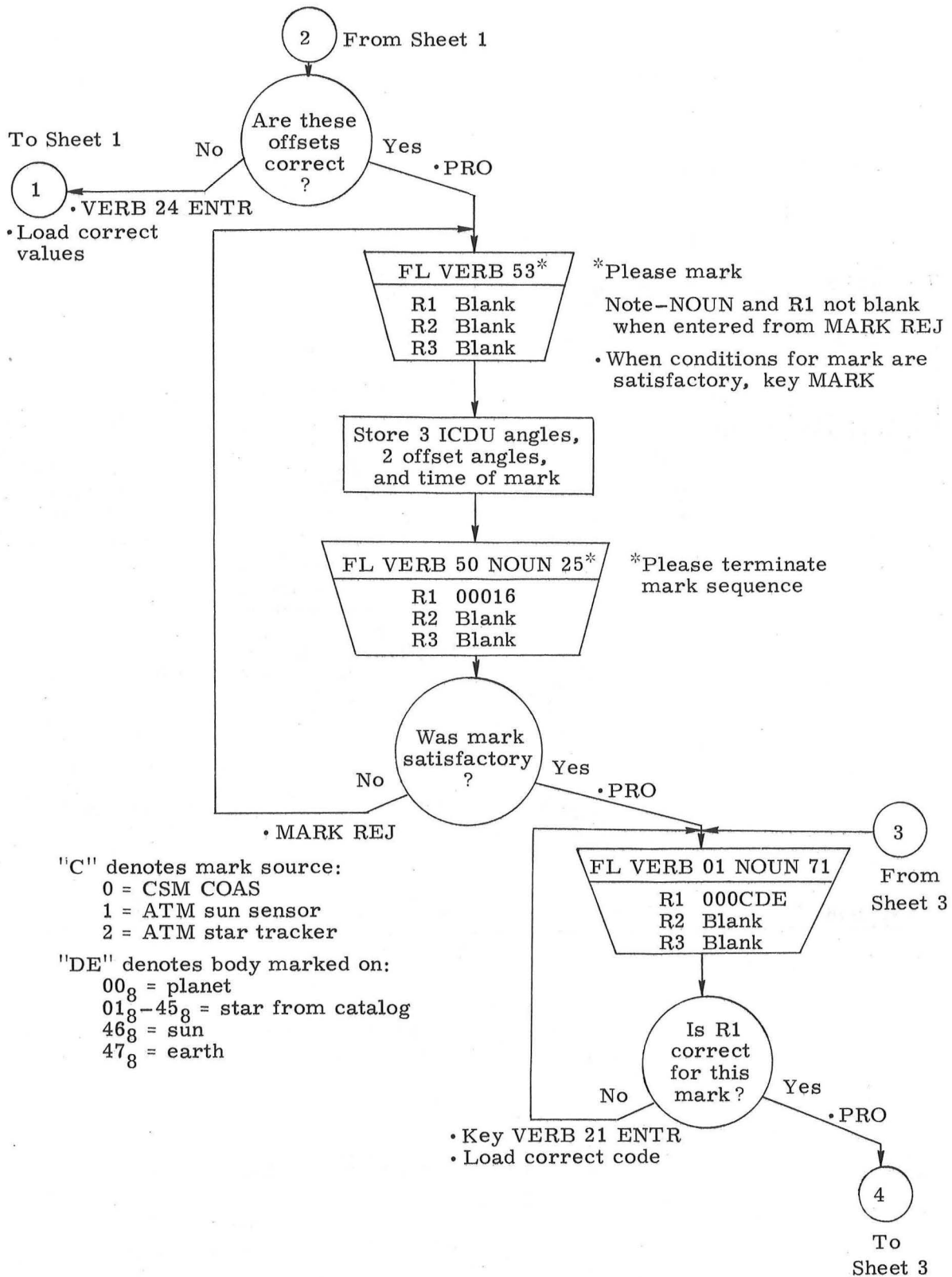


Figure 7.9-4. Backup IMU Orientation Program (P53)  
(Sheet 2 of 4)

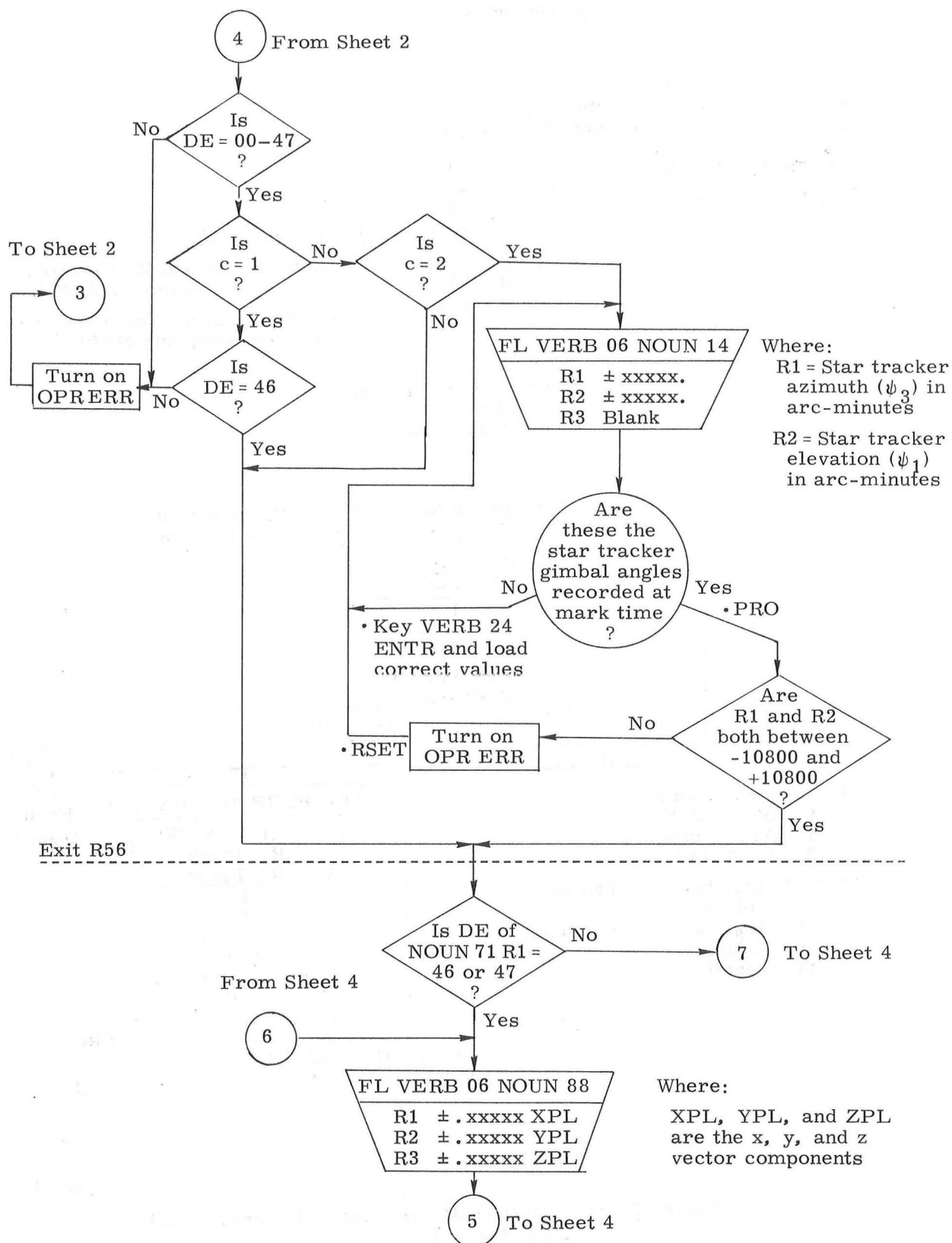


Figure 7.9-4. Backup IMU Orientation Program (P53)  
(Sheet 3 of 4)



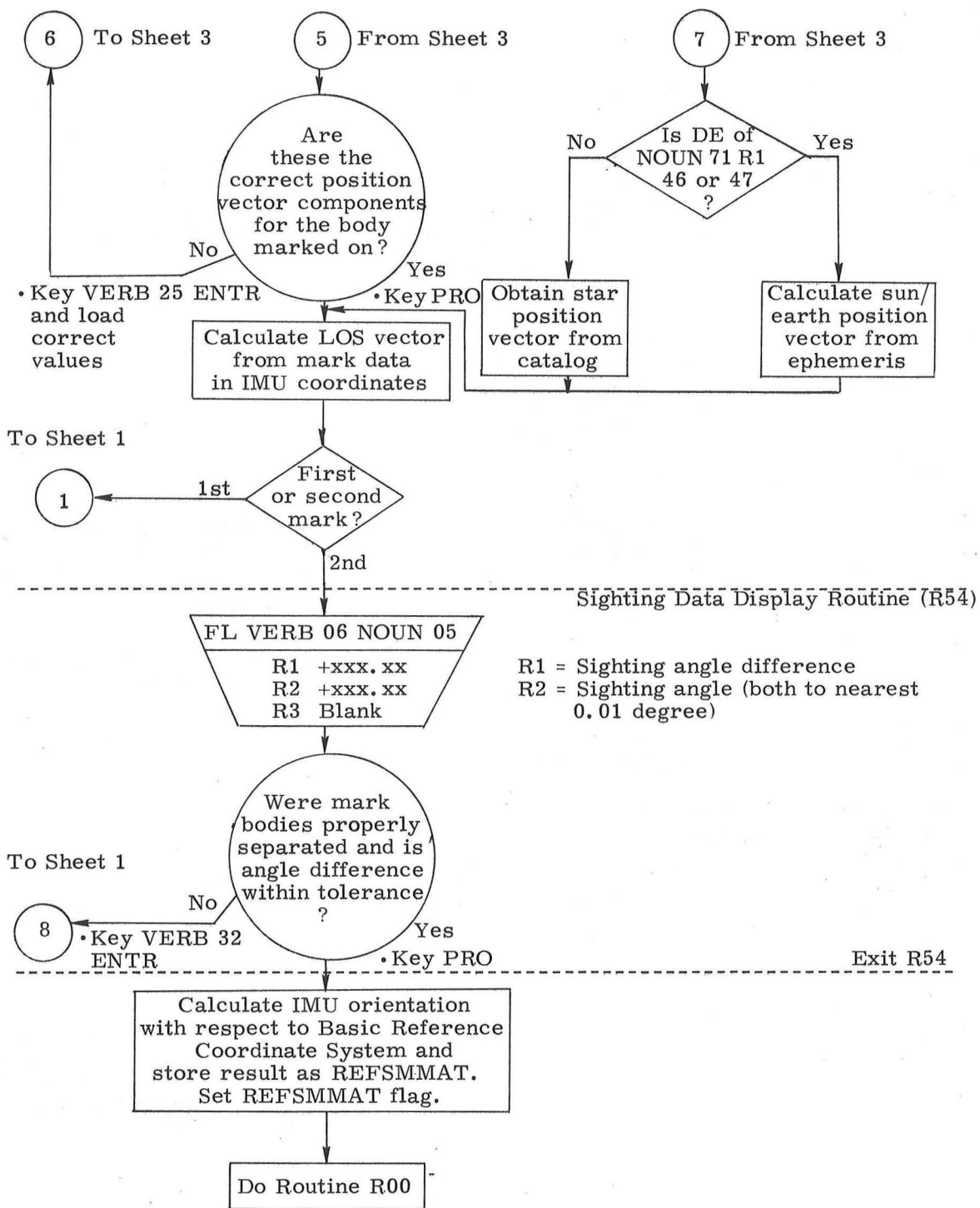


Figure 7.9-4. Backup IMU Orientation Program (P53)  
(Sheet 4 of 4)

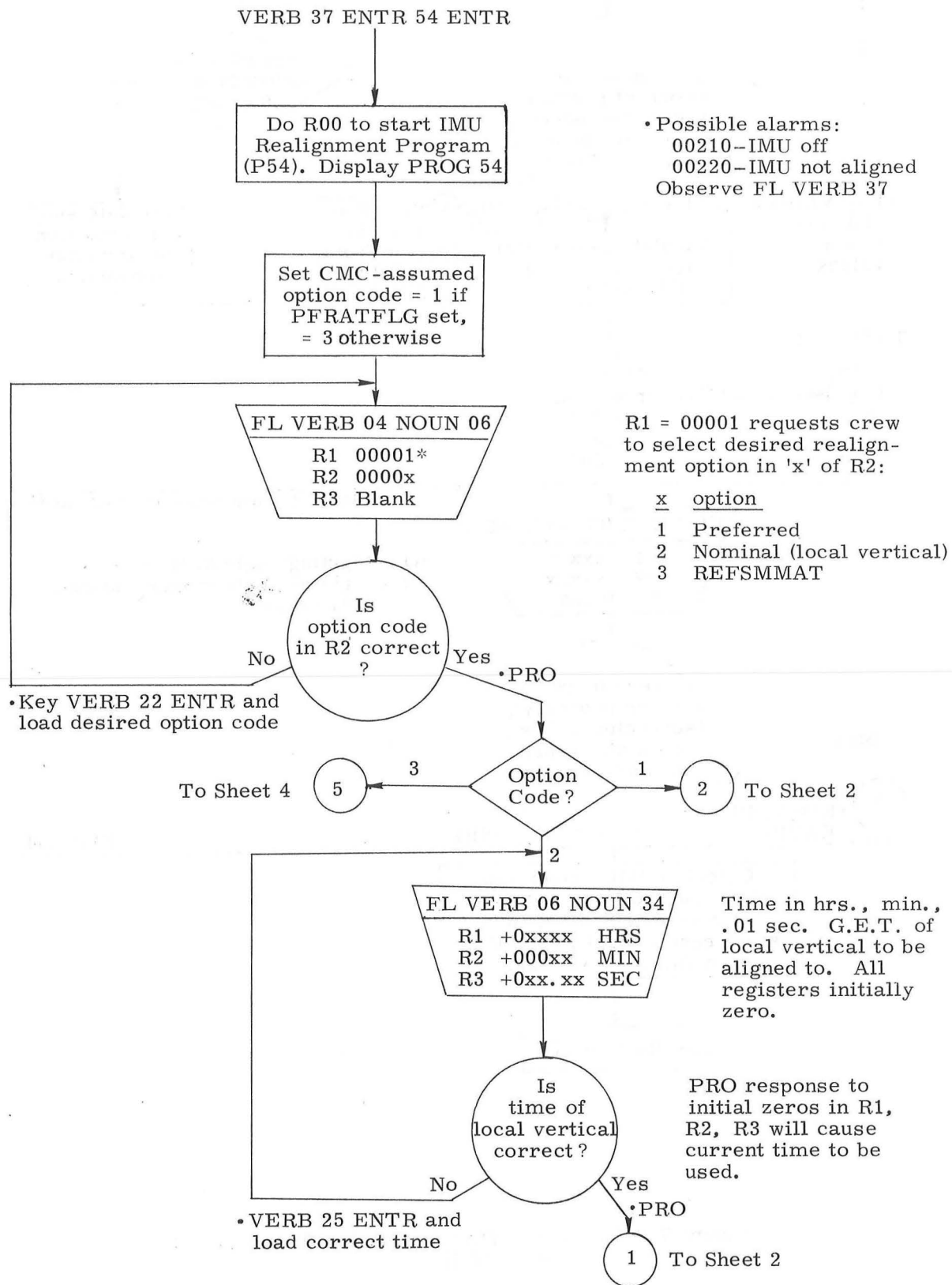


Figure 7.9-5. Backup IMU Realign Program (P54)  
(Sheet 1 of 9)

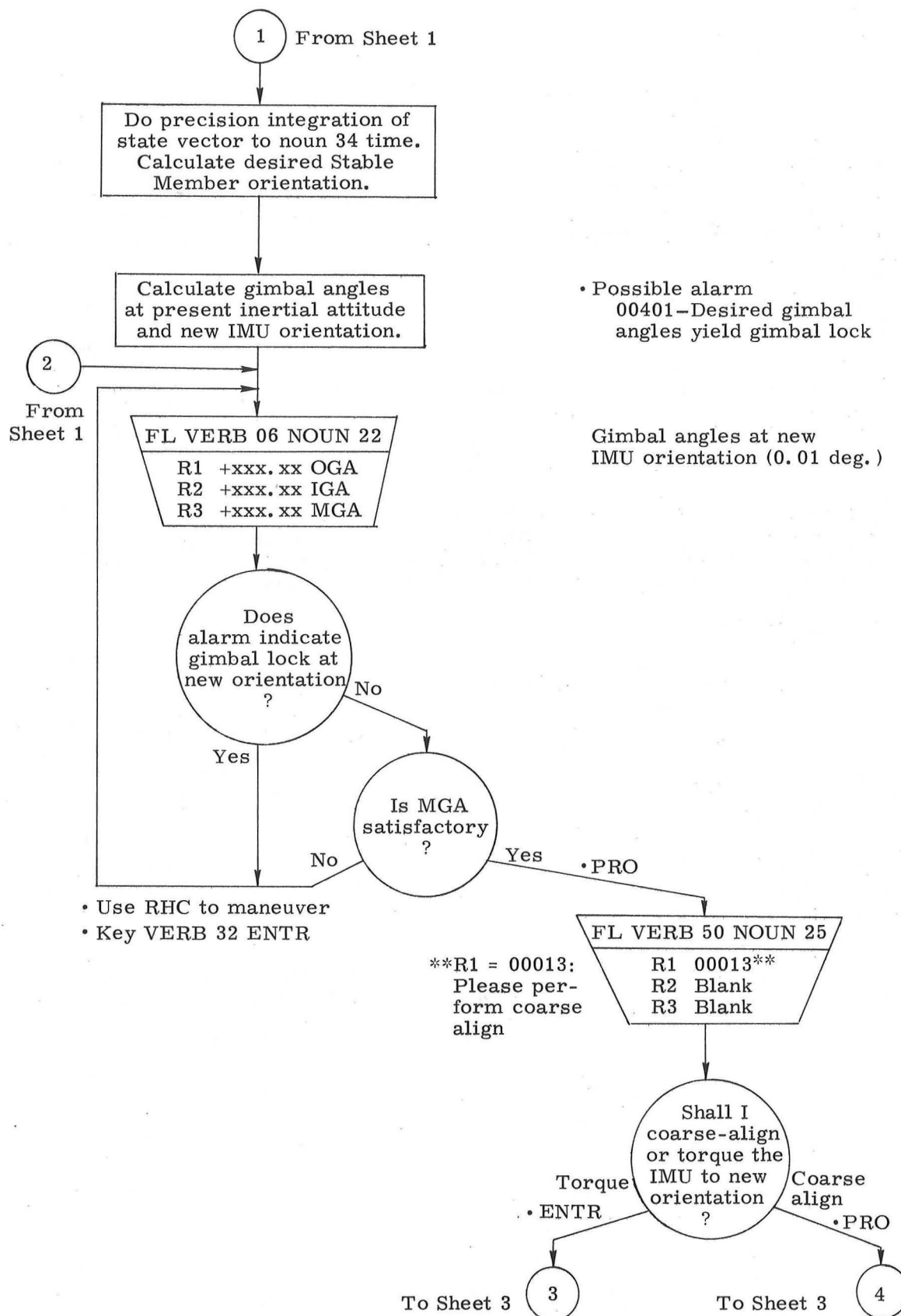


Figure 7.9-5. Backup IMU Realign Program (P54)  
(Sheet 2 of 9)

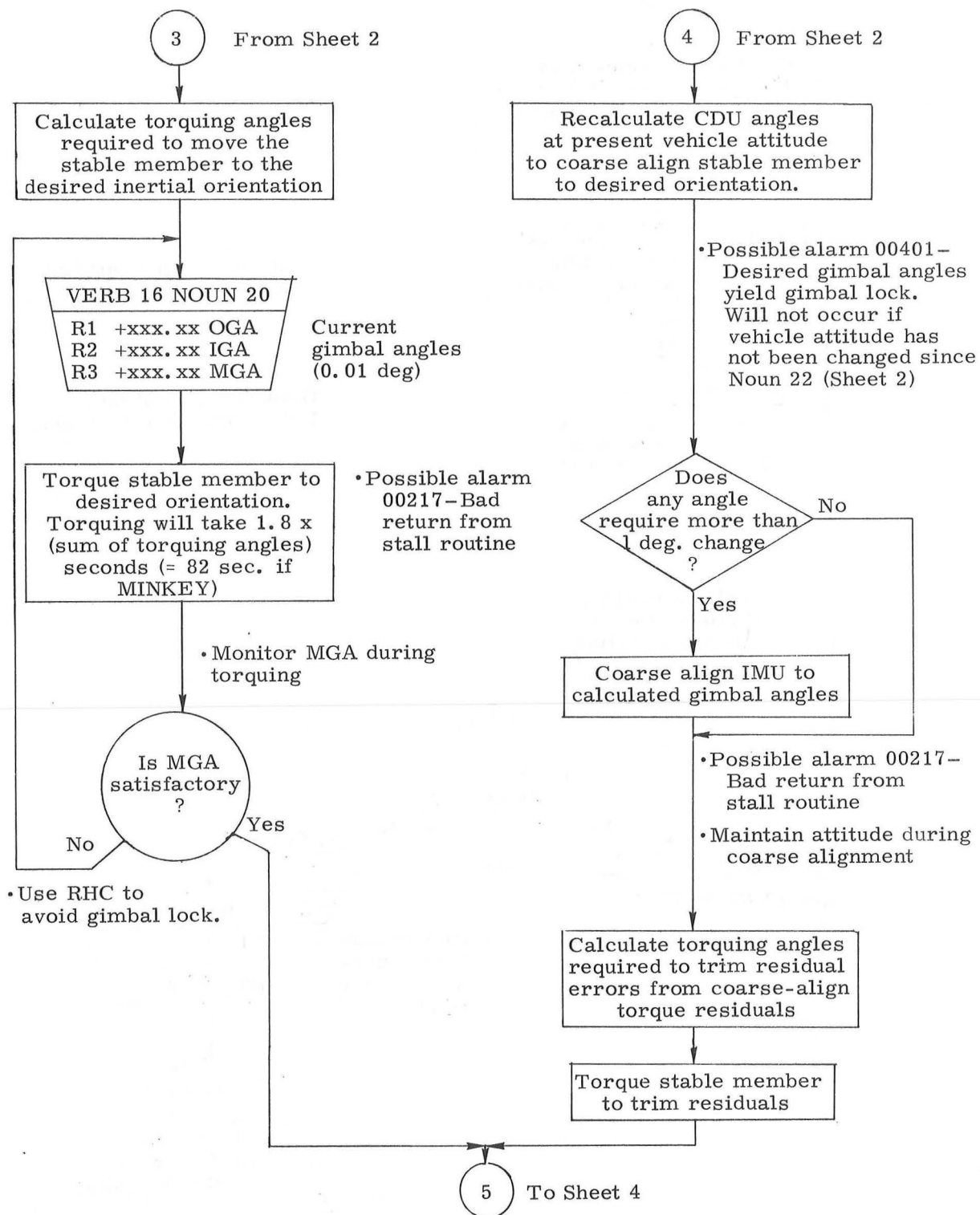


Figure 7.9-5. Backup IMU Realign Program (P54)  
(Sheet 3 of 9)

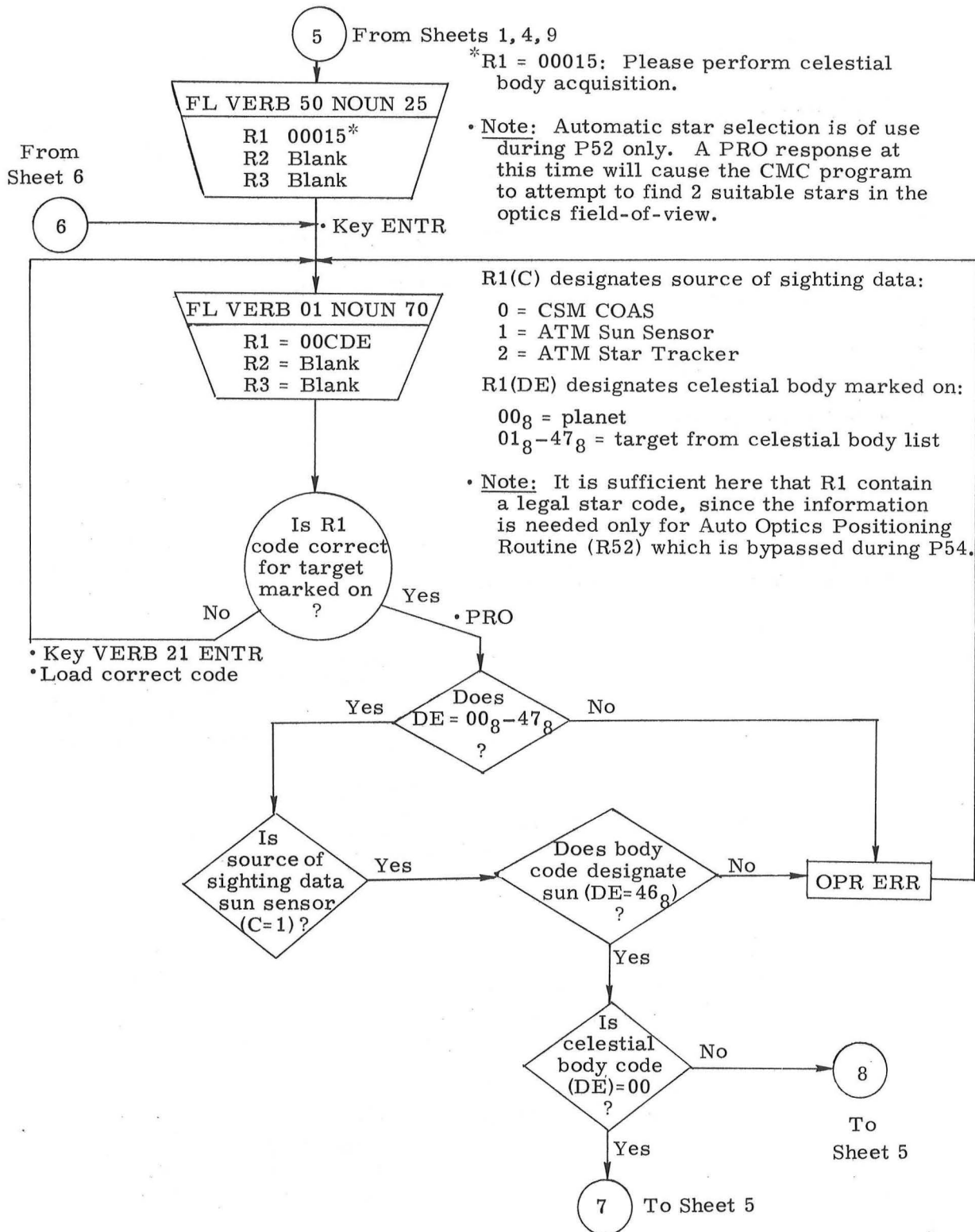


Figure 7.9-5. Backup IMU Realign Program (P54)  
(Sheet 4 of 9)

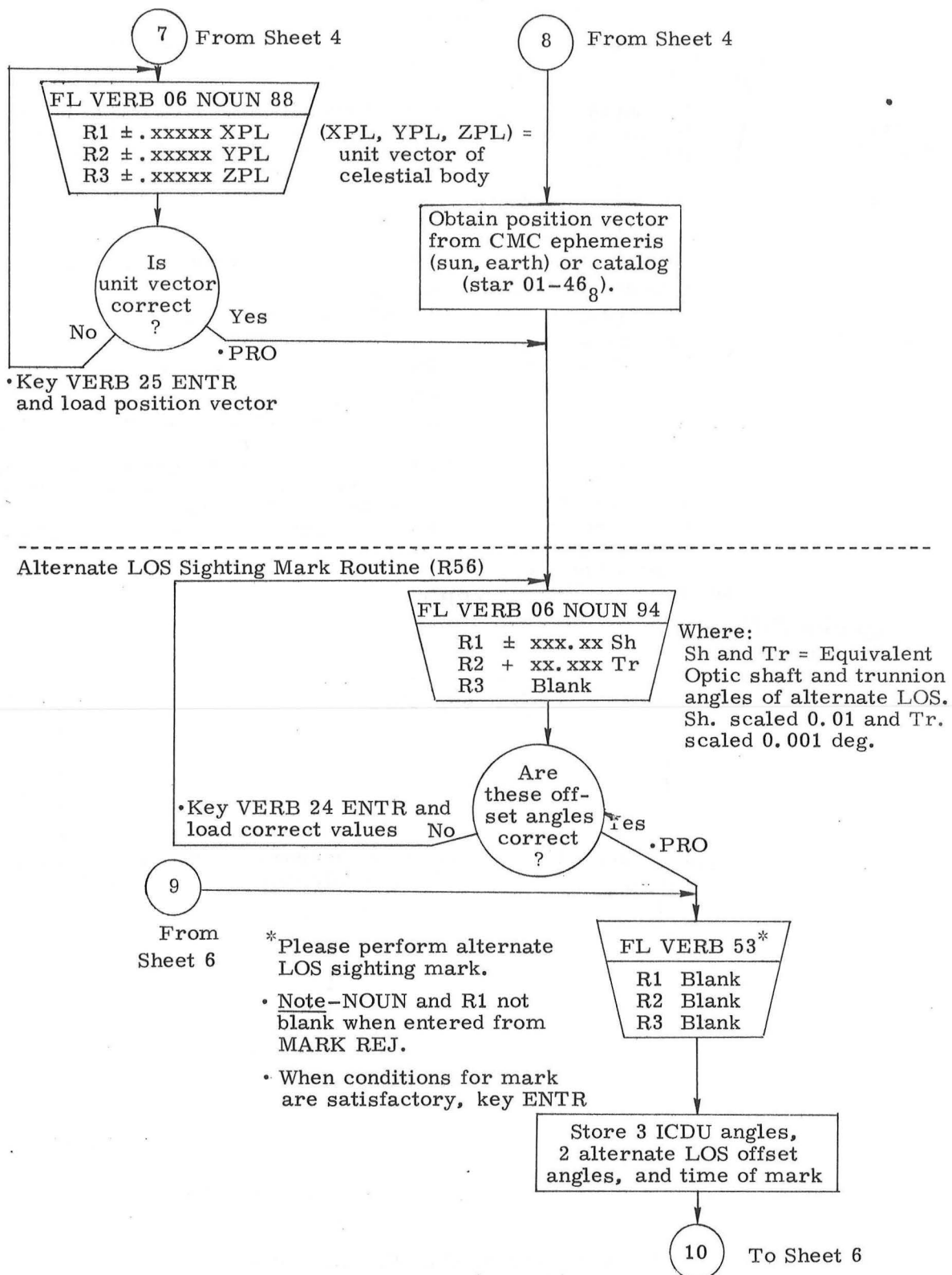


Figure 7.9-5. Backup IMU Realign Program (P54)  
(Sheet 5 of 9)

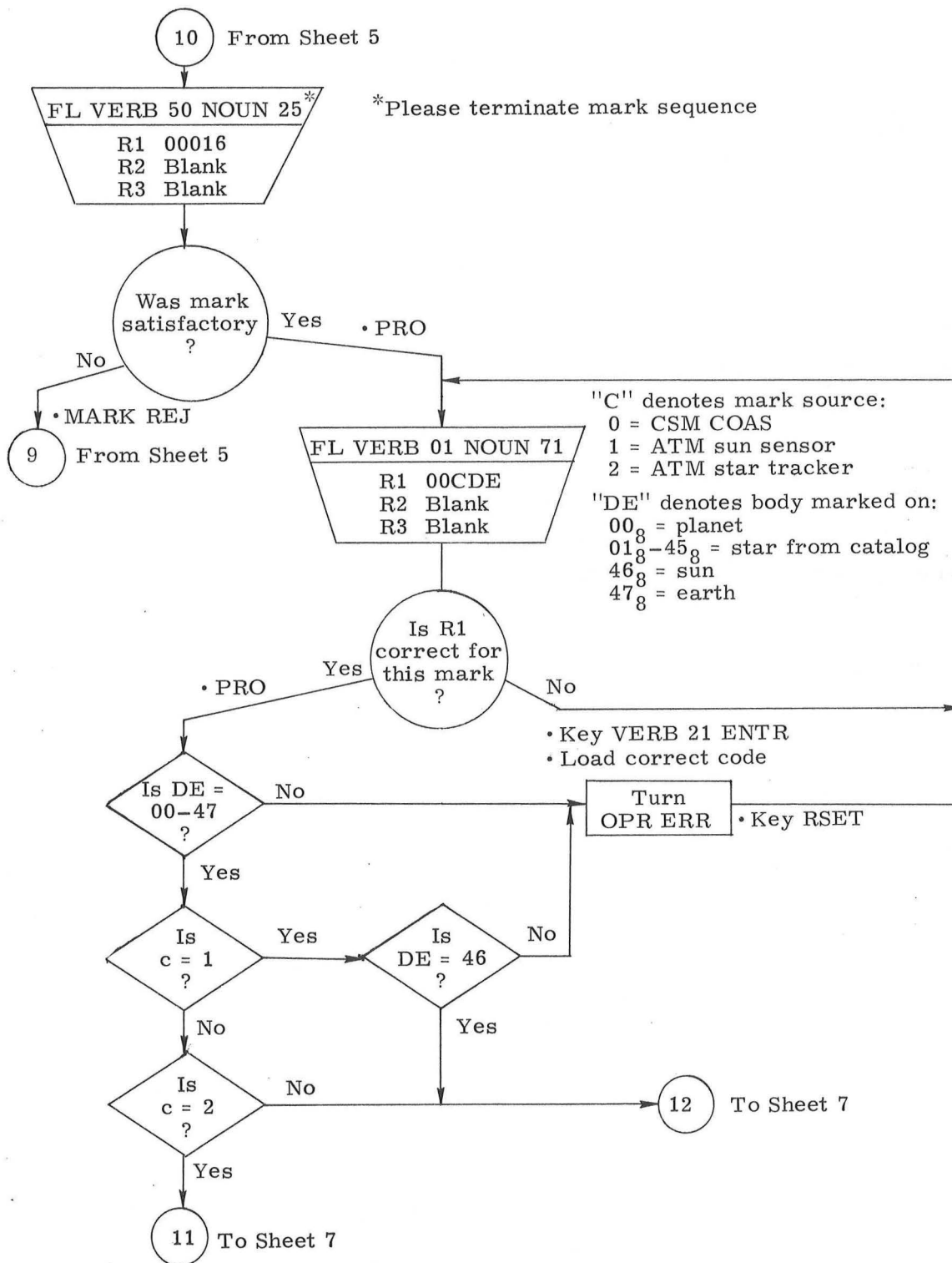


Figure 7.9-5. Backup IMU Realign Program (P54)  
(Sheet 6 of 9)

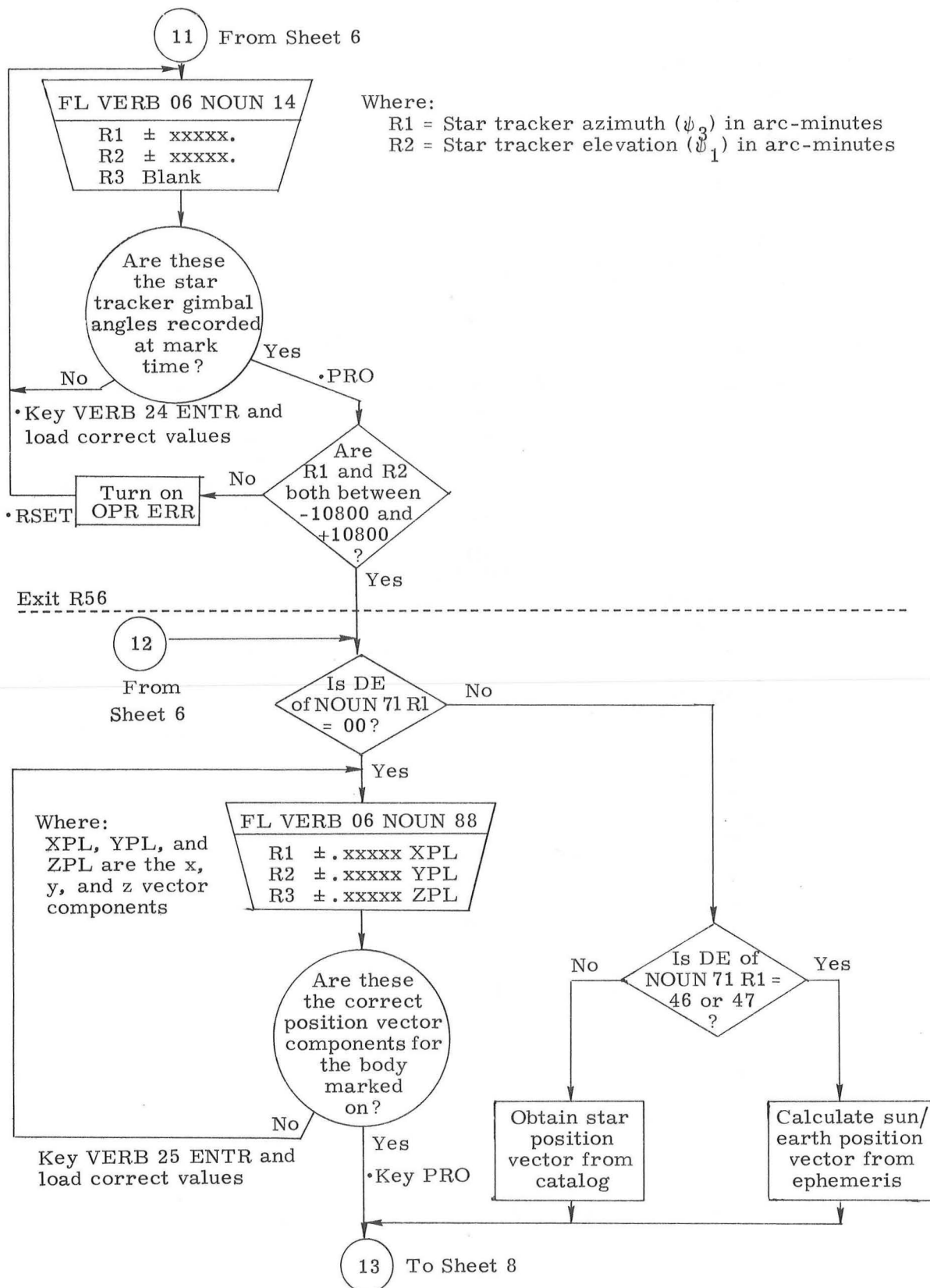


Figure 7.9-5. Backup IMU Realign Program (P54)  
(Sheet 7 of 9)



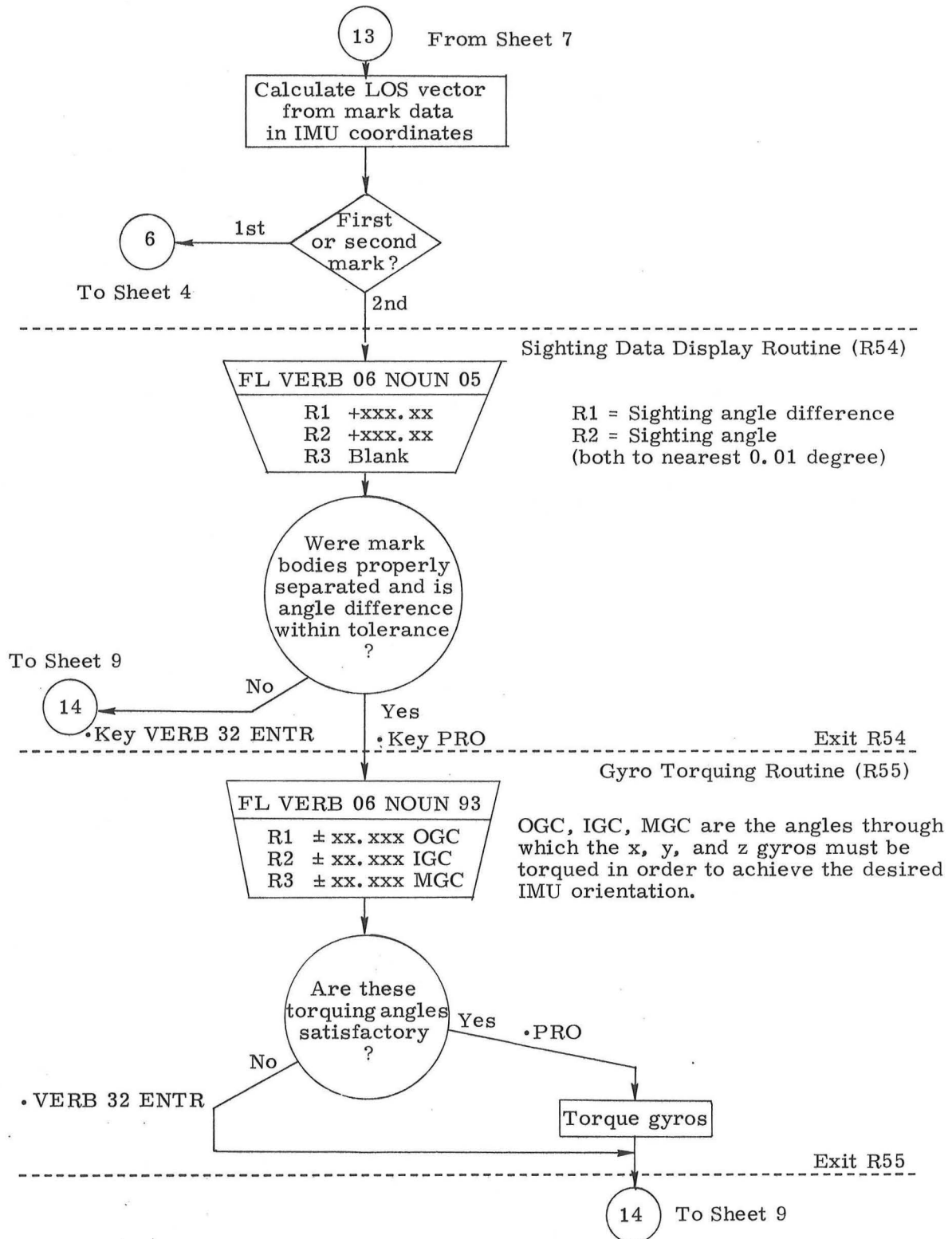


Figure 7.9-5. Backup IMU Realign Program (P54)  
(Sheet 8 of 9)

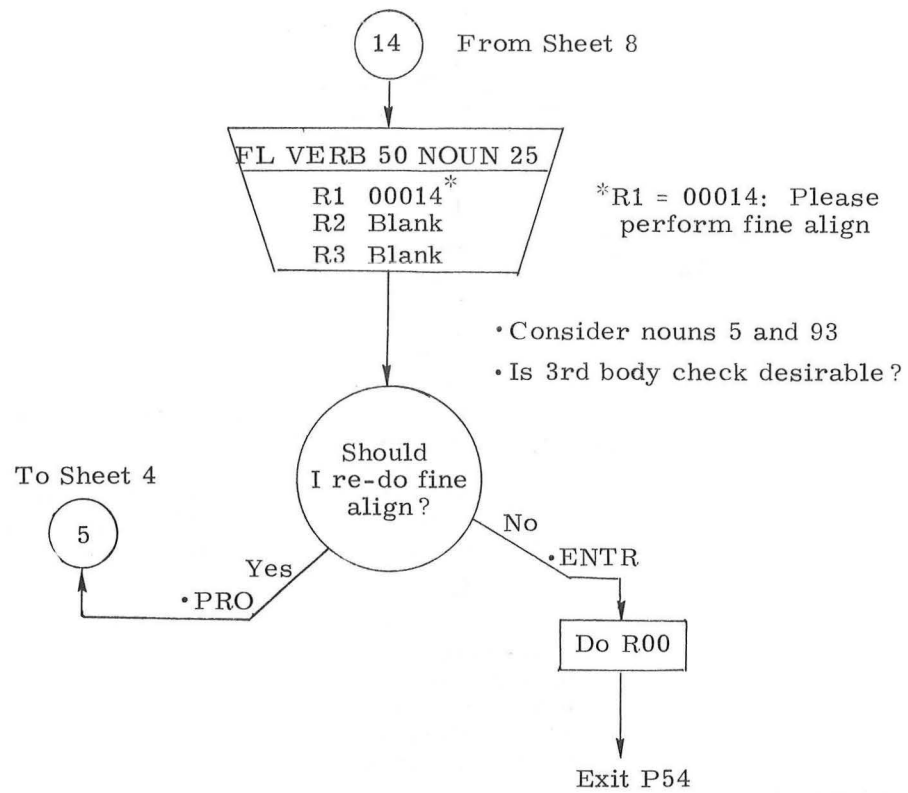


Figure 7.9-5. Backup IMU Realign Program (P54)  
(Sheet 9 of 9)

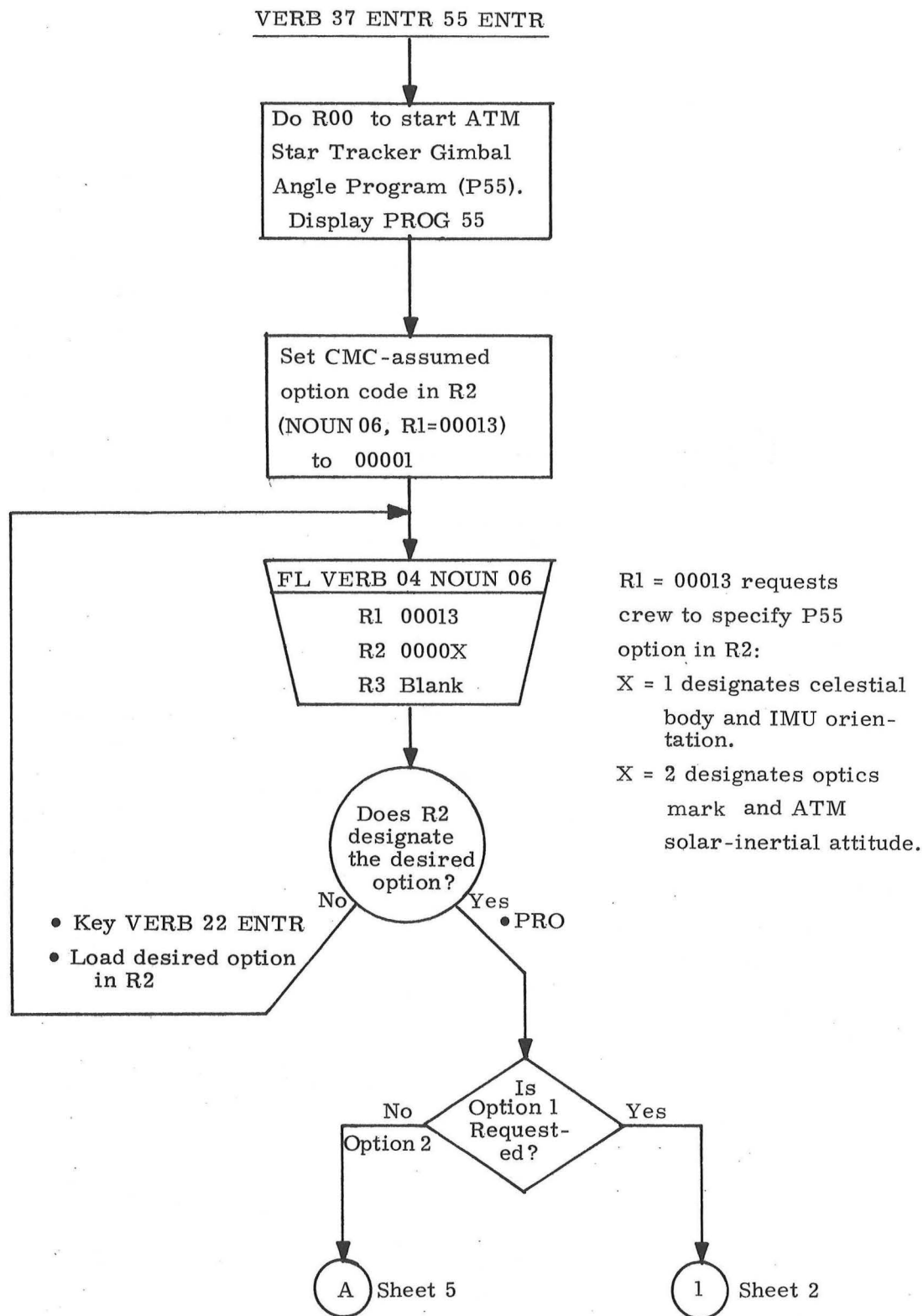


Figure 7.9-6. ATM Star Tracker Gimbal Angle Program (P55)  
(Sheet 1 of 7)

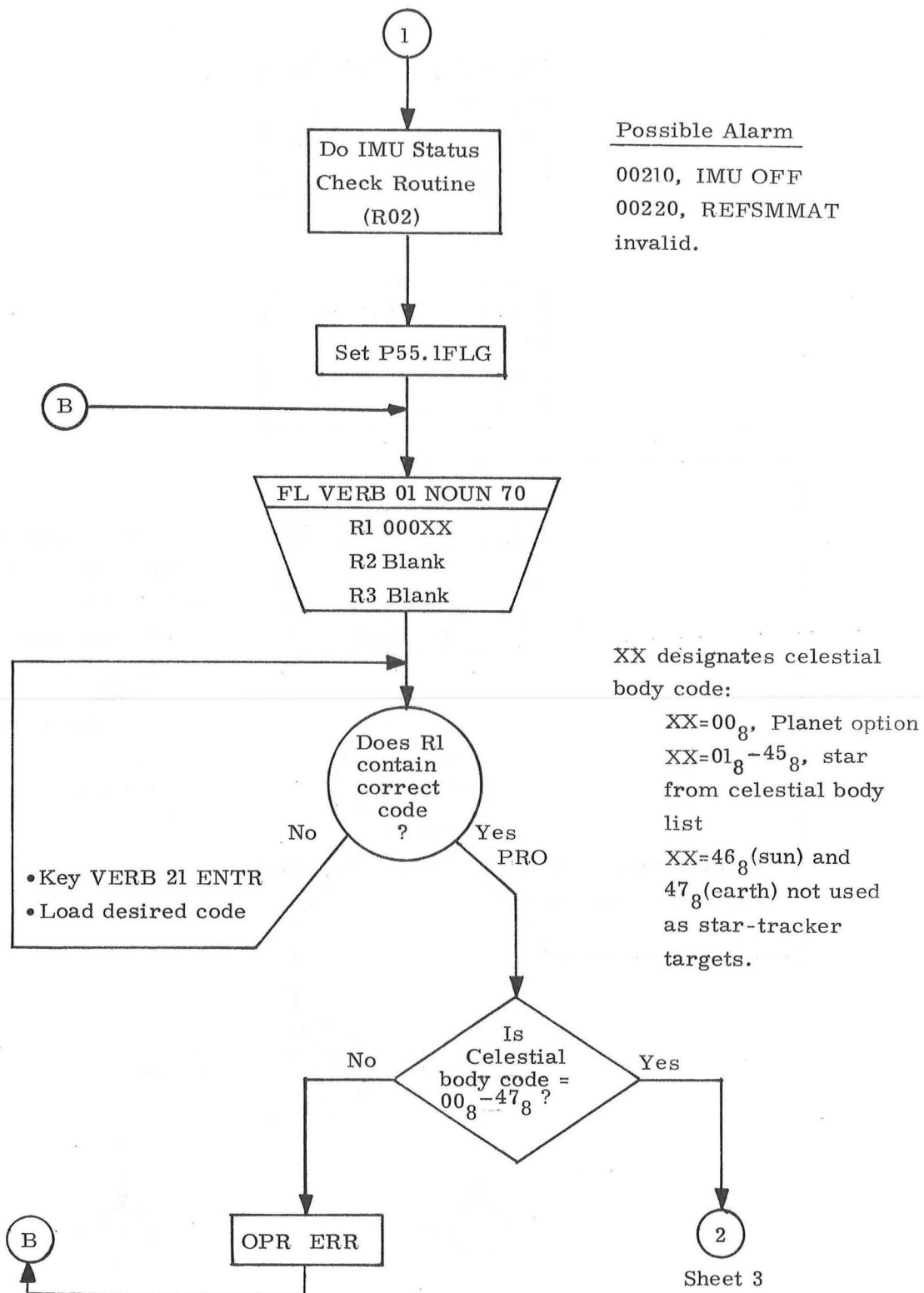
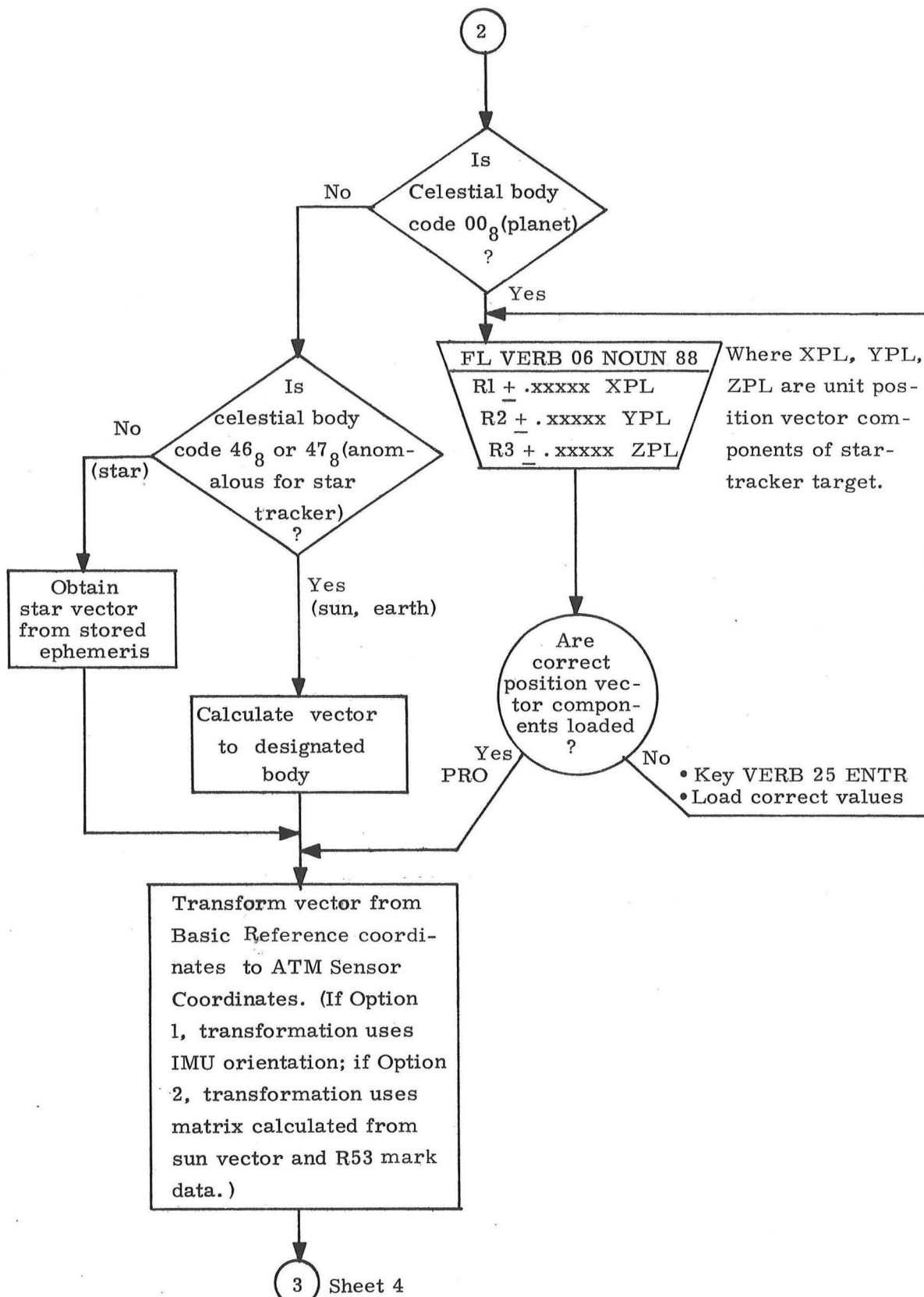


Figure 7.9-6. ATM Star Tracker Gimbal Angle Program (P55)  
(Sheet 2 of 7)



Sheet 4

Figure 7.9-6. ATM Star Tracker Gimbal Angle Program (P55)

(Sheet 3 of 7)

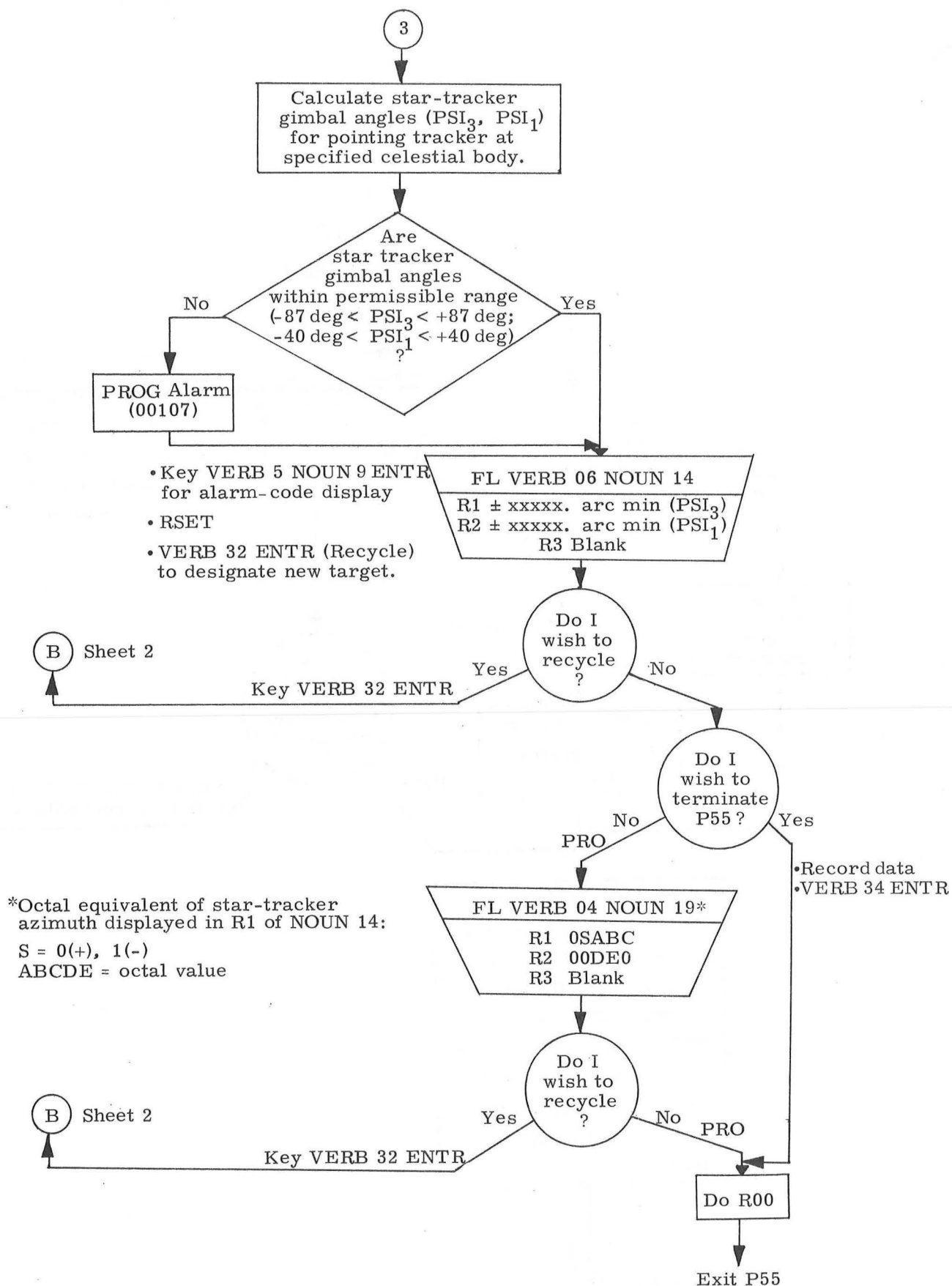


Figure 7.9-6. ATM Star Tracker Gimbal Angle Program (P55)

(Sheet 4 of 7)

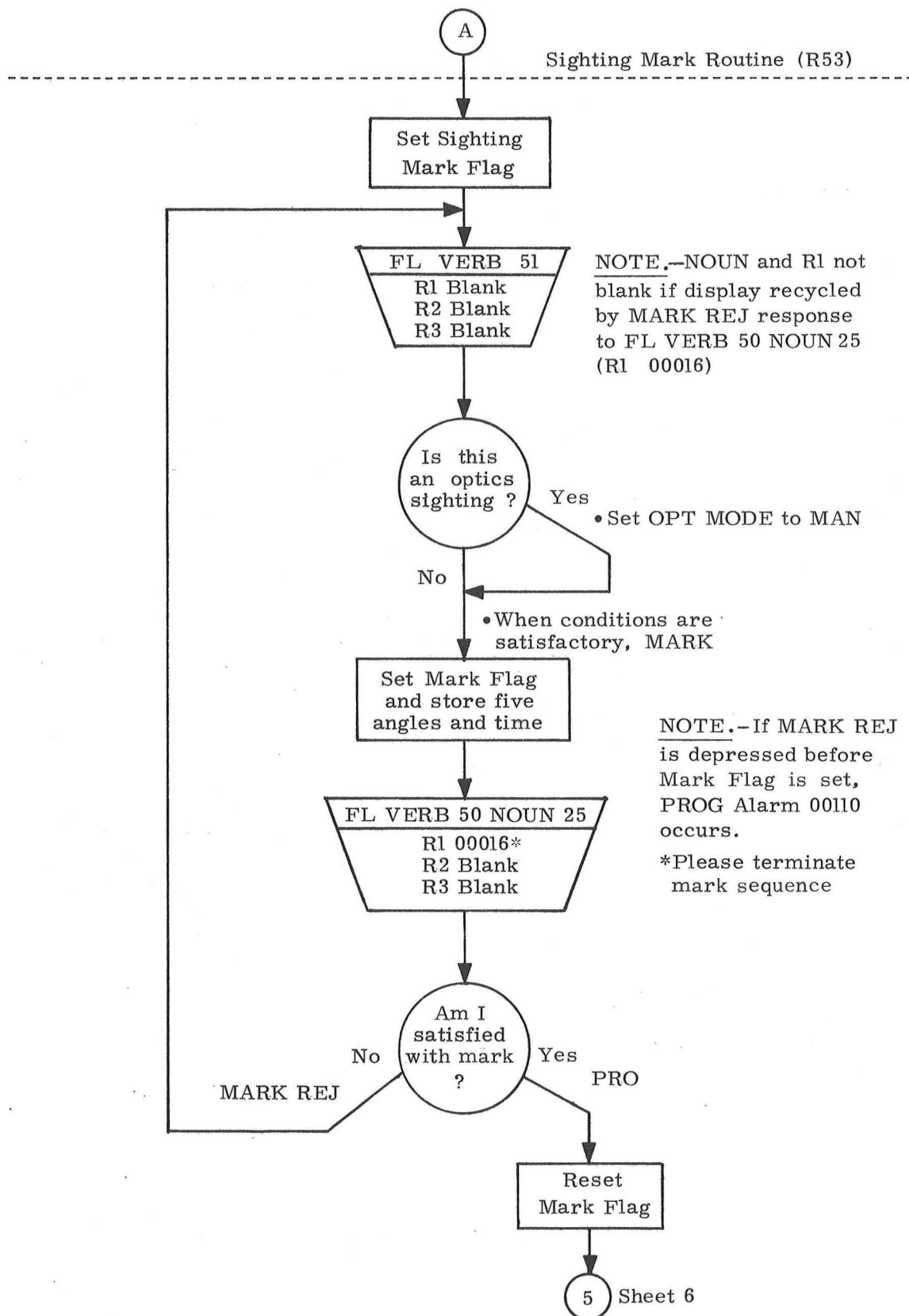


Figure 7.9-6. ATM Star Tracker Gimbal Angle Program (P55)  
(Sheet 5 of 7)

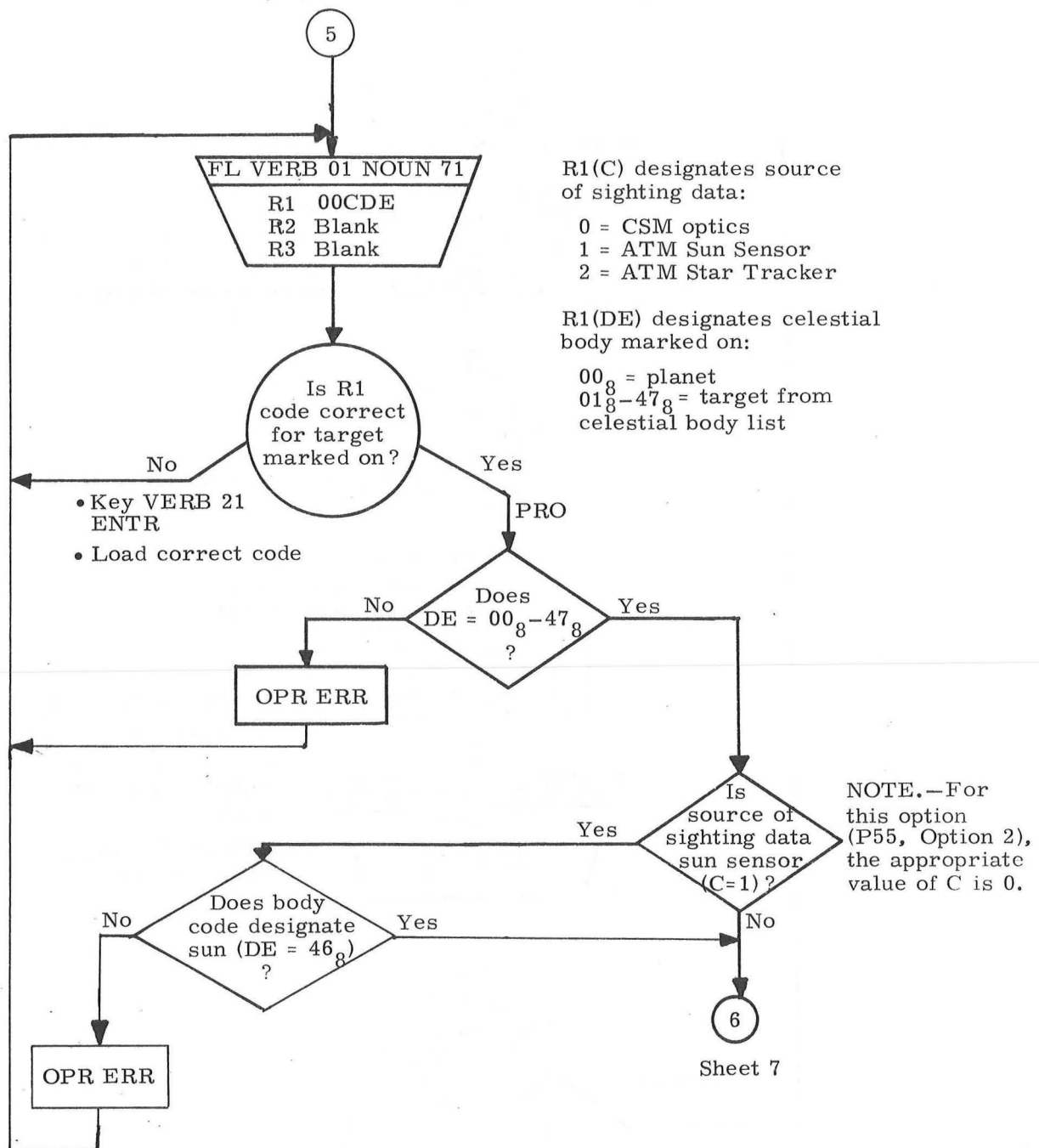


Figure 7.9-6. ATM Star Tracker Gimbal Angle Program (P55)  
(Sheet 6 of 7)



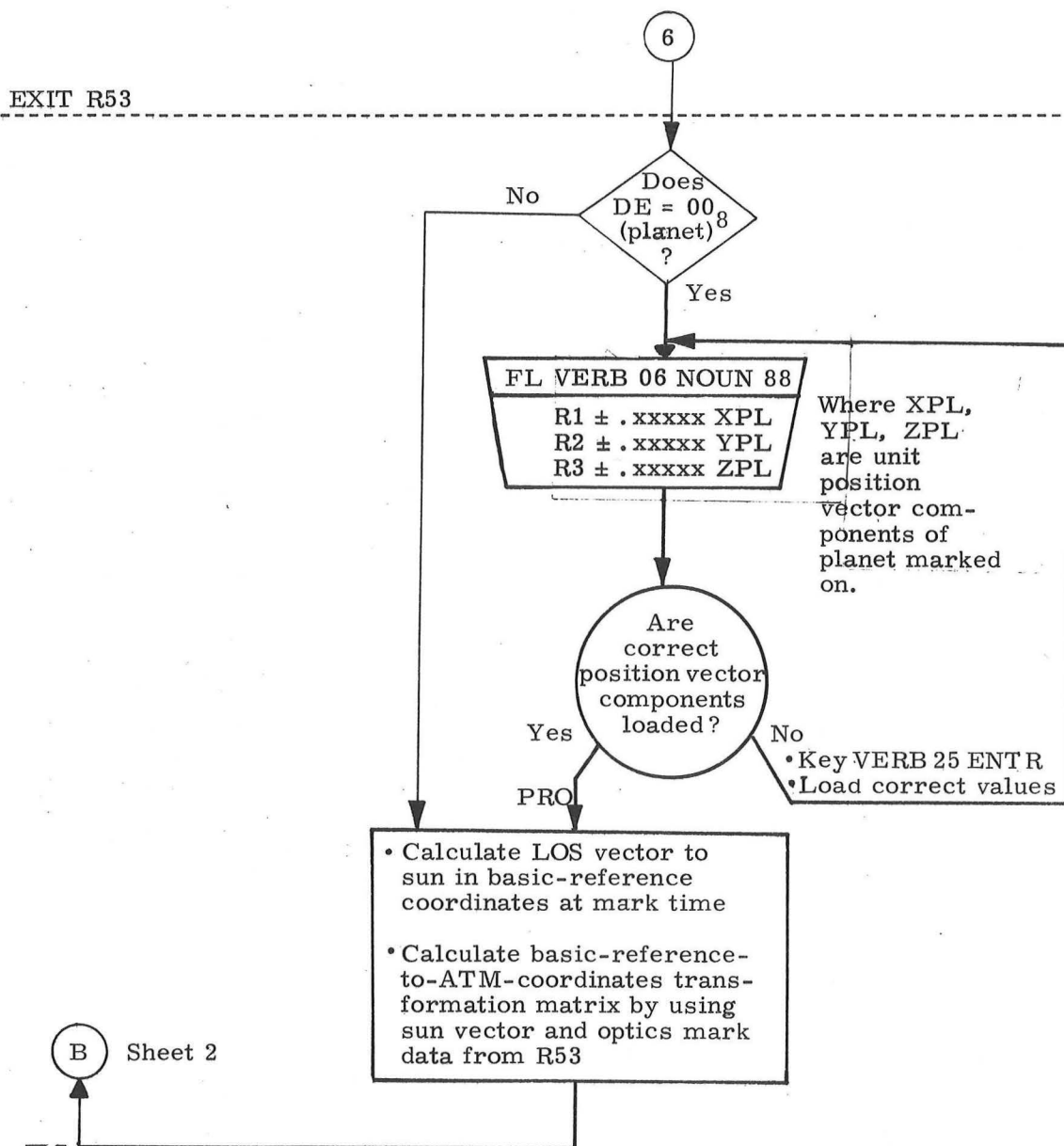


Figure 7.9-6. ATM Star Tracker Gimbal Angle Program (P55)  
(Sheet 7 of 7)

SECTION 9.0

ROUTINES

## 9.1 INTRODUCTION

This section provides a description of routines that are callable by the crew. Each of these routines is initiated by the selection of an Extended Verb.\*

CMC routines are described in subsection 9.2. A general discussion of the Extended Verbs and their operational restrictions is given in subsection 10.1.

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\* Some routines initiated by Extended Verbs are described in other sections of this volume. For each Extended Verb, a reference to the associated routine is provided in Section 10.

### 9.2.1 R03, Digital Autopilot (DAP) Data Load

R03 allows the crew to load and verify CSM-alone 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.

The following types of information, needed by the autopilots, can be loaded via R03.

- 1) Mass of the vehicle
- 2) Pitch and yaw trim for the SPS engine [physically a function of the vehicle center of gravity (c.g.)]
- 3) Configuration of the vehicle (for example, SIVB, CSM alone)
- 4) Quad information (i.e., which quads are enabled, and which are to be used for roll and X-translation)
- 5) Deadband width, maneuver rate.

No one autopilot requires all types of information. Good knowledge of pitch and yaw trim is important during TVC maneuvers in order to point the thrust vector through the vehicle c.g. and thus to eliminate or minimize disturbance torques and start-up attitude transients. Accurate knowledge of vehicle inertias, which are computed within the CMC as a function of vehicle mass and configuration, minimizes fuel expenditure during CSM-alone DAP operation.

Pitch trim, and yaw trim are updated by the TVC DAP during SPS maneuvers. CSM-alone DAP 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, pitch trim, and yaw trim. 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 CSM-alone 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

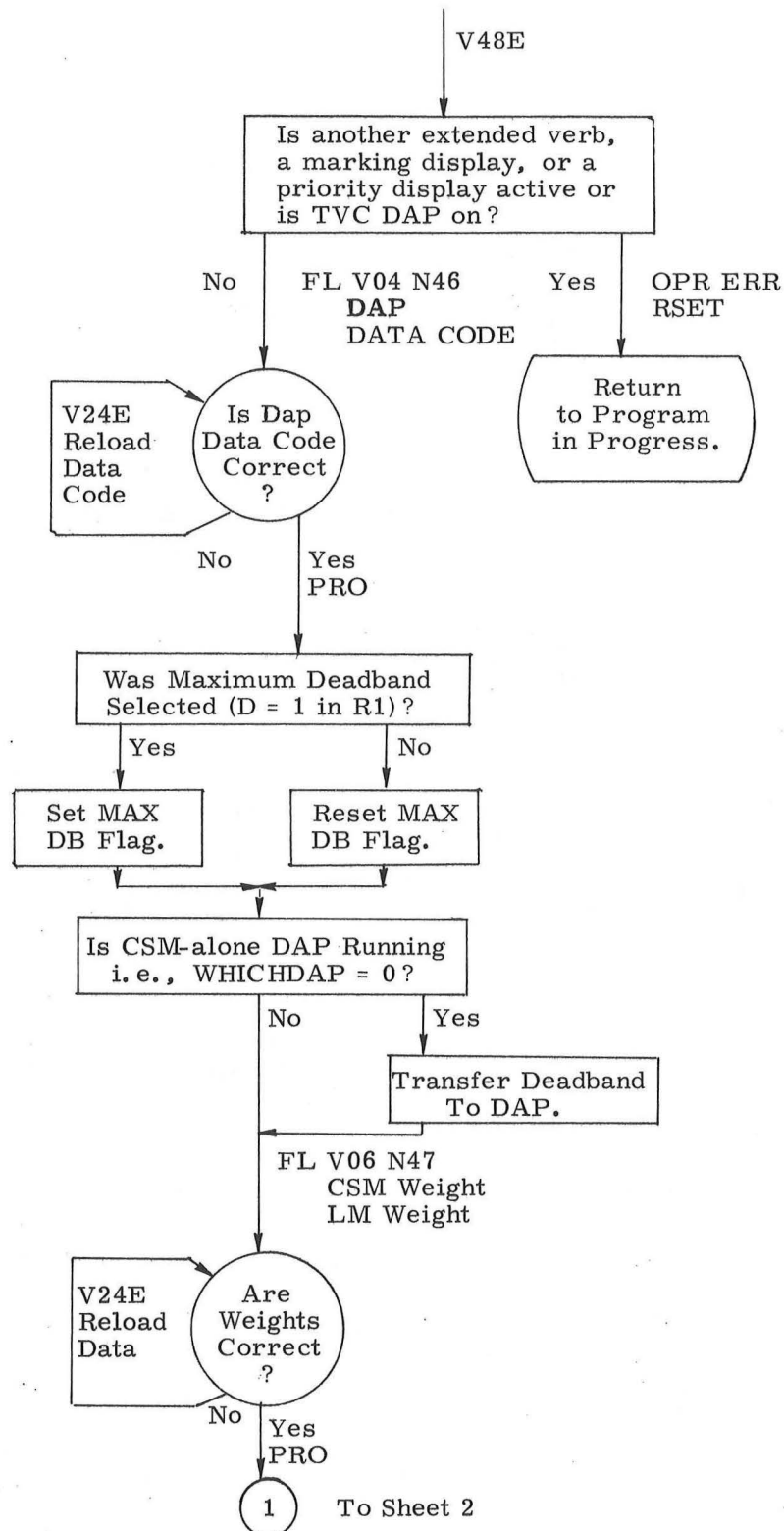


Figure 9.2.1-1. CMC Digital Autopilot (DAP) Data Load Routine (CSM R03)  
(Sheet 1 of 2)

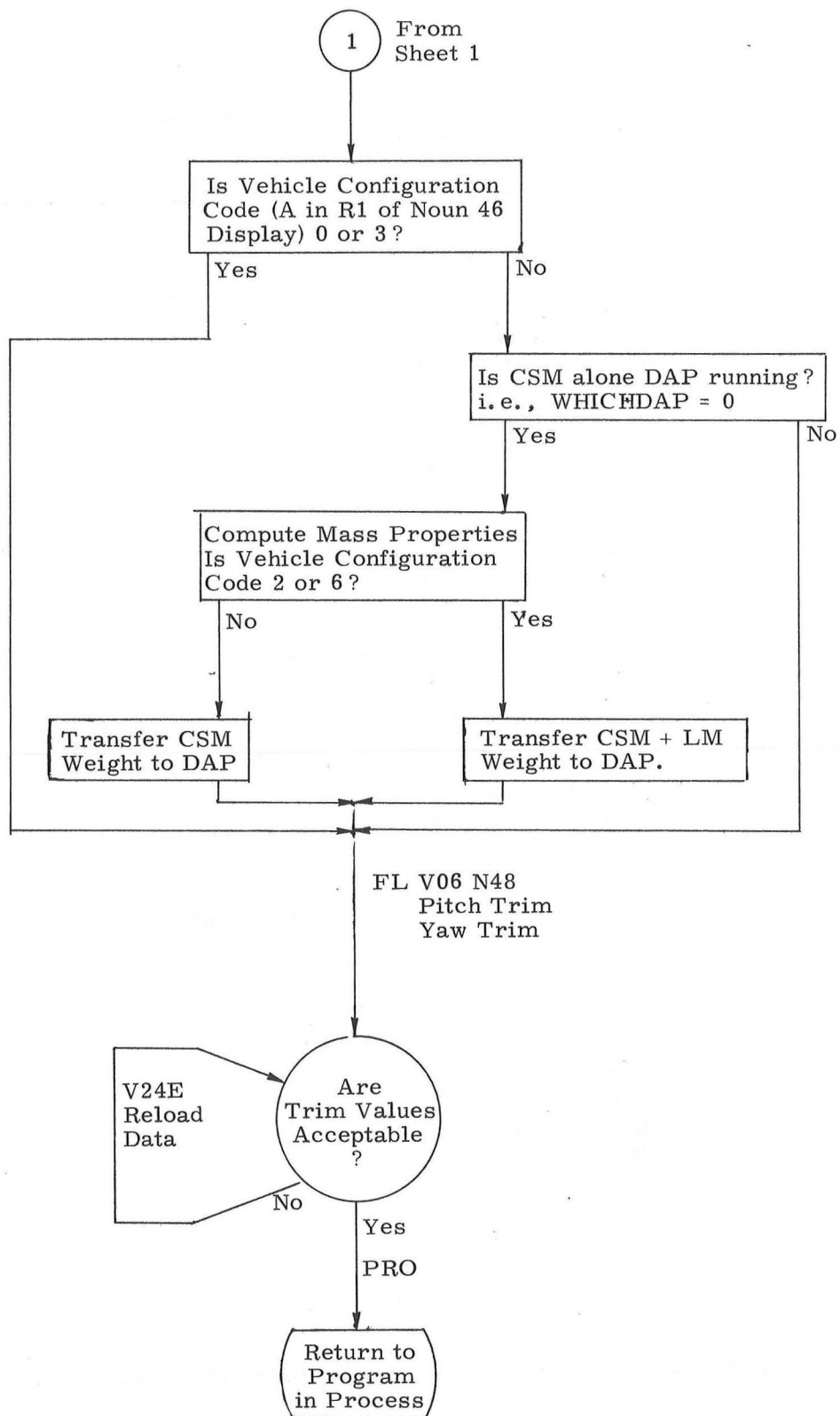


Figure 9.2.1-1. CMC Digital Autopilot (DAP) Data Load Routine (CSM R03)  
(Sheet 2 of 2)

TABLE 9. 2. 1-I  
DAP DATA-LOAD ROUTINE DISPLAYS (CSM R03)  
(SHEET 1 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
FL V04 N46	R03	DAP configuration data	<p>R1 of VERB 04 NOUN 46 must be loaded with the correct code, as follows:</p> <p><u>A</u> Vehicle configuration code  0 = no DAP  1 = CSM  2 = CSM+LM (ascent+descent)  3 = SIVB  6 = CSM+LM (ascent only)</p> <p><u>B</u> Quad AC for +X translation code  0 = do not use quad  1 = use quad</p> <p><u>C</u> Quad BD for +X translation code  0 = do not use quad  1 = use quad</p> <p><u>D</u> Deadband code 0-0.5 deg  1-5.0 deg</p> <p><u>E</u> Maneuver rate code  0-0.05 deg/sec  1-0.2 deg/sec  2-0.5 deg/sec  3-2.0 deg/sec</p> <p><u>NOTE:</u> If both B and C display zero, 4-jet translation will be used.</p>	R1 xxxxx* octal
FL V04 N46	R03	Data code	<p>R2 of VERB 04 NOUN 46 must be loaded with the correct code, as follows:</p> <p><u>A</u> Quad AC or BD roll code  0 = use BD  1 = use AC</p> <p><u>B</u> Quad A Code  0 = do not use quad  1 = use quad</p> <p><u>C</u> Quad B Code  0 = do not use quad  1 = use quad</p>	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

DAP DATA-LOAD ROUTINE DISPLAYS (CSM R03)  
(SHEET 2 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
			<u>D</u> Quad C code 0 = do not use quad 1 = use quad <u>E</u> 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



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 engine trim gimbal angles (physically a function of c.g.) for approval or change. A PRO response to the NOUN 48 display terminates R03.

Changes from one CSM-alone DAP to another are made automatically, at termination of R03. But a transition from Docked DAP or from one of the following configurations (1) Saturn DAP, (2) CSM-alone 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 responses to the VERB 04 NOUN 46 and the VERB 06 NOUN 47 displays are necessary if the loaded data is to be converted into CMC parameters used by the autopilots. Keying a VERB 34 ENTR will not cause the required conversion.

Quads A and C cannot be failed (inhibited) simultaneously. Also quads B and D cannot be failed simultaneously.

#### 9.2.1.4 Restarts

R03 is not restart protected. Should a restart occur, the astronaut must reselect R03.

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\* LM weight is not expected to be used during SKYLAB operations.

### 9.2.2 R64, Optics Angles Transform Routine

VERB 84 ENTR initiates the Optics Angles Transform Routine (R64), which computes and displays the tracking angles that correspond to given sextant shaft and trunnion angles. The computed tracking angles specify the spacecraft axis to be pointed by the tracking program in use when R64 is called.

The crew keys in VERB 64 ENTR, and, if no other extended verb or priority display is running, R64 flashes VERB 06 NOUN 94 requesting sextant shaft and trunnion angles:

#### FL VERB 06 NOUN 94

R1	xxx.xx deg	sextant shaft angle
R2	xx.xxx deg	sextant trunnion angle
R3	Blank	

The crew loads the desired values and then keys PRO. R64 then computes the desired tracking angles,  $\theta$  and flashes VERB 06 NOUN 78:

#### FL VERB 06 NOUN 78

R1	xxx.xx deg	$\theta$
R2	xxx.xx deg	$\rho$
R3	xxx.xx deg	o

If P20 is active, these angles will be used for tracking. The crew can load different values into Noun 78 if the tracking angles are not acceptable. He then keys PRO to terminate R64.

### 9.2.3 R30, Orbital-parameters Display

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.

TABLE 9.2.3-1  
 ORBITAL-PARAMETERS DISPLAY ROUTINE  
 (CSM 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 OWS is to be assumed vehicle.	Request astronaut to indicate assumed vehicle	R1 00002 R2 0000x
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 00xxx. hrs R2 000xx. min R3 0xx.xx sec

\*No astronaut inputs are required when AVERAGEG is running.

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—OWS 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, 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

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\*

The orbital interface is 300,000 feet above launch pad radius.

TABLE 9.2.3-II  
ORBITAL-PARAMETERS DISPLAY ROUTINE  
(CSM R30) OUTPUTS

DSKY	Initiated By	Purpose	Condition	Register
FL V16 N44	R30	These apsidal altitudes measured above launch pad radius  Once computed, counts down Sign convention is in text.	Apogee altitude Perigee altitude  Time to inter- (free fall)	R1 xxxx. x n. mi. R2 xxxx. x n. mi. Maximum number (9999.9) if scaling is exceeded.  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 oxxxx. 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

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 or priority display 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 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

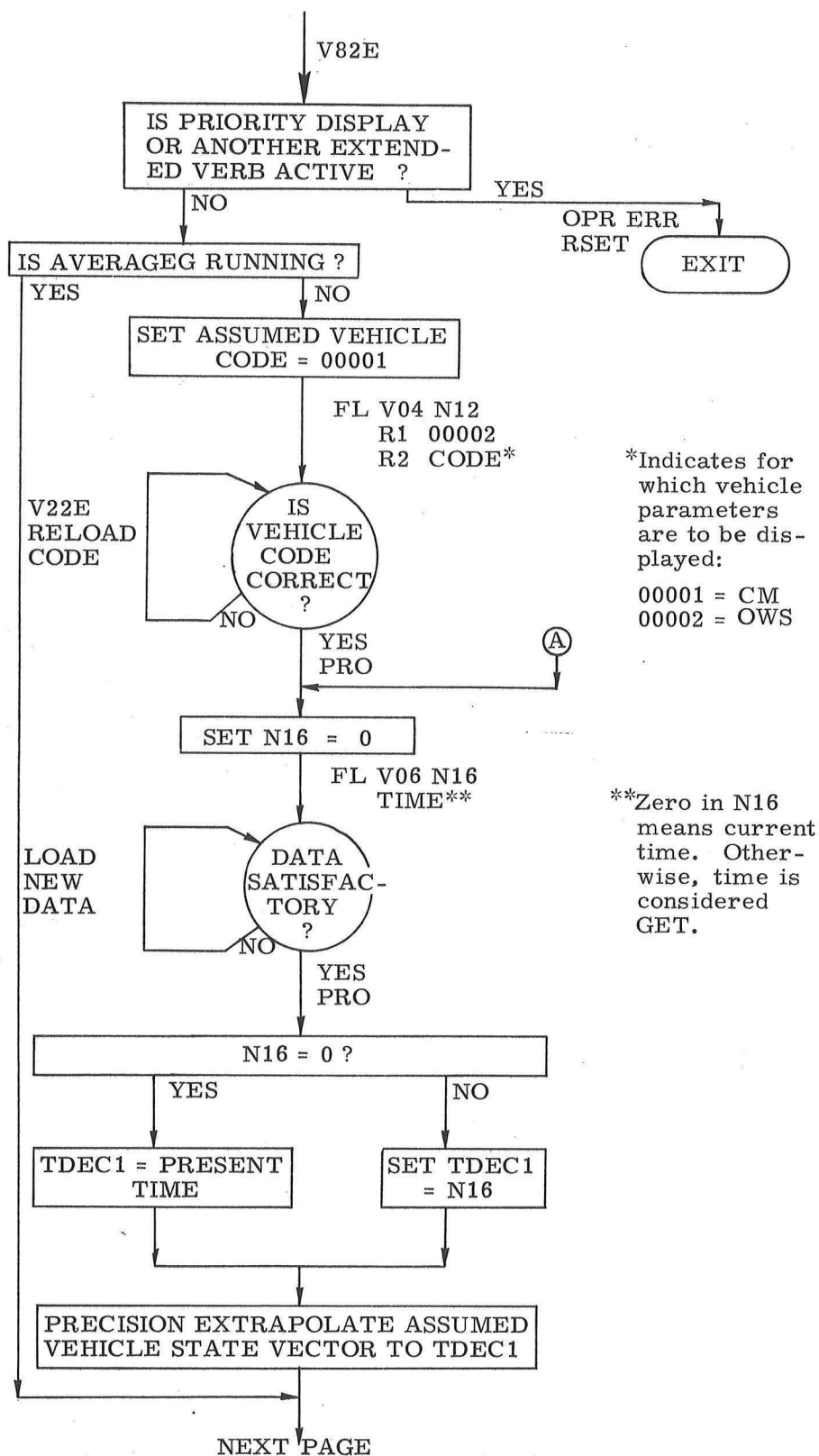


Figure 9.2.3-1. Orbital-parameters Display Routine (CSM R30) (Sheet 1 of 2)

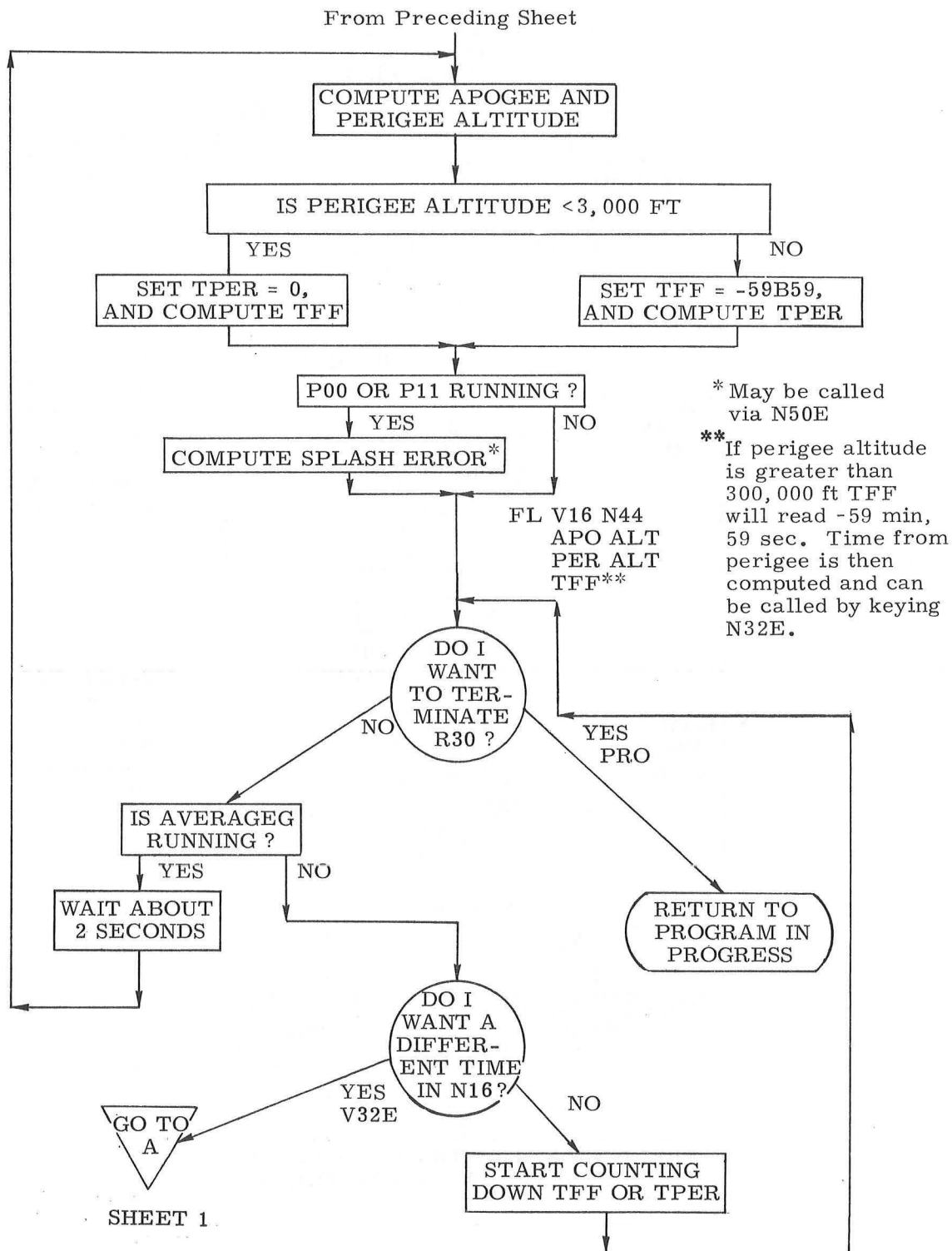


Figure 9.2.3-1. Orbital-parameters Display Routine (CSM R30) (Sheet 2 of 2)



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 and TPER is as follows: the DSKY display is negative and decreasing (in magnitude) as the interface altitude approaches.\* Between the interface altitude and perigee altitude, the display is positive and increasing. When perigee is passed, R30 continues to display positive increasing time, except during AVERAGEG, when negative, decreasing time is displayed for ellipses. If AVERAGEG is off, keying VERB 32 ENTR to repeat R30 calculations also causes negative decreasing time to be displayed for ellipses.

#### 9.2.3.5 Procedures

When AVERAGEG is running, the astronaut keys in VERB 82 ENTR, and, if no other extended verb or priority display is running, R30 begins its computations and flashes VERB 16 NOUN 44. If P11 is running, the astronaut keys in NOUN 50 ENTR to

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\*The maximum display for TFF 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.

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 OWS 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. 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.), the astronaut keys in NOUN 32 ENTR, 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.

#### 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 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.

#### 9.2.3.8 Restarts

R30 is not restart-protected. Should a restart occur, the astronaut must reselect the routine.

#### 9.2.4 R31, Rendezvous Parameter Display No. 1 Routine

VERB 83 ENTR initiates R31, which computes and displays the range and range rate between the CSM and the OWS, and an angle  $\theta$ , shown in Figure 9.2.4-1. The angle  $\theta$  represents the angle between the CSM X-body axis and the local horizontal plane, referenced to the direction of flight. The computational sequence is illustrated in Figure 9.2.4-2.

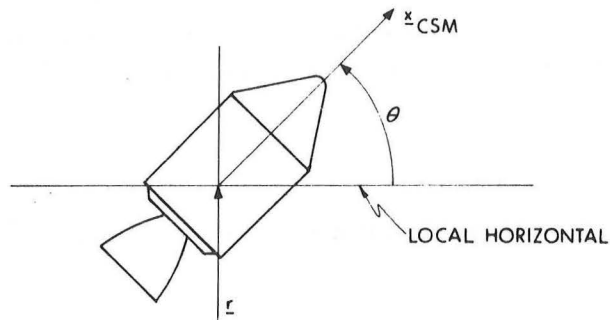


Figure 9.2.4-1 Definition of Theta

##### 9.2.4.1 Input and Output

There is no astronaut input required for R31. The only output is a display of range, range rate and  $\theta$ .

FL VERB 16 NOUN 54

R1	xxx.xx n. mi.	Range
R2	±xxxx.x ft/sec	Range rate
R3	xxx.xx deg	$\theta$

##### 9.2.4.2 Procedures

The crew keys in VERB 83 ENTR, and, if no other extended verb or priority display is running, R31 begins its computations and flashes VERB 16 NOUN 54. R31 then repeats the computations until the crew keys PRO or VERB 34 ENTR to terminate R31.

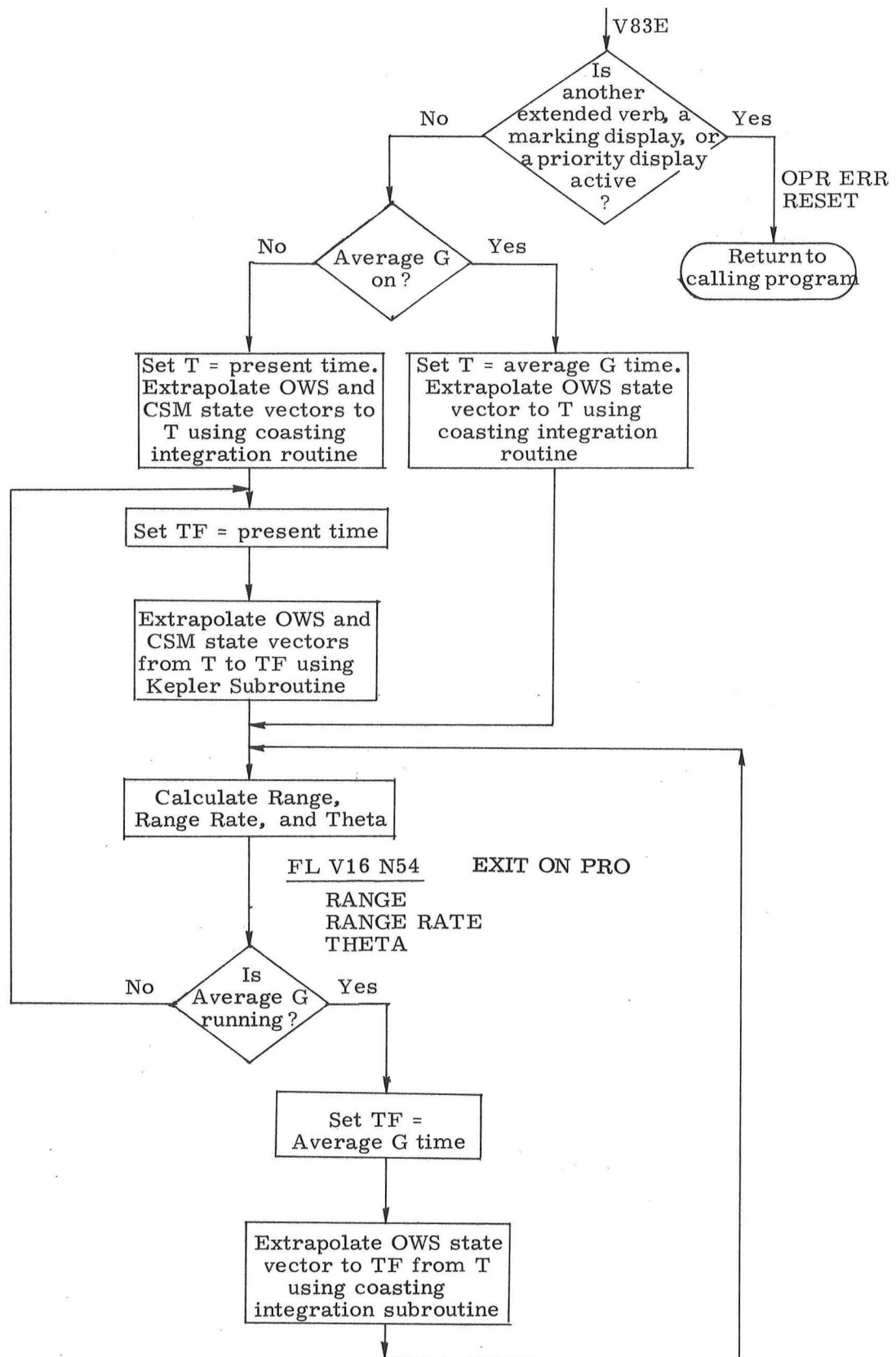


Figure 9.2.4-2. Rendezvous Parameter Display (R31) Routine No. 1

### 9.2.5 R34, Rendezvous Parameter Display Routine No. 2

VERB 85 ENTR initiates R34, which computes and displays the range and range rate between the CSM and the OWS, and an angle  $\phi$  shown in Figure 9.2.5-1. The angle  $\phi$  represents the angle between the SXT line of sight and the local horizontal plane, referenced to the direction of flight. The computational sequence is illustrated in Figure 9.2.5-2.

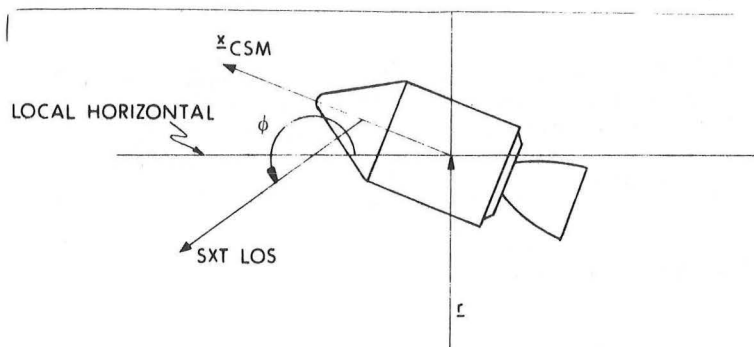


Figure 9.2.5-1 Definition of Phi

#### 9.2.5.1 Input and Output

There is no astronaut input required for R34. The only output is a display of range, range rate and  $\phi$ .

#### FL VERB 16 NOUN 53

R1	xxx.xx n.mi.	Range
R2	±xxxx.x ft/sec	Range-rate
R3	xxx.xx deg	$\phi$

#### 9.2.5.2 Procedures

The crew keys in VERB 85 ENTR, and, if no other extended verb or priority display is running, R34 begins its computations and flashes VERB 16 NOUN 53. R34 then repeats the computations until the crew keys PRO or VERB 34 ENTR to terminate R34.

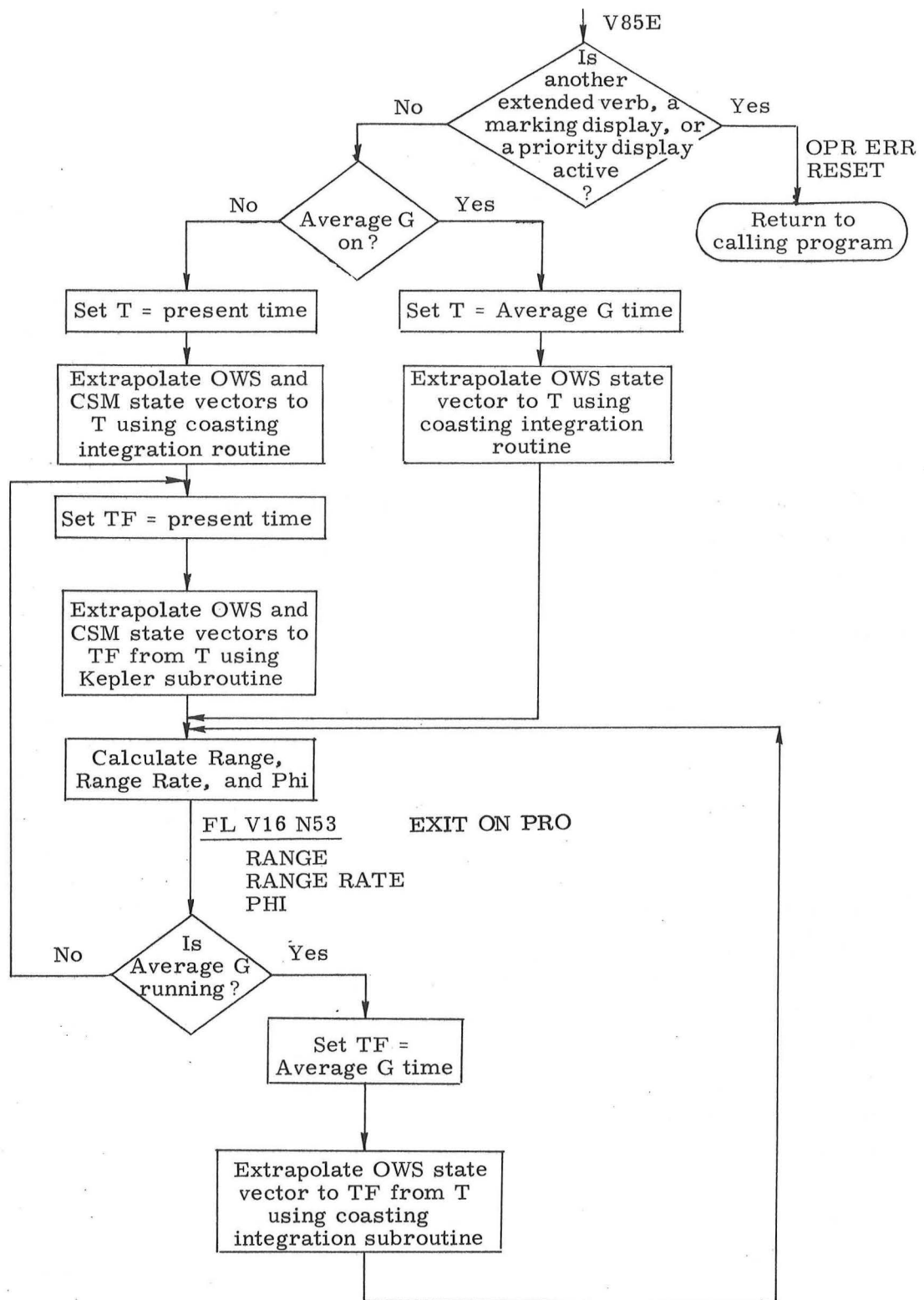


Figure 9.2.5-2. Rendezvous Parameter Display Routine No. 2 (R34)

#### 9.2.6 R36, Rendezvous Out-of-plane Display

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. P35—targets transfer phase initiation (TPI) maneuvers.
- c. P36—targets transfer phase midcourse (TPM) maneuvers.

The routine calculates the parameters on the basis of the stored OWS and CSM state vectors, and 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. Out-of-plane position of the CSM relative to the OWS orbital plane Y(CM).
2. Out-of-plane velocity of the CSM relative to the OWS orbital-plane Y-dot (CM).
3. Out-of-plane velocity of the OWS relative to the CSM orbital plane Y-dot (OWS).

For the astronaut, the most significant of these displays is Y-dot (CM), the CSM out-of-plane velocity, because it allows him to target for a coplanar orbit. Each of the targeting programs listed above displays the  $\Delta y(LV)$  for the astronaut's approval or modification. The astronaut then loads the negative of the Y-dot into the Y component (register 2) of the  $\Delta y(LV)$  display. This value is designed to produce a node 90 deg later. If the out-of-plane velocity (Y-dot) of the assumed vehicle is nulled at a particular point by thrusting an equal  $\Delta v$  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.)

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\*In general, it is desirable to carry out a rendezvous under circumstances in which the OWS and the CSM orbits are coplanar.



#### 9.2.6.1 Input and Output

As mentioned above, R36 calculates the parameters displayed using one astronaut input, the time at which the calculations are to be valid. If the astronaut desires the present time, as he might during P36, he can indicate the present time by supplying all zeros for the time.

The outputs of R36 are displayed via flashing VERB 06 NOUN 96. Inputs and outputs to R36 are listed in Tables 9.2.6-I and 9.2.6-II, respectively. Note that, since the desire is to null out the Y, the crew must change the sign when loading Y-dot into R2 of the  $\Delta v$ (LV) targeting display. Figure 9.2.6-1 presents a flowchart of R36.

#### 9.2.6.2 Computational Sequence

When the astronaut keys in R36, via VERB 90 ENTR, the CMC first checks to determine if any other extended verb or priority display 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 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  $\Delta v$ , 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.

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 96 display. If the astronaut responds to the flashing VERB 06 NOUN 96 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 96 with a PRO, the routine terminates.

#### 9.2.6.3 Restrictions and Limitations

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.

TABLE 9.2.6-I

RENDEZVOUS OUT-OF-PLANE DISPLAY ROUTINE  
(CSM R36) INPUTS

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	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 desires the present time, in which case, he should load all zeros.

TABLE 9.2.6-II

## RENDEZVOUS OUT-OF-PLANE DISPLAY ROUTINE (CSM R36) OUTPUTS

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Distance CSM is from plane of OWS at T(EVENT)	Y (CM)	FL V06 N96	R1 xxx.xx n. mi.	
2.	Out-of-plane velocity of the CSM relative to the OWS orbital plane	$\dot{Y}$ (CM)	FL V06 N96	R2 xxxx.x fps	
3.	Out-of-plane velocity of the OWS relative to the CSM orbital plane	$\dot{Y}$ (OWS)	FL V06 N96	R3 xxxx.x fps	

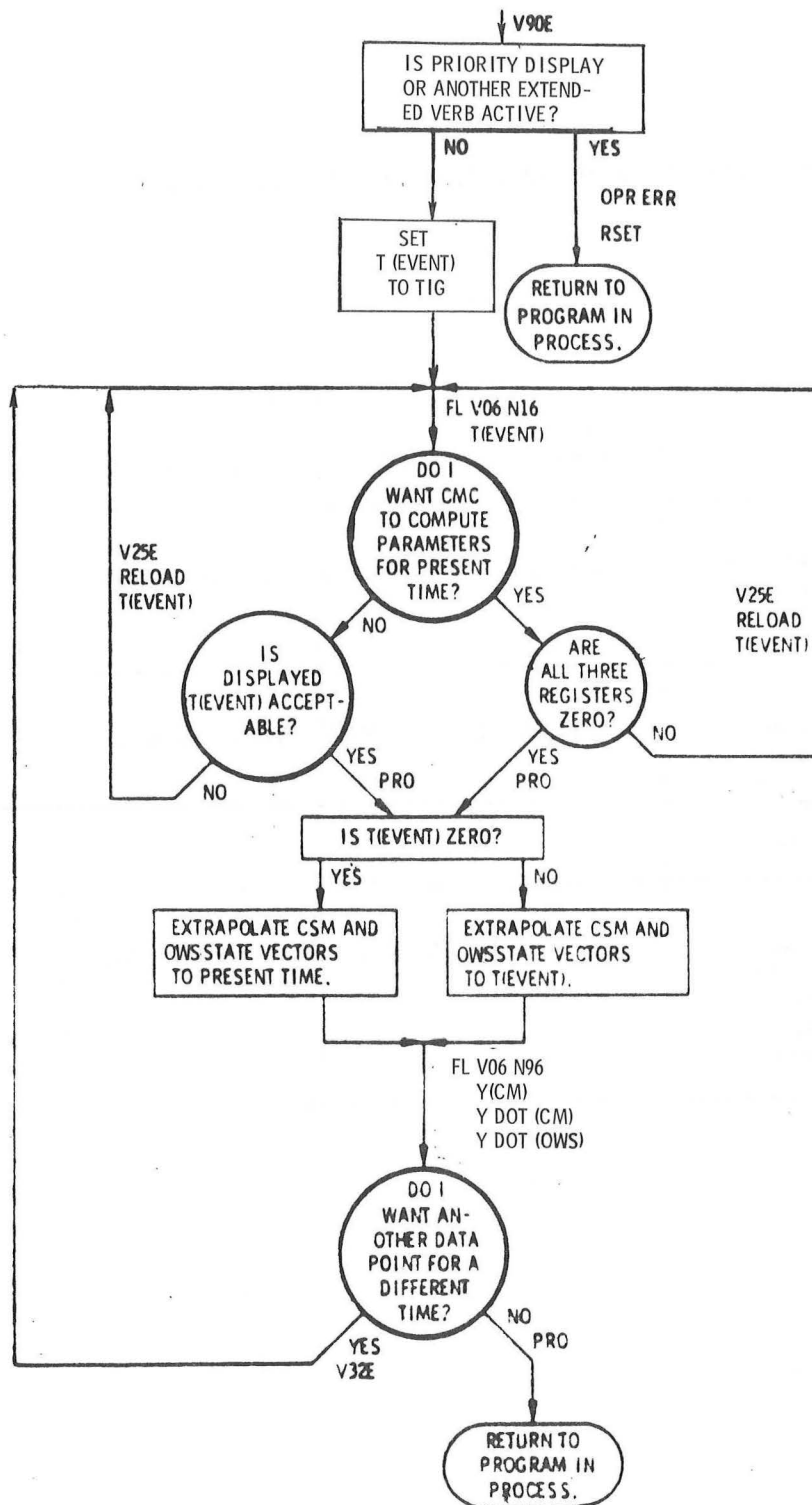


Figure 9.2.6-1. Rendezvous Out-of-plane Display Routine (CSM R36)

#### 9.2.6.4 Restarts

R36 is not restart protected. Should a restart occur while R36 is operating, R36 must be reselected.

#### 9.2.6.5 Coordination

R36 may be run at any time (with the restrictions given above). The ISS need not be running or aligned for R36.

SECTION 10.0

ADDITIONAL EXTENDED VERBS

## 10.1 INTRODUCTION

Extended Verbs (those verbs numbered 40 through 99) are provided as a means of enabling the crew to select by DSKY entry a number of special routines, functions, and displays. The crew selects the extended verb by keying VERB xx ENTR.\* The purpose of each of the extended verbs is given in the paragraph describing that verb.

Subsection 10.2 contains the extended verb descriptions for the CMC. The following extended verbs are unused and, if selected by the crew, cause the OPR ERR DSKY light to be illuminated:

. Verbs 52, 68, 79, 84, 92, 94, 95 and 98.

These verbs are omitted in subsection 10.2.

Also omitted are those verbs which, although numbered between 40 and 99, are used only for program-generated displays and should not be selected by the crew. They are as follows:

. Verbs 50, 51, 53, 97 and 99.

Extended verbs which initiate DSKY displays are prevented from conflicting with each other by means of an extended verb interlock. When this interlock is set, other extended verbs which use the DSKY are locked out. Each of these verbs sets the interlock when activated and resets it before exiting. The interlock is also set during priority displays and "PLEASE MARK" displays for optics and COAS marking routines to prevent display conflicts between the marking or priority displays and extended verb displays.\*\*

The extended verb interlock has another function. Should a situation arise that would cause a POODOO abort to occur while the interlock is set, a BAILOUT restart

\* VERB 41 requires either NOUN 20 or NOUN 91 to distinguish between the IMU and the Optics System.

\*\* All references in subsection 10.2 to interlock due to extended verbs are meant to include the lockout by marking or priority displays as well.



rather than a POODOO abort is performed by the program.\* This has the effect of terminating the extended verb and restarting the current major mode, thus ensuring that the main mission program is not aborted due to an alarm condition generated by an extended verb.

Since the selection of an extended verb by the crew causes at least one additional job to be scheduled by the Executive, BAILOUT restarts due to executive overflow (alarm codes 31201 or 31202) may occur when extended verbs are selected during periods of high computer activity. These restarts terminate the extended verb. Reselection of the extended verb may be possible without causing another restart, since the executive overflow condition is usually correctable by a change in job-request timing.

Displays initiated by extended verbs take precedence over non-priority displays initiated by a major mode. Therefore, when important non-priority major mode displays are expected, it is unwise to select extended verbs which initiate displays. Priority displays (such as FL VERB 06 NOUN 49 in P20) take precedence over extended verb displays and will replace them on the DSKY. When the priority display is answered, the extended verb display will return to the DSKY.

None of the extended verb routines or functions is restart protected.\*\* Should a restart occur during its execution, the extended verb procedure must be repeated.

## 10.2 CSM EXTENDED VERBS

### 10.2.1 Verb 40

Extended Verb 40 zeroes the Inertial Measurement Unit (IMU) CDUs. The process can be selected by the crew if the Inertial Subsystem (ISS) is not in the coarse align mode and gimbal lock. Refer to paragraph 7.2.2.7, Table 7.2.2-II, and Figure 7.2.2-13 for details.

\* The software generates POODOO aborts when non-recoverable errors are encountered; e.g., an attempt to take the square root of a negative number, or to integrate a sub-surface state vector.

\*\* An exception is P27, initiated by Verb 70-Verb 73. (See paragraph 4.2.3.6.)



#### 10.2.2 Verb 41 Noun 20

Extended Verb 41 (Noun 20) coarse aligns the Inertial Measurement Unit (IMU). If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 7.2.2.7, Table 7.2.2-II, and Figure 7.2.2-10 for details.

#### 10.2.3 Verb 41 Noun 91

Extended Verb 41 (Noun 91) coarse aligns the Optics Subsystem (OSS). Unless a fresh start situation exists (blank major mode) or P00 is operating, the process will not be initiated and the OPR ERR DSKY light will be illuminated. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. If the Optics mode switch is not CMC, the PROG light (alarm code 00115) and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 7.2.2.7, Table 7.2.2-II, Figure 2.2.1-8, and Figure 7.2.2-11 for details.

#### 10.2.4 Verb 42

Extended Verb 42 fine aligns the Inertial Measurement Unit (IMU) by torquing the gyros. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. This process is primarily intended for ground testing. Refer to paragraph 7.2.2.7, Table 7.2.2-II and Figure 7.2.2-12 for details.

#### 10.2.5 Verb 43

Extended Verb 43 enables the astronaut to specify angles for the FDAI error needles. If a fresh start situation does not exist (major mode not blank), and if P00 is not operating, or if the IMU is not in the fine align mode, the process will not be initiated

and the OPR ERR DSKY light will be illuminated. After liftoff,\* if the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated; before liftoff, other extended verbs will be overridden by selection of this process. After liftoff,\* the extended verb interlock is set by this process. Refer to paragraph 2.2.1.4.3.2 and Figure 2.2.1-6 for a description of the procedure.

#### 10.2.6. Verb 44

Extended Verb 44 calls R04, the Docked DAP Data Load Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Verb 44 will have no effect on the operation of undocked DAPs. Refer to subsection 11.3 for a description of R04.

#### 10.2.7 Verb 45

Extended Verb 45 is executed to establish autopilot control of the docked spacecraft-OWS complex using the Docked DAP. If P40 is operating, this process will not be initiated and the OPR ERR DSKY light will be illuminated. Otherwise the Docked DAP will begin initialization and will become fully operational within 1.7 seconds. Verb 44 should have been performed previous to initiation of this process.

#### 10.2.8 Verb 46

Extended Verb 46 is executed to establish autopilot control of the spacecraft (Verb 48 (R03) should previously have been completed). If the TVC DAP is not operational and the configuration digit (from R03, digit A of R1 of Noun 46) is 1 (CSM only), 2 (CSM-LM, i.e., CSM docked with a complete LM, ascent and descent stages), or 6 (CSM-LM, i.e., CSM docked with LM, ascent stage only) the CSM-alone RCS DAP will begin initialization.\*\* This will occur even if the CSM-alone RCS DAP is already running. If the IMU is on and useable, the CSM-alone RCS DAP is fully operational within 1.7 seconds. If the TVC DAP is on and the vehicle configuration

\* Liftoff is indicated by channel discrete or backup liftoff flagbit. (See Verb 75, paragraph 10.2.32)

\*\* Configurations 2 and 6 are not expected to be used during SKYLAB operations.

is not CSM-LM, then the OPR ERR DSKY light will be illuminated. If the TVC DAP is on and the vehicle configuration is CSM-LM, then the stability filter, primarily for slosh frequency oscillations, is changed from high band-width to low band-width. If the TVC DAP is not on and the vehicle configuration is 0 (no DAP), the present DAP is turned off. If the TVC DAP is not on and the vehicle configuration is 3, the Saturn DAP is enabled. The Saturn DAP allows rotational hand controller (RHC) commands to be available to the SIV-B autopilot and steering jets for manual rate control.

During TVC operation, execution of Verb 46 does not affect the CSM-alone RCS DAP since it is not operational. During Entry, execution of Verb 46 will have no effect since the Entry DAP sets the vehicle configuration to 0.

#### 10.2.9 Verb 47

Extended Verb 47 is used to transfer the OWS state vector information to the CSM state vector registers. Verb 47 is callable any time; but when AVERAGEG integration is operational, i.e., during a powered flight program, Verb 47 should not be selected, since there is danger of destroying the CSM state vector. See also Verb 66 (paragraph 10.2.24).

If integration is in process, when Verb 47 is initiated, the Verb 47 process is delayed until integration is completed. If integration is not in process, the OWS state vector (position, velocity, time) is transferred to the CSM state vector registers.

#### 10.2.10 Verb 48

Extended Verb 48 calls R03, CSM-alone DAP Data Load Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. If Verb 48 is selected while the TVC DAP is on, the OPR ERR DSKY light will be illuminated. Verb 48 will have no effect on Docked DAP operation. Refer to paragraph 9.2.1 and Figure 9.2.1-1 for a description of R03.

#### 10.2.11 Verb 49

Extended Verb 49 calls R62, the Crew-Defined Maneuver Routine. Unless a fresh start situation exists (blank major mode) or P00 is operating, the process will not be initiated and the OPR ERR DSKY light will be illuminated. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 2.2.1.4.1 and Figure 2.2.1-2 for a description of R62.

#### 10.2.12 Verb 54

Extended Verb 54 calls R23, the Rendezvous Backup Sighting Mark Routine. The process enables sighting marks in conjunction with options 0 or 4 of the Universal Tracking Program (P20) using the backup device, COAS. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Selection of Verb 54 at any time except during options 0 or 4 of P20 will result in a PROG alarm (code 00406). Refer to paragraph 4.2.1.2.2, Table 4.2.1-III.

#### 10.2.13 Verb 55

Extended Verb 55 is used to initiate the process of changing the CMC clock time (GET) using decimal increments (or decrements) loaded by the astronaut. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process.

#### Procedures

1. Key VERB 55 ENTR.
2. Observe DSKY display of request to load clock increment (decrement)

#### FL VERB 21 NOUN 24

R1	±00xxx.	Hours
R2	±000xx.	Minutes
R3	±0xx.xx	Seconds

NOTE.—R1, R2, and R3 will initially be blank.

- . Load desired time increment (decrement). Go to Step 3.
- . Terminate via VERB 34 ENTR or VERB 33 ENTR if it is not desired to increment the CMC clock time.

3. Exit Verb 55

NOTE.—If desired time increment loaded, CMC clock time (GET) can be monitored via:

VERB 16 NOUN 65

R1	±00xxx.	Hours
R2	±000xx.	Minutes
R3	±0xx.xx	Seconds

10.2.14 Verb 56

Extended Verb 56 terminates P20, the Universal Tracking Program. It will also terminate MINKEY. It will not terminate other programs running in conjunction with P20. If P20 is running, a software restart will occur. If P20 is the only program running, R00 will be selected. Verb 56 has no effect if P20 is not enabled. Refer also to paragraph 4.2.1 and Table 4.2.1-III.

10.2.15 Verb 57

Extended Verb 57 displays the status of the tracking (SXT only, VHF only, or both), and allows the change of that status by DSKY entry. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer also to paragraph 4.2.1.2, and Table 4.2.1-III.

### Procedure

1. Key VERB 57 ENTR
2. Observe flashing display of option code for full or partial tracking:

FL VERB 04 NOUN 12

R1 00004  
R2 0000x  
R3 blank

NOTE.—R2 is the current status of FULTKFLG:  
Option code values are:

<u>VALUE</u>	<u>MEANING</u>
--------------	----------------

00000	FULL TRACKING (SXT AND VHF)
00001	PARTIAL TRACKING (SXT only or VHF only)

3. To change status, key VERB 22 ENTR and load desired option code.
4. Key PRO.
5. Exit Verb 57.

NOTE.—If step 3 is interrupted by a priority display or a restart, step 3 (and if necessary, steps 1 and 2) should be repeated to ensure that the desired flag setting is obtained.

#### 10.2.16 Verb 58

Extended Verb 58 resets the STIKFLAG and sets V50N18FL to enable an automatic maneuver (R60) in options 0, 1, 4 and 5 of P20, Universal Tracking Program. For further description of the process refer to paragraph 4.2.1.2.2.2 and Table 4.2.1-III.

#### 10.2.17 Verb 59

Extended Verb 59 is used during Docked DAP operation to reenable all jets disabled during R04. Refer to subsection 11.7 for details.

#### 10.2.18 Verb 60

Extended Verb 60 is used to set the registers associated with Noun 17 equal to the registers associated with Noun 20. Noun 17 registers are those which display the astronaut total attitude while Noun 20 provides the present attitude. Refer to Table 4.2.1-III. See also Verb 63 (paragraph 10.2.21).

#### 10.2.19 Verb 61

Extended Verb 61 initiates the display of the Mode 1 (DAP attitude) error on the FDAI error needles. Refer to Table 4.2.1-III for details.

#### 10.2.20 Verb 62

Extended Verb 62 initiates the display of the Mode 2 (total attitude) error (the difference between Noun 22 and Noun 20) on the FDAI error needles. Refer to Table 4.2.1-III for details.

#### 10.2.21 VERB 63

Extended Verb 63 initiates the display of the Mode 3 (total astronaut attitude) error (the difference between Noun 17 and Noun 20) on the FDAI error needles. Refer to Table 4.2.1-III for details.

#### 10.2.22 Verb 64

Extended Verb 64 initiates R64, the Optics Angles Transform Routine. Refer to paragraph 9.2.2 for a description of R64.

#### 10.2.23 Verb 65

Extended Verb 65 is used during P02 to select P03. Selection of Verb 65 at any time except during P02 will result in the illumination of the OPR ERR DSKY light. Refer to paragraph 2.2.4 for a description of P03.

#### 10.2.24 Verb 66

Extended Verb 66 transfers the CSM state vector information to the OWS state vector registers. During AVERAGEG, Verb 66 should not be selected, since the pre-burn value of the CSM state vector rather than the current value will be transferred and the CSM state vector may be destroyed. See also Verb 47 (paragraph 10.2.9).

If integration is in process when Verb 66 is initiated, the Verb 66 process is delayed until integration is completed. If integration is not in process, the CSM state vector (position, velocity, time) is transferred to the OWS state vector registers.

#### 10.2.25 Verb 67

Extended Verb 67 displays the W-matrix RSS error and allows a change of the W-matrix re-initialization values if desired by the crew. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer also to paragraph 4.2.1.2.2.2 and Table 4.2.1-III.

#### Procedure

1. Key VERB 67 ENTR
2. Observe flashing display of W-matrix RSS position and velocity errors:

FL VERB 06 NOUN 99

R1	xxxxx. ft.	RSS Position error
R2	xxxx.x fps	RSS Velocity error
R3	xxxxx.	Option Code

NOTE.—The option code defines which values will be initialized if the Noun 99 display is changed. Option code values are:



<u>Value</u>	<u>Meaning</u>
00000	No initialization
00001	Rendezvous

3. To allow initialization of the W-matrix values, key VERB 25 ENTR and load new data, making sure that R3 of Noun 99 contains 00001.
4. Key PRO.
5. Exit Verb 67.

NOTE.—Selection of option 1 will not result in W-matrix initialization until Verb 93 is performed (paragraph 10.2.47.)

#### 10.2.26 Verb 69

Extended Verb 69 is used to cause a crew-initiated computer restart. Selection of Verb 69 causes an automatic hardware restart. All current jobs and tasks are terminated; then, all restartable jobs and tasks are restarted. Verb 69 can be selected at any time.

#### Procedure

1. Key VERB 69 ENTR
2. Monitor DSKY and observe RESTART light illuminated on DSKY panel. DSKY should re-establish the last restartable display of the current major mode.
3. Key RSET to extinguish RESTART light.
4. Exit Verb 69.

#### Possible Alarm

If the DSKY panel light PROG is illuminated, key VERB 05 NOUN 09 ENTR. If R1, R2, or R3 of Noun 09 is 01107, the crew performs the fresh start procedures and exits Verb 69. If R1, R2, or R3, of Noun 09 is not 01107, the crew exits Verb 69 normally.

#### 10.2.27 Verb 70

Extended Verb 70 is used to initiate P27 to update liftoff time. Refer to paragraph 4.2.3 and Table 4.2.3-II for details.

#### 10.2.28 Verb 71

Extended Verb 71 is used to initiate P27 for a block update. Refer to paragraph 4.2.3 and Table 4.2.3-II for details.

#### 10.2.29 Verb 72

Extended Verb 72 is used to initiate P27 for a scatter update. Refer to paragraph 4.2.3 and Table 4.2.3-II for details.

#### 10.2.30 Verb 73

Extended Verb 73 is used to initiate P27 to update the CMC clock. Refer to paragraph 4.2.3 and Table 4.2.3-II for details.

#### 10.2.31 Verb 74

Extended Verb 74 is used to terminate the existing downlink list and to begin downlink of all of erasable memory. Two complete memory dumps are performed (taking 41.6 seconds at high bit rate) and then the current downlink list is restored.

#### 10.2.32 Verb 75

Extended Verb 75 is a back-up procedure for setting the liftoff discrete in order to initiate P11, the Earth Orbit Insertion Monitor Program. This process is intended for the prelaunch portion of the mission, specifically during P02, the Gyro Compassing Program. Refer to paragraph 2.2.3, paragraph 3.1.1.2, and Table 3.1.1-II for details.

#### 10.2.33 Verb 76

Extended Verb 76 sets R27FLAG, enabling R22 to call R27, the VHF Range Rate Mark Processing Routine, during P20 options 0 or 4. It is also used to select a time at which the range rate will be optimized, and to re-initialize the range rate filter. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 4.2.1.3.1 for details.

#### 10.2.34 Verb 77

Extended Verb 77 resets R27FLAG, preventing R22 from calling R27, the VHF Range Rate Mark Processing Routine, during P20 options 0 or 4. Refer to paragraph 4.2.1.3.1 for details.

#### 10.2.35 Verb 78

Extended Verb 78 is used in P02 to enable the crew to change the launch azimuth. Selection of Verb 78 at any time except during P02 will result in the illumination of the OPR ERR DSKY light. Refer to paragraph 2.2.3 for details.

#### 10.2.36 Verb 80

Extended Verb 80 specifies the OWS state vector as the vector to be updated during P20 options 0 and 4. Selection of P20 automatically specifies the CSM state vector to be updated. Refer to Table 4.2.1-III.

#### 10.2.37 Verb 81

Extended Verb 81 specifies CSM state vector as the vector to be updated during P20 options 0 and 4. Selection of P20 automatically specifies this, so Verb 81 is not required unless Verb 80 has been performed since the start of P20. Refer to Table 4.2.1-III.

#### 10.2.38 Verb 82

Extended Verb 82 is used to call R30, the Orbital-parameters Display Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 9.2.3 and Figure 9.2.3-1 for a description of R30. See also paragraph 3.1.1.4, Table 3.1.1-II, Table 4.2.1-III, Table 6.2.1-II, Table 6.2.2-II, and Table 6.2.3-II.

#### 10.2.39 Verb 83

Extended Verb 83 is used to call R31, the Rendezvous Parameter Display No. 1 Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 9.2.4 and Figure 9.2.4-2 for a description of R31. Refer also to paragraph 4.2.1.2.2.2, Sequence V, Final Phase, Table 4.2.1-III, Table 6.2.1-II, Table 6.2.2-II, and Table 6.2.3-II.

#### 10.2.40 Verb 85

Extended Verb 85 is used to call R34, the Rendezvous Parameter Display No. 2 Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 9.2.5 and Figure 9.2.5-2 for a description of R34. Refer also to Table 4.2.1-III, and Table 6.2.3-II.

#### 10.2.41 Verb 86

Extended Verb 86 enables the crew to reject a mark taken while using R23, the Rendezvous Backup Sighting Mark Routine, or R21, the Rendezvous Tracking Sighting Mark Routine. The process can be used in options 0 or 4 of P20, the Universal Tracking Program. Refer to Table 4.2.1-III.

#### 10.2.42 Verb 87

Extended Verb 87 sets the VHF range flag (VHFRFLAG), allowing R22 to accept VHF range data. VHFRFLAG is not changed during MINKEY otherwise, it must be manually set following each VERB 37 ENTR xx ENTR if VHF data are desired. Refer to Table 4.2.1-III.

#### 10.2.43 Verb 88

Extended Verb 88 resets the VHF range flag (VHFRFLAG), inhibiting VHF range data acceptance by R22. VHFRFLAG is not changed during MINKEY; it will be automatically reset by each VERB 37 ENTR xx ENTR otherwise. Refer to Table 4.2.1-III.

#### 10.2.44 Verb 89

Extended Verb 89 is used to call R63, the Rendezvous Final Attitude Routine. Unless a fresh start situation exists (blank major mode) or P00 is operating, the process will not be initiated and the OPR ERR DSKY light will be illuminated. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. For a description of R63, refer to paragraph 2.2.1.4.2 and Figure 2.2.1-4. See also Table 4.2.1-III.

#### 10.2.45 Verb 90

Extended Verb 90 is used to call R36, the Rendezvous Out-of-Plane Display Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. For a description of R36, refer to paragraph 9.2.6, and Figure 9.2.6-1. See also Table 4.2.1-III.

#### 10.2.46 Verb 91

Extended Verb 91 displays the banksum for each bank on the DSKY. Unless a fresh start situation exists (blank major mode) or P00 is operating, the process will not

be initiated and the OPR ERR DSKY light will be illuminated. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. For a description of Verb 91 use, refer to paragraph 2.2.1.4.3.3 and Figure 2.2.1-7.

#### 10.2.47 Verb 93

Extended Verb 93 allows re-initialization of the W-matrix. Refer to Table 4.2.1-III and paragraph 4.2.1.2.2.2.

#### 10.2.48 Verb 96

Extended Verb 96 provides a means of suspending state vector integration if it is in progress and activating the CMC Idling Program P00. The current program is terminated, P00 is initiated, and P00 state vector integration is bypassed until a new program selection is made. The process does not maintain state vector synchronization. If the coasting integration routine is in operation, it is terminated at the current time step.



SECTION 11.0

DOCKED DAP

## 11.1 OVERVIEW OF DOCKED DAP

The Docked DAP provides capability for stabilizing and maneuvering the SKYLAB Orbital Assembly (OA) by means of the CSM RCS jets. It thus serves as a backup system to the OWS attitude control systems. It can also serve as the primary system for performing x-translation maneuvers, general rotation maneuvers, and transitions between solar inertial and z local-vertical tracking.

This users' guide presents crew procedures for initiating and controlling Docked DAP operation. It also discusses special situations during which the Docked DAP can be used.

## 11.2 GEOMETRIC FACTORS AFFECTING THE DOCKED CONFIGURATION

The Docked DAP executes rotations and x translation of the OA by means of the 16 RCS jets located on the forward end of the service module. Figure 11.2-1 shows the docked configuration and the location of the jets. These jets are clustered in four quads, lettered A-D, four jets to a quad. Quads A and C are aligned with the z-control axis. Quads B and D are aligned with the y-control axis. (The RCS control axes are rotated with respect to the spacecraft axes by  $-7.25$  deg about  $+x_{SC}$ .)

Figures 11.2-2 and 11.2-3 show the center of gravity (c.g.) of the orbital assembly. It is located about 40 feet from the plane of the CSM RCS jets, and is off the longitudinal centerline of the vehicle by about 2 feet. Because this c.g. position is different from that of the CSM alone, the effect of a jet firing will be different for the docked configuration than for the CSM alone.

In the docked configuration, several jets should normally be inhibited to prevent impingement problems. Because the  $-x$  jets, A3, B3, C4, D4 all point towards the docking adapter and workshop, they should be inhibited. Jets A1 and D2, which are aimed towards the ATM solar arrays, should also be inhibited.

### 11.2.1 Roll

For roll (i.e., rotation about the x-control axis) jets A1, B1, C1, and D1 provide roll control in the positive direction and jets A2, B2, C2, and D2 provide roll control in the negative direction. For simple roll control, jets are fired in couples (i.e., pairs selected from opposite quads). For example, A2 and C2 form a negative roll couple. The jets of a roll couple exert equal and opposite force, and produce negligible pitch, yaw, and translation of the vehicle. When fired individually,



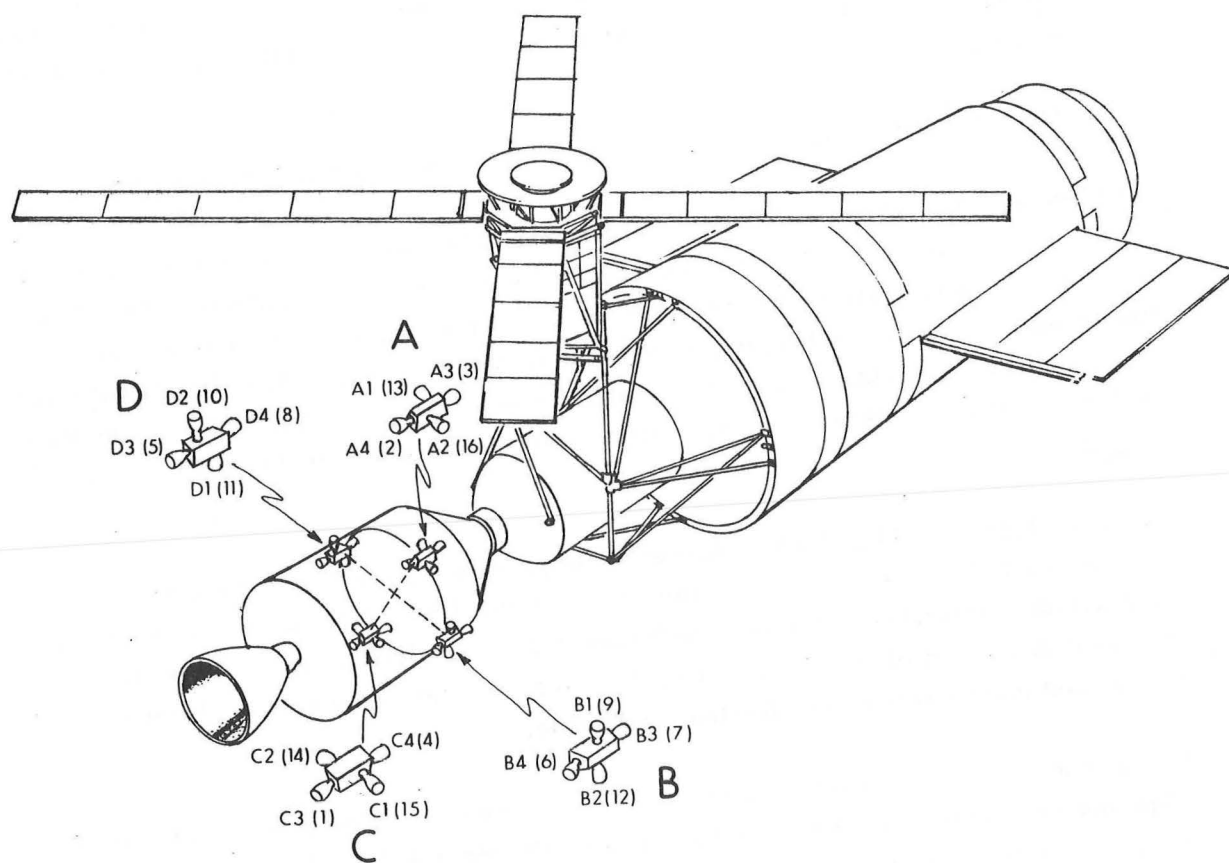


Figure 11.2-1 Docked Configuration

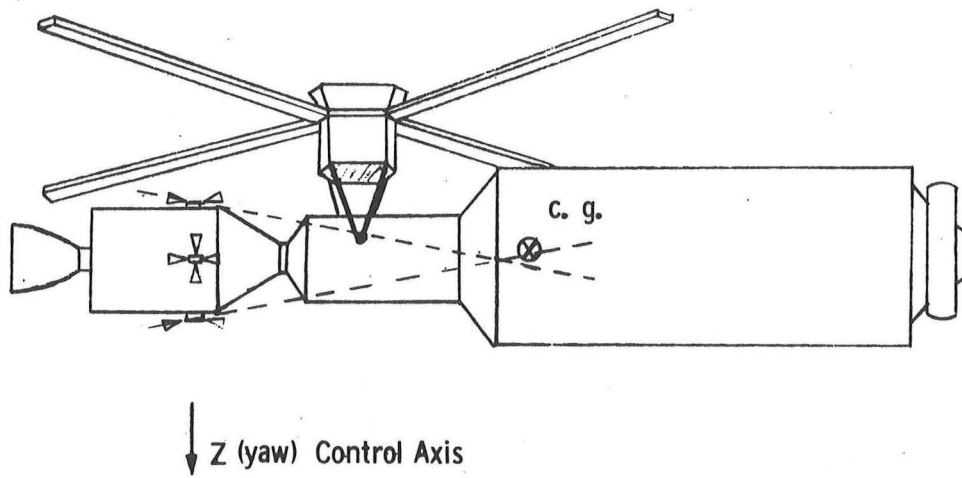


Figure 11.2-2 Center of Gravity of OA

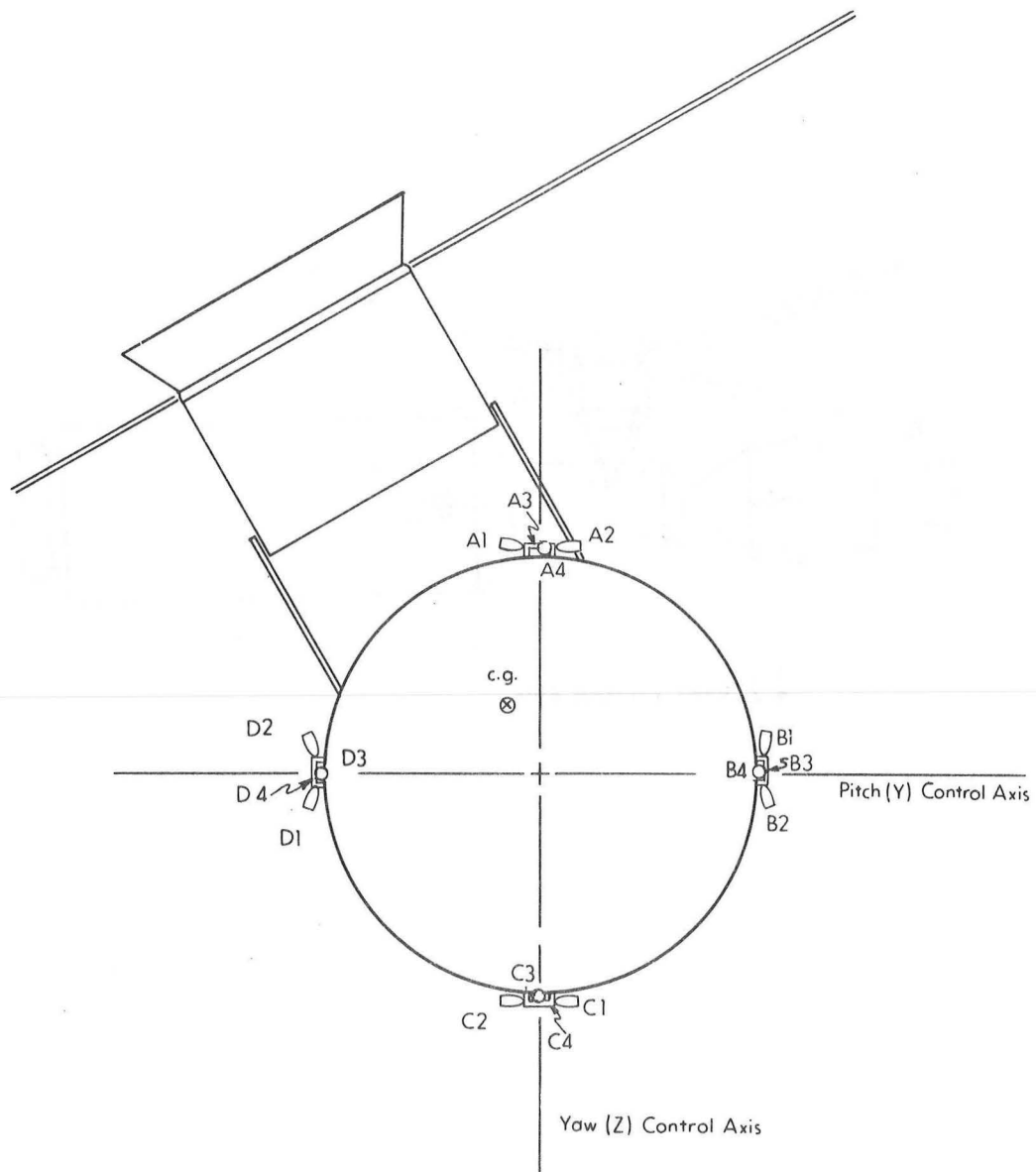


Figure 11.2-3 End View of Docked Configuration

jets on the B and C quads have a greater roll effect than those on quads A and D, since quads B and C have longer roll-moment arms (i. e., a longer projection in the y-z plane of the vector from the c. g. to the quad).

The roll acceleration for jets on the various quads is calculated using the padloaded constants ALPHAP and ALPHAYW. These constants reflect the effect of offset c.g. in the z and y directions. The roll acceleration of the jets on the various quads is represented as follows (ALPHAR is the average single roll-jet acceleration):

<u>Quad</u>	<u>Acceleration</u>
A	ALPHAR (1-ALPHAYW)
B	ALPHAR (1-ALPHAP)
C	ALPHAR (1+ALPHAYW)
D	ALPHAR (1+ALPHAP)

Note that for the nominal OA configuration ALPHAP is a negative number. In the event of large changes in the c. g. of the orbital assembly (such as radial docking), the values ALPHAP and ALPHAYW should be changed by the crew or by uplink.

The firing of roll jets is commanded via output channel 6 of the CMC. (See Table 11.2.1-I.)

#### 11.2.2 Pitch

Pitch (i.e., rotation about an axis parallel to the y-control axis) can be accomplished in two ways, using either force pairs or torque couples.

##### Force Pairs

The preferred method for pitching the orbital assembly is to fire the z-force jets (i.e., jets that fire in the  $\pm z$  direction). Since the moment arm of the z-force jets extends about 40 feet to the c.g., these jets are very effective in producing pitch motions. Consequently, the length of firing needed to produce pitch rotation will be short, resulting in relatively little translation. As Figure 11.2-3 shows, firing jets B1 and D2 produces positive pitch, while firing jets B2 and D1 produces negative pitch. Firing a pair of z-force jets for identical durations, however, has a net roll effect on the vehicle since the roll-moment arm of the D quad is shorter than that of the B quad (Figure 11.2-3). By unbalancing the firing time, so that the D-quad jets fire longer than the B-quad jets, this roll effect can be cancelled.

Channel 6

<u>Bit</u>	<u>Roll</u>	<u>Pitch</u>	<u>Yaw</u>	<u>Jet</u>
1	+	+		B1
2	-	-		B2
3	+	-		D1
4	-	+		D2
5	+		-	A1
6	-		+	A2
7	+		+	C1
8	-		-	C2

Channel 5

<u>Bit</u>	<u>X-Trans</u>	<u>Pitch</u>	<u>Yaw</u>	<u>Jet</u>
1	+	+		C3
2	-	-		C4
3	-	+		A3
4	+	-		A4
5	+		+	D3
6	-		-	D4
7	-		+	B3
8	+		-	B4

Table 11.2.1-I. Channel 5 and 6 Effects

If it is not possible to fire a pair of z-force jets because of jet inhibitions, a single jet can be fired, and the resulting roll disturbance corrected by roll-jet firings. For example, if jet D2 is inhibited, jet B1 can be fired to produce positive pitch, and roll-couple jets C2 and A2 fired at the same time to counteract the expected roll disturbance. The firing of pitch force pair jets is commanded by channel 6 of the CMC. (See Table 11.2.1-I.)

#### Torque Couples

The Docked DAP also includes provisions for producing pitch by using torque couples (similar to the CSM-alone configuration). Firing jets A3 and C3 produces positive pitch, while firing jets A4 and C4 produces negative pitch. Since torque couples exert an equal and opposite force, they produce no significant roll, yaw, or translation of the vehicle. Because the moment arm of the jets is only seven feet, however, torque couples cannot efficiently rotate the vehicle. Moreover, during normal operating conditions, jets A3 and C4 are inhibited, making torque-couple pitch impossible. The firing of pitch torque jets is commanded by channel 5 of the CMC. (See Table 11.2.1-I.)

#### 11.2.3 Yaw

The geometry of yaw rotations (i.e., rotations about an axis parallel to the z-control axis) is similar to that of pitch rotation. The preferred method is to fire y-force pairs A2 and C1 for positive yaw and A1 and C2 for negative yaw. Firing times will be unbalanced so that A-quad jets fire longer than C-quad jets, thus counteracting the roll effect of the off-center c.g. If, due to jet inhibitions, it is not possible to fire a pair of y-force jets, a single jet can be fired, and the resulting roll disturbance corrected by roll-jet firings. The firing of yaw force pair jets is commanded by channel 6 of the CMC. (See Table 11.2.1-I.)

Torque couples B3 and D3 (positive yaw) and B4 and D4 (negative yaw) can also be used; but they are relatively inefficient, and require firing jets B3 or D4, which are inhibited during normal docked operation. The firing of yaw torque couple jets is commanded by channel 5 of the CMC. (See Table 11.2.1-I.)

#### 11.2.4 X Translation

Translation of the OA is only practical in the +x direction. (y and z translation is not possible since the y and z jets have such a large moment arm around the c.g. that they mainly produce rotation; -x translation should not be used since it requires jets that point towards the docking adapter and workshop, and these jets are normally inhibited.) Jets A4, B4, C3, D3 are referred to as +x jets since firing them causes translation in the +x direction of the CSM. They can be fired in pairs from opposite quads (for example, jets D3 and B4) or all four jets can be fired at once. The

firing of x-axis jets is commanded via output channel 5 of the CMC. (See Table 11.2.1-I.)

Each RCS jet is canted 10 deg away from the spacecraft skin. Because of this, the nominal thrust direction of each of the +x jets intersects the longitudinal centerline of the vehicle about 39 feet ahead of the plane of the jet quads. (See Figure 11.2-2.) Since this intersection is very close to the c.g., +x jets apply very little rotational moment to the vehicle. A pitch or yaw rotation, therefore, cannot be combined with a +x translation by firing a single +x jet. (This is unlike the CSM-alone case.) Thus, the autopilot turns off any torque-couple pitch firings whenever AC jets are being used for x translation, and turns off any torque-couple yaw firings whenever BD jets are being used for x translation. (This is another reason why force pairs are preferable to torque couples for pitch and yaw control.)

See paragraph 11.8.4 for a description of crew procedures during x-translation maneuvers.

### 11.3 R04 DATA LOAD FOR DOCKED DAP (VERB 44 ENTR)

Input data for the docked configuration can be loaded via the DSKY using R04, called by extended Verb 44. Crew inputs to R04 are:

- . Preference of quads AC or quads BD for roll control
- . Choice of quads AC and/or quads BD for x translation
- . Preference of torque couple or z- (or y-) force control for pitch (or yaw)
- . Jet inhibition data
- . DAP maneuver rate
- . DAP angular deadband

Figure 11.3-1 illustrates the R04 sequence. Keying VERB 44 ENTR initiates the routine and causes a V05 N87 to be displayed on the DSKY:

#### FL V05 N87

R1	ABCDE	DAPDATR3
R2	xxxxx	CH5FAIL
R3	xxxxx	CH6FAIL

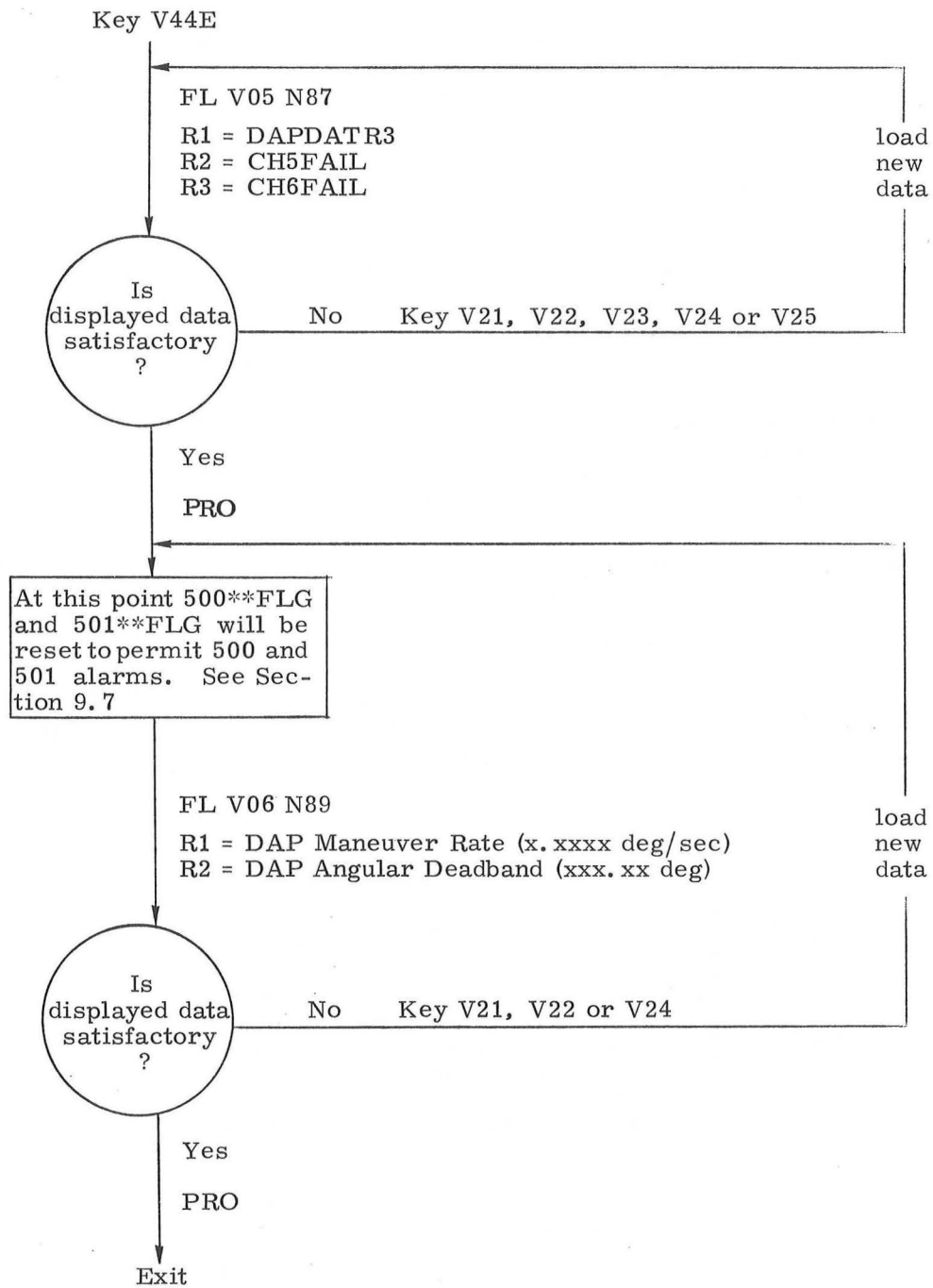


Figure 11.3-1. R04 Data Input Procedure



The crew can change any or all of the displayed data. When the crew is satisfied with the displayed data, he keys PRO. Upon a PRO response, 500\*\*FLG and 501\*\*FLG are automatically reset to permit 00500 and 00501 alarms. (See Section 11.7 for an explanation of these alarms.) A flashing V06 N89 is then displayed on the DSKY:

FL V06 N89

```
R1   x,xxxx deg/sec   DKRATE
R2   xxx,xx deg       DKDB
R3   Blank
```

If desired, the crew can change the displayed data. When satisfied with the displayed values, the crew keys PRO to terminate the routine. The meaning and recommended values of the contents of Nouns 87 and 89 is detailed in the following sections.

11.3.1 Noun 87: R1—DAPDATR3

Recommended value: R1—x1111

The octal digits of R1 of Noun 87 are referred to as A through E when read left to right. The significance of the digits and their values is as follows:

A. AC/BD roll control specification

VALUE	MEANING	
0	BD Preference - i.e., try to use BD-quad jets for the "phase-plane" roll command, but if an inhibited jet is encountered, then try AC-quad jets.	During normal docked operation roll jets A1 and D2 are inhibited so all positive roll will use jets B1 and D1 (BD quads), while all negative roll will use jets A2 and C2 (AC quads); thus the choice of a value for digit A is irrelevant.
1	AC Preference - i.e., try to use AC-quad jets for the "phase-plane" roll command, but if an inhibited jet is encountered then try BD-quad jets.	

B. ACXTRANS

0	Do not use AC quads for x translations	If both ACXTRANS and BDXTRANS are loaded 0, no jets will fire in response to $\pm x$ THC commands; if both are loaded 1 the autopilot will attempt to use all four quads. It is suggested that both digits be loaded 1.
1	Use AC quads for x translations	

C. BDXTRANS

0	Do not use BD quads for x translations
1	Use BD quads for x translations

D. Pitch Control

0	Torque-couple control preferred for pitch	For normal operation Digit D should be 1.
1	z Force control preferred for pitch	

E. Yaw Control

0	Torque-couple control preferred for yaw	For normal operation Digit E should be 1.
1	y Force control preferred for yaw	

11.3.2 Noun 87: R2 and R3—CH5FAIL and CH6FAIL

Recommended value: R2—00146, R3—00030

The AGC erasables CH5FAIL and CH6FAIL are displayed in octal as R2 and R3 of Noun 87. These erasables are used to communicate to the DAP which RCS jets are to be inhibited. When inhibited, a jet cannot be fired by the DAP, regardless of hand controller commands, or automatic-maneuver commands. An inhibited jet is

indicated by a 1 in CH5FAIL/CH6FAIL in the same bit position used to turn that jet on and off via channel 5 or channel 6.

To inhibit one or more channel-5 jets, the crew obtains the CH5FAIL octal values for these jets (Table 11.3.2-I), sums these values, and loads the sum into R2 of Noun 87. A similar procedure is used to inhibit channel-6 jets. For example, to inhibit jets A3, B3, C4, and D4 of channel 5 and jets A1 and D2 of channel 6, the crew loads the following values into R2 and R3 of Noun 87:

R2 = CH5FAIL = 00004 + 00100 + 00002 + 00040 = 00146

R3 = CH6FAIL = 00020 + 00010 = 00030

NOTE.—These are the jets that would normally be inhibited while docked.

Although the crew can inhibit jets directly by placing individual AUTO RCS SELECT switches in the OFF position, the CMC is unable to read these switches, and will continue to send commands and make rate estimates for jets inhibited via these switches. To prevent degraded autopilot performance, therefore, all jets inhibited via the AUTO RCS SELECT switches should also be inhibited via CH5FAIL/CH6FAIL.

Note that keying VERB 59 ENTR at any time during the mission causes all zeros to be written into CH5FAIL and CH6FAIL. This procedure reenables all jets that may have been inhibited via R04. This procedure should not be performed when the Docked DAP is running during normal operation, since roll jets A1 and D2 may then fire and impinge upon the solar panels of the ATM. (It was included as a rapid means of enabling all RCS jets in case of emergency.)

Having loaded Noun 87 as desired, the crew keys PRO.

### 11.3.3 Noun 89: R1—Maneuver Rate (DKRATE)

Recommended values: 0.01 through 0.2 deg/sec

This register specifies the angular rate at which the Docked DAP is to perform manual and automatic maneuvers. The display is scaled x,xxxx deg/sec. Since R04 does not check the magnitude or the sign of the value loaded by the crew, care must be taken not to load an unreasonably large or small values or a negative value.

The structural limit on rotation rate is 0.3 deg/sec. For automatic maneuvers, DKRATE is the magnitude of the total commanded angular velocity for all axes. For manual maneuvers, however, DKRATE is used independently for each axis. Thus, a 2-axis manual maneuver at the highest recommended rate (0.2 deg/sec) produces a resultant rate of approximately 0.283 deg/sec; and a 3-axis manual maneuver produces a resultant rate of 0.346 deg/sec, which exceeds the structural limitations of the OA. It is therefore important that 3-axis manual maneuvers be avoided whenever the DKRATE exceeds 0.17 deg/sec.

#### Jet/Bit Correspondence

Channel 5			Channel 6		
<u>Jet</u>	<u>Bit #</u>	<u>Value</u>	<u>Jet</u>	<u>Bit #</u>	<u>Value</u>
C3	1	00001	B1	1	00001
C4	2	00002	B2	2	00002
A3	3	00004	D1	3	00004
A4	4	00010	D2	4	00010
D3	5	00020	A1	5	00020
D4	6	00040	A2	6	00040
B3	7	00100	C1	7	00100
B4	8	00200	C2	8	00200

Table 11. 3. 2-I. CH5FAIL/CH6FAIL Values

#### 11.3.4 Noun 89: R2—Angular Deadband (DKDB)

Recommended Values: 0.5 deg through 20.0 deg

The angular deadband specifies how far (in degrees) the actual attitude can vary from the desired attitude before jet firings are commanded to correct the discrepancy. This display is scaled xxx.xx deg.

The same value (DKDB) is used for each of the three control axes. Since R04 does not check the magnitude or the sign of the value loaded by the crew, care must be taken not to load an unreasonably large or small value or a negative value.

Several of the control equations use small-angle approximations. Thus, as the size of the angular deadband increases, the control of the vehicle progressively degrades. Values of up to 20 deg generally provide reasonable performance. Values above 30 deg can result in serious degradation of performance.

Rotational maneuvers are not recommended for angular deadbands of less than 0.5 deg. Much smaller deadbands can result in undesirable limit cycling during rotational maneuvers, and, thus, excessive firings. Moreover, for extremely small deadbands, vehicle vibrations can feed back into the control system, producing harmonic oscillation. In certain special cases, there may be reasons for using deadbands smaller than 0.5.

If it is reasonably certain that the problems mentioned above are unlikely to occur in a particular case, then a value smaller than the generally recommended minimum of 0.5 deg is permissible. However each case should be considered on its own merits.

Changes to R2 of Noun 89 do not immediately affect the deadband. The deadband is changed only after VERB 45 ENTR is keyed. (See paragraph 11.3.5.) Since VERB 45 causes the center of the deadband to be reinitialized to the present attitude, no special precaution need be taken when collapsing Docked DAP deadbands via R04 and VERB 45.

#### 11.3.5 Use of R04

R04 can be entered at any time during CSM-alone or docked operation. Executing R04 during CSM-alone DAP operation has no effect on the CSM-alone DAP. When the Docked DAP is subsequently activated via VERB 45 ENTR, the configuration loaded in Nouns 87 and 89 of R04 becomes effective.

If the Docked DAP is active, changes to Noun 87 become current when the astronaut keys ENTR. Likewise, changes to R1 of Noun 89 (maneuver rate) become current when the astronaut keys ENTR for this Noun\*. Changes to deadband (R2 of Noun 89), however, do not become effective immediately, but, rather, only when VERB 45 ENTR is keyed into the DSKY. Note that this is unlike CSM-alone DAP operation.

#### 11.4 DOCKED DAP TURN-ON (VERB 45 ENTR), TRANSITIONS, AND TURN-OFF

When satisfied with the autopilot control data (R04), the crew can activate the Docked DAP by keying VERB 45 ENTR. This enables the Docked DAP and disables the RCS DAP or the SATURN takeover function if either is active. If P40 is active, VERB 45 ENTR illuminates the OPR ERR light, but otherwise has no effect.

Turn-on of the Docked DAP using VERB 45 ENTR is similar to RCS DAP turn-on using VERB 46 ENTR. Thus, if the SC CONT switch is in CMC position and the IMU is on and usable, the Docked DAP becomes fully operational within 1.7 sec after VERB 45 ENTR is keyed. If the SC CONT switch is placed in SCS or if the translational hand controller (THC) is rotated clockwise, the DAP reverts to an idle mode. In this mode, the Docked DAP does not respond to inputs, but does display attitude errors—provided the IMU is on and usable. When the SC CONT switch is returned to CMC, or the THC is rotated back to detent, the DAP performs its start-up sequence and becomes fully operational within 1.1 sec, provided the IMU is on and usable. If IMU power is off, or if the IMU is on, but is in the coarse-align or CDU-zero mode, computer-initiated jet firings are inhibited when the CMC MODE switch is in AUTO or HOLD. The Auto and Hold modes are disabled, therefore, under the conditions stated, and the Docked DAP does not respond even to RHC inputs. The Free mode does not require an attitude reference in order to operate; therefore, the autopilot can be used in the Free mode at any time. Table 11.4-I summarizes the effects of hardware configuration on Docked DAP operation.

The normal means for exiting the Docked DAP is to return to CSM-alone DAP by keying VERB 46 ENTR (CSM-alone DAP turn-on). Changes to CSM-alone DAP variables can be made during Docked DAP operation by using R03 (VERB 48 ENTR). Executing R03 (CSM-alone DAP data load) while the Docked DAP is running has no effect on the Docked DAP; the changes become effective when VERB 46 ENTR is keyed. Thus, to completely halt all DAP operation, a zero should be placed in the

---

\* Except that the rate will not change for an R60-automatic maneuver that is already in progress. The new rate will be in effect for subsequent maneuvers.

HARDWARE CONFIGURATION	IMU On and Usable		IMU Off, Coarse Align or CDU Zero		
	SC Cont Switch in CMC	SC Cont Switch in SCS	SC Cont Switch in CMC		SC Cont Switch in SCS
	THC Not Rotated	-or- THC Rotated Clockwise	-and- THC Not Rotated	CMC Mode Switch in HOLD or AUTO	-or- THC Rotated Clockwise
STATE OF THE DAP	DAP OPERA- TIONAL	DAP IDLE No jet firings but will display attitude errors	All jet fir- ings inhi- bited, no attitude reference or displays	Jet firings possible via THC, RHC and MIC. No attitude reference or displays	No jet firings, no attitude reference or displays

Table 11.4-1. Hardware Configuration for DAP Operation

Noun 46 configuration code (no DAP requested). Executing VERB 46 ENTR then turns off any jets that are on, and turns off the T6 clock and idles the autopilot control interrupt (T5), so that no DAP coding is executed.

#### 11.5 MODES OF OPERATION

The Docked DAP has three modes of operation corresponding to the three positions of the CMC MODE switch: FREE, HOLD, and AUTO.

During Free mode, the Docked DAP does not try to align the spacecraft with any reference attitude, and the spacecraft drifts freely unless jet firings are commanded by the crew by means of the hand controllers.

During Hold mode and Auto mode, the Docked DAP provides rate and attitude control for the spacecraft, and maintains a reference attitude as specified by a set of desired IMU gimbal angles. The two modes are similar in operation. They both use the attitude-hold function, the manual-rate control function, and the rate-damping function to actively control the vehicle.

Attitude-Hold Function—The DAP commands jet firings to maintain spacecraft attitude within a deadband of the reference attitude.

Manual-Rate Control Function—In response to commands from the RHC, the Docked DAP actively controls both rate and attitude. Jet firings are commanded to keep the vehicle rate within a deadband of the rate specified in R04. The vehicle attitude reference is moved at the specified rate, and, if necessary, jet firings are commanded to keep the vehicle attitude within a deadband of the moving attitude reference.

Rate-Damping Function—When changes in rate are commanded by the RHC, the Docked DAP commands jet firings to bring the spacecraft to within a deadband of the commanded rate before resuming active control of attitude and rate. At the beginning of an RHC maneuver, attitude errors are not computed until the estimated rate is driven within a deadband of the commanded rate. A moving attitude reference is then established. At the end of an RHC maneuver, rates are brought to within a deadband of zero rate before the attitude hold function is resumed.

During Auto mode, automatic maneuvers specified by the CMC can also be performed.



The following paragraphs give a detailed description of the three autopilot modes.

#### 11.5.1 Hold Mode

The spacecraft is in Hold mode whenever the CMC MODE switch is in the HOLD position. (See also Table 11.4-I.) During Hold mode, the spacecraft attitude is maintained by the Docked DAP. The crew can perform rotations using the RHC, and  $\pm x$  translations using the THC. MIC commands are ignored.

If there are no RHC commands, the DAP performs the attitude-hold function about the attitude reached either upon switching to HOLD or upon completion of rate damping at the end of a manual rotation.

RHC commands override attitude hold. The manual-rate control function is used to rotate the spacecraft at the rate specified in R04 on each of the appropriate control axes for as long as the RHC remains out of detent. When the RHC returns to detent in all three axes, the rate-damping function is used to drive all angular rates to within a deadband about zero rate; attitude hold is then established about the new spacecraft attitude.

Only x-axis THC commands are honored. They are accepted at any time and cause the firing of x-axis jets (as specified in R04) for as long as the THC is out of detent in the  $\pm x$  direction. THC commands along the x axis are combined with jet-firing commands from the attitude hold logic and with RHC commands, with the exception that torque-couple pitch commands are zeroed whenever AC-quad jets are being used for x translation (either 2-jet AC or 4-jet AC, BD specified in R04), and that torque-couple yaw commands are zeroed whenever BD-quad jets are being used for x translation (2-jet BD or 4-jet AC, BD). Therefore, for effective pitch control during x translation using AC-quad jets, z-force control must be selected in R04 for the pitch axis. Similarly, for effective yaw control during x translation using BD-quad jets, y-force control must be selected for the yaw axis. In a normal situation, torque-couple pitch and yaw commands will not be possible, since minus-x jets are inhibited. Moreover, z-force control for pitch and y-force control for yaw are preferred regardless of x translation since they are more efficient in producing pitch and yaw motion.

#### 11.5.2 Auto Mode

The spacecraft is in Auto mode whenever the CMC MODE switch is in the AUTO position. (See also Table 11.4-I.) The Auto mode is identical to the Hold mode

unless an automatic maneuver is being commanded by the CMC. Among the possible automatic maneuvers are KALCMANU-supervised maneuvers and P20-Universal Tracking maneuvers. A particular capability of Universal Tracking is that of local-vertical tracking. This feature of P20 provides the DAP with rate and incremental-attitude commands for keeping any spacecraft vector pointed toward the center of the earth.

If there are no RHC commands and an automatic maneuver is not in progress, the attitude-hold function maintains spacecraft attitude.

If there are no RHC commands, the DAP accepts rate and attitude commands from automatic-maneuver programs in the CMC and performs the specified maneuver, subject to the constraints of the calling program. If, during an automatic maneuver the MGA should exceed 75 degrees, the autopilot performs the attitude-hold function. For a description of the automatic-maneuver programs, see paragraph 4.2.1.

RHC commands override automatic maneuvers. They are interpreted as rate commands, and are executed using the manual-rate control function as described above. When RHC command ceases, automatic maneuvers are resumed subject to the constraints of the calling program.

MIC commands are ignored.

Only x-axis THC commands are honored. They are accepted at any time, and can be combined with RHC commands or automatic maneuvers. The x-axis jets (as specified in R04) fire for as long as the THC is out of detent in the  $\pm x$  direction. For effective control of the vehicle (as described above), z-force control should be specified for the pitch axis if AC-quad x jets are to be used for translation, and y-force control should be specified for the yaw axis if BD-quad x jets are to be used for translation.

#### 11.5.3 Free Mode

The spacecraft is in Free mode whenever the CMC MODE switch is in the FREE position. (See also Table 11.4-I.) While in Free mode, the spacecraft drifts freely, unless rotation or translation is being commanded by the crew via the hand controllers. The x translation of the OA can be commanded by a  $\pm x$  deflection of the THC. Rotations of the OA can be commanded by the RHC, the MIC, and  $\pm y$  and  $\pm z$  deflections of the THC as specified below.

RHC commands are treated as angular impulse commands. Each deflection of the RHC produces one set of impulse firings. Depending on the data loaded via R04, the angular impulse will be produced by (1) a pair of torque-couple jets, (2) a pair of force jets or (3) a single force jet. For any of these possibilities, the effective total on-time of the one or two jets that produce the desired impulse is 200 ms.

The Docked DAP jet-selection logic is used in the implementation of the impulse function in such a way that there is an open-loop compensation for roll disturbances resulting from the offset c.g. When force pairs are used for pitch or yaw, the individual firing times are unbalanced (the effective total on-time remaining 200 ms) to approximately compensate for the roll effect of the offset c.g. When a single force jet is used for pitch or yaw, the single force jet is commanded to fire 200 ms and, in addition, two roll-couple jets on the adjacent quads are commanded for a time sufficient to cancel the roll effect of the single force jet. (This description does not include the superposition of roll, pitch, and yaw commands, which are permissible.)

MIC commands are honored if no RHC commands are present. Each deflection of the MIC produces one set of impulse firings, using the same logic as the RHC commands described above, but these firings are of 50-ms effective duration (instead of 200 ms for RHC). Thus, for example, a single force jet used for pitch or yaw is commanded to fire for 50 ms, and two roll jets on adjacent quads are commanded for a time sufficient to cancel the roll effect.

THC commands (x, y, or z deflections) result in the application of x, y, or z forces on the vehicle. The x translation is two-jet AC, two-jet BD, or four-jet, as specified in R04 by digits B and C of R1 of Noun 87 (DAPDATR3). If both these octal digits are zero, no x jets are specified and, thus, x translation is inhibited. The x forces are applied to the vehicle continuously for as long as the THC is out of detent in x.

Rotations using MIC, RHC, or THC (y or z) can be combined with  $\pm x$  translations since these commands are summed by the autopilot (with the exception that torque-couple pitch commands are zeroed whenever AC-quad jets are being used for x translation, and torque-couple yaw commands are zeroed whenever BD-quad jets are being used for x translation.)

NOTE. —It has been decided that because of the potential iteration of the periodic firings resulting from y- and z-THC deflections with the bending modes of the Orbital Assembly, use of the THC in the y or z direction will be procedurally prohibited for SKYLAB missions. The capability still physically exists, however, and for the sake of completeness is described in the next paragraph.

The y and z deflections of the THC produce rotation of the OA. Unlike  $\pm x$  (translation) control,  $\pm y$  and  $\pm z$  deflections produce a string of impulses for as long as the THC is out of detent. Each of these impulses is identical to a RHC commanded set of firings using force-preference. The values of ALPHAP and ALPHAYW, the particular jets inhibited and the specific deflection of the THC all enter into determining the repetition period of the impulses. Depending on the specific circumstances the period can be 0.2 sec, 0.3 sec, or 0.4 sec. For the normal values of ALPHAP and ALPHAYW with jets 10 and 13 inhibited, the repetition period for single axis y or z THC deflections is 0.3 sec. Using a string of impulses allows the Docked DAP jet-selection logic to compensate for the roll disturbance caused by the off-center c.g. of the OA. Firing sequences in response to y and z THC commands are interrupted to allow the execution of RHC and MIC commands. DAP jet-selection logic to compensate for the roll disturbance caused by the off-center c.g. of the OA. Firing sequences in response to y and z THC commands are interrupted to allow the execution of RHC and MIC commands.

## 11.6 DOCKED DAP DISPLAYS

### Attitude Error and Estimated Rate Display

The DAP generates three types of attitude errors for display on the FDAI error meters and on the DSKY. The modes of operation are designated as Mode 1, Mode 2, and Mode 3, and display the following quantities:

Mode 1. Autopilot phase-plane errors—selected through the DSKY by keying VERB 61 ENTR.

Mode 2. Total attitude errors with respect to the angles in Noun 22—selected by keying VERB 62 ENTR.

Mode 3. Total astronaut attitude errors with respect to the angles in Noun 17—selected by keying VERB 63 ENTR.

Mode 1 is provided as a monitor of the DAP and its ability to track automatic-steering commands. The attitude errors between the center of the DAP deadband and the current CDU angles are resolved into RCS control axes. In this mode, the display is zeroed when the CMC MODE switch is placed in the FREE position.

Mode 2 is provided to assist the crew in manually maneuvering the spacecraft to the attitude (gimbal angles) specified in Noun 22. The attitude errors between these angles and the current CDU angles are resolved into RCS control axes. Automatic maneuvers load Noun 22 with the desired final attitude.

Mode 3 is provided to assist the crew in manually maneuvering the spacecraft to the attitude (gimbal angles) specified in Noun 17. The attitude errors between these angles and the current CDU angles are resolved into RCS control axes. Verb 60 is provided to load Noun 17 with a snapshot of the current CDU angles, synchronizing the Mode-3 display with the current spacecraft attitude. This verb can be used at

any time. The crew can also load Noun 17 with desired values, directly, by keying VERB 25 NOUN 17 ENTR.

In all three modes, the error needles are updated every 200 ms.

Note that the same set of digital-to-analog converters (DACs) is used for coarse aligning the inertial platform and for driving the error needles. After a coarse align has been done, several variables used in the needle drive routine must be re-initialized, or a bias error will be introduced in the needle display. If the coarse align is done with the CMC MODE switch in FREE (SC CONT switch in either CMC or SCS), the re-initialization of the variables will not occur. In order to produce the proper re-initialization, VERB 45 ENTR should be keyed after the coarse align is complete (NO ATT light off). Switching to Hold or Auto will also produce the proper re-initialization.

These displays are available in any mode of operation (AUTO, HOLD, FREE) and under either SCS or CMC control once the Docked DAP has been initiated via VERB 45 ENTR. Mode 1, however, will be meaningful only in CMC AUTO or HOLD; all display modes assume that the IMU is on and inertially stabilized. The crew can preset an attitude reference (desired gimbal angles) into Noun 17 at any time.

It is also possible to display any of the three modes of attitude errors digitally in R1, R2, and R3 of the DSKY. This is done by keying Verb 16 NOUN 04 ENTR to obtain:

FL VERB 16 NOUN 04

R1	±xxx.xx deg
R2	±xxx.xx deg
R3	±xxx.xx deg

The particular mode displayed digitally will be the same as the mode currently being displayed on the FDAI needles. Sign convention is such that a positive attitude error about an axis will require a negative rate about that axis to reduce the error.

Keying VERB 16 NOUN 56 ENTR brings up a digital display of estimated rate in control axes in R1, R2, and R3 of the DSKY:

FL VERB 16 NOUN 56

R1     $\pm x,xxxx$  deg/sec  
R2     $\pm x,xxxx$  deg/sec  
R3     $\pm x,xxxx$  deg/sec

11.7 DOCKED DAP ALARMS

Two alarms are specifically associated with the Docked DAP. The 00500 alarm indicates that there are not enough jets left uninhibited to control pitch or yaw. The 00501 alarm indicates that there are not enough jets left uninhibited to control roll.

These alarms are triggered by the jet-selection logic when it has exhausted all possible means of performing a specified type of control. For example, if positive yaw is required (by attitude-hold logic or by hand controller) and if force preference is specified for yaw (digit E of Noun 87 R1 is 1), the jet-selection logic first attempts to fire a pair of y-force jets (A2 + C1). If one jet is inhibited, the logic tries to fire the other as a single y-force jet. If both are inhibited, the logic tries the corresponding torque couple (B3 + D3). If one of these jets is inhibited, it is not possible to produce positive yaw; the 00500 alarm is then set. Note, however, that the autopilot continues to attempt control of the vehicle, including negative yaw and  $\pm$ pitch as well as roll.

Once a 00500 or a 00501 alarm has occurred, it is not repeated on subsequent Docked-DAP cycles, since this ties up the alarm system. Rather, the 500\*\*FLG or 501\*\*FLG is set inhibiting future 00500 or 00501 alarms. These flags are reset in R04. (See Figure 11.3-1.) To clear the alarm system (and fix the problem), the astronaut should enter R04 and modify the configuration of CH5FAIL or CH6FAIL. This procedure automatically resets 500\*\*FLG and 501\*\*FLG.

Note also that keying VERB 59 ENTR at any time during the mission causes all zeros to be written into CH5FAIL and CH6FAIL. This procedure reenables all jets that may have been inhibited via R04. This procedure should not be performed when the Docked DAP is running during normal operation, since roll jets A1 and D2 may then fire and impinge upon the solar panels of the ATM. (It was included as a rapid means of enabling all RCS jets in case of emergency.) Also note that keying VERB 59 ENTR does not reset 500\*\*FLG or 501\*\*FLG.

## 11.8 DOCKED DAP PROCEDURES

The following subsections briefly outline procedures that could require using Docked DAP. These include docking and undocking, rescue via the radial port, CMG desaturation, x translation, and wide deadband attitude control.

### 11.8.1 Docking and Undocking

The following procedure is recommended during the docking of the CSM.

1. Key VERB 44 ENTR to initiate R04.
2. Follow the R04 procedures outlined in subsection 11.3, loading the recommended values into Noun 87 and Noun 89.
3. Immediately upon docking, switch the CMC MODE switch to FREE so that the CSM-alone RCS DAP and the OWS attitude control system are not fighting each other.
4. Perform one of the following:
  - A. Select the Docked DAP by keying VERB 45 ENTR. (The OWS attitude control system should be disabled before switching out of FREE mode.)
  - B. Select NODAP by keying VERB 48 ENTR, loading 0xxxx into Noun 46, and keying VERB 46 ENTR.
  - C. Prepare for CMC Power Down (P06) by keying VERB 37 ENTR 06 ENTR and following P06 procedures. (Refer to Section 2.)

For undocking, the following procedure is recommended:

1. Key VERB 48 ENTR to initiate R03.
2. Follow the R03 procedures outlined in Section 9 to initialize the CSM-alone RCS DAP variables.
3. Switch the CMC MODE switch to FREE and key VERB 46 ENTR to initiate the CSM-alone RCS DAP.
4. Undock and then switch the CMC MODE switch to ATT HOLD or AUTO for CSM-alone RCS DAP control.

### 11.8.2. Rescue Mission

The docking and undocking procedures using the radial port are identical to those using the axial port. The Docked DAP can be used to maintain attitude hold in this



configuration. In addition, present mission plans call for rotation of the CSM after soft docking and before hard latching so as to align the Docked DAP control axes with the axes of the OWS. This will enable the radial CSM to command automatic maneuvers with reasonable efficiency. Reconfiguration of the Docked DAP will probably be required, however, using different values for Noun 87 and Noun 89 in R04.

#### 11.8.3 CMG Desaturation

The Docked DAP can be used to maintain attitude control during CMG desaturation. CMG desaturation produces a torque somewhat greater than that produced by gravity gradient, but less than that produced by a failed-on jet. The procedure is as follows:

1. Key VERB 44 ENTR and load correct Docked DAP parameters.
2. Key VERB 45 ENTR to initiate the Docked DAP.
3. Deactivate the Thruster Attitude Control System (TACS).
4. Switch CMC MODE switch to HOLD and perform CMG desaturation.

#### 11.8.4 X-translation Maneuvers

The Docked DAP can be used for x-translations for shaping maneuvers and other purposes. (Refer also to paragraph 5.1.1.2.1.) Since the c.g. is not in the center of the vehicle, however, +x translation produces +pitch and -yaw rotation. A procedure involving an erasable memory program has been developed that will impart a compensating -pitch and +yaw rotation rate to the vehicle prior to the translation which is then done in the FREE mode. The purpose of this procedure is to leave the contaminants from the attitude control firings behind in the original orbit.

#### 11.8.5 Wide Deadband (Quasi-inertial) Attitude Hold

The Docked DAP can be used to maintain wide-deadband-attitude hold for quasi-inertial control. The following is a simplified description of the factors involved.

In general, as the workshop orbits the earth, the force exerted by the gravity gradient changes direction in a cyclical fashion. With proper initial conditions, and in the absence of attitude control, this force would result in a slow elliptical motion of the spacecraft attitude on the pitch and yaw axis. After a long period of time, however, the vehicle motion would probably diverge from the nominal elliptical path. Thus, some form of attitude control is necessary. Wide-deadband-attitude control can be established by changing several DAP erasable padloads. A description of these are contained in Table 11.8.5.I and Figure 11.8.5-1. This wide deadband control allows the cyclical motion to occur, but prevents it from degrading. Since propellant



<u>Erasable</u>	<u>Definition</u>
J/M, J/MDCKD J/M1, J/M1DCKD J/M2, J/M2DCKD	Inverse of modelled roll, pitch, and yaw acceleration provided by one jet of a roll, pitch, or yaw torque couple
ALPHAP	Constant used to represent the effect of the c. g. offset when using Z force jets
ALPHAYW	Constant used to represent the effect of the c. g. offset when using Y force jets
ECP	Pitch effectiveness constant—modelled ratio between acceleration of one pitch torque couple jet and acceleration of one Z-force pair jet
ECYW	Yaw effectiveness constant—modelled ratio between acceleration of one yaw torque couple jet and acceleration of one Y-force pair jet
SLOPE	Slope of the slanted side of the deadzone (see Figure 11.8.5-1)*
SLOPE2	Slope of the slanted target line (see HSLOPE in Figure 11.8.5-1)
WLH/SLOP, WL-H/SL	See Figure 11.8.5-1

Table 11.8.5-I. Docked DAP Padloads Affecting Wide Deadband Control

\*This erasable is initialized to  $-.3^{\circ}/s/^{\circ}$  following VERB 45 ENTR or hardware restart.

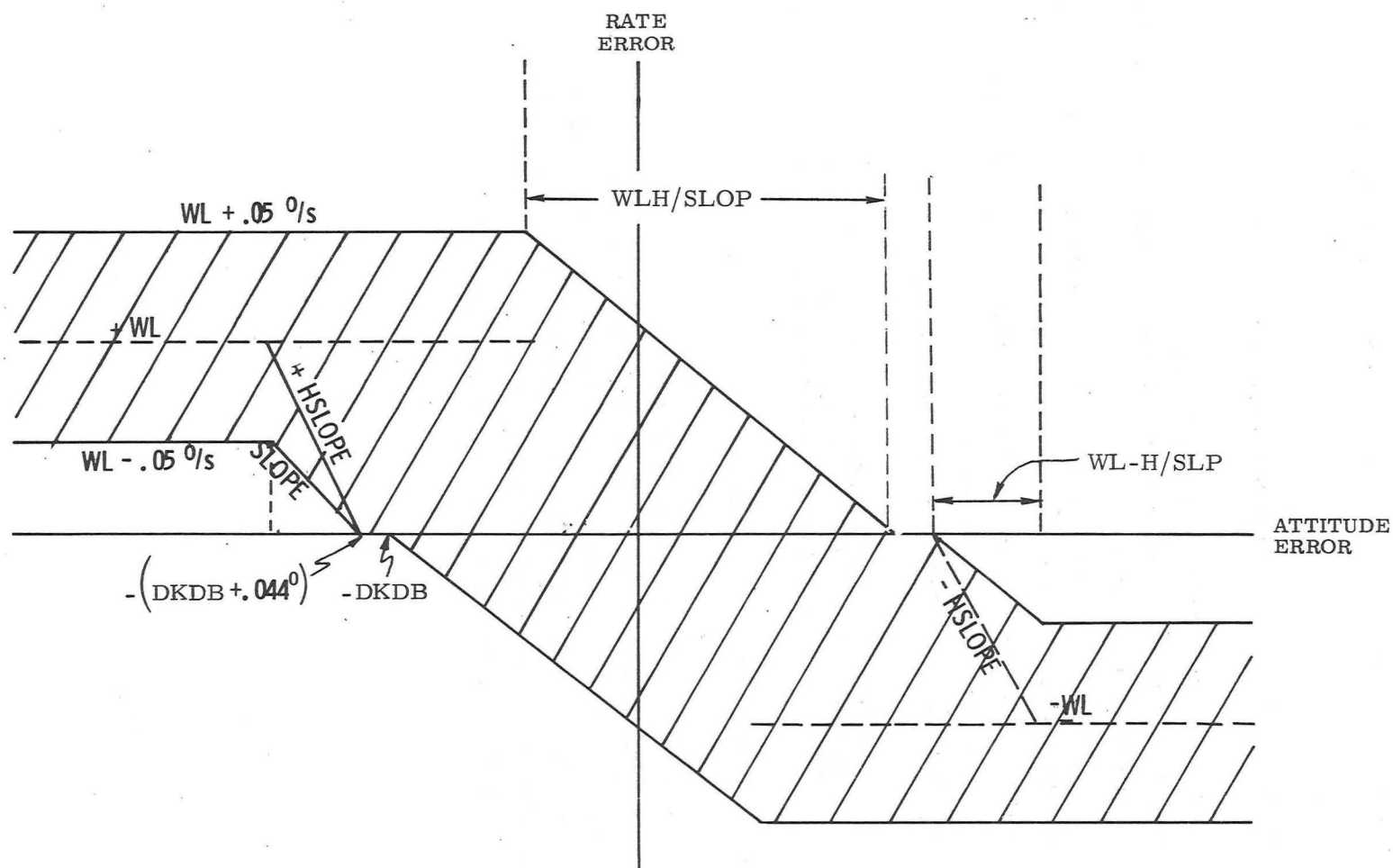


Figure 11.8.5-1

Phase Plane for Docked DAP

is not expended to continuously counteract the gravity gradient, fuel economy is achieved.

To establish wide-deadband control use the following procedure:

1. Switch the CMC MODE switch to FREE.
2. Key VERB 44 ENTR and load R2 of Noun 89 with the wide-deadband value (nominally 16 deg).
3. A) If P20 is running load R2 of Noun 79 with the wide-deadband value.  
B) Otherwise, Key VERB 45 ENTR.
4. Select P27 to load new values of Docked DAP erasable padloads.
5. Use RHC to initiate vehicle motion.
6. Set the CMC MODE switch to AUTO or HOLD.

NOTE.—A hardware restart will destroy the modified value of SLOPE, restoring the nominal value. Following the restart the crew must reload the desired value.

To switch from wide-deadband control, use the following procedure:

1. Switch the CMC MODE switch to FREE.
2. Select P27 to load new values of Docked DAP padloads.
3. Key VERB 44 ENTR and load R2 of Noun 89 with desired deadband.
4. A) If P20 is running load R2 of Noun 79 with desired deadband.  
B) Otherwise, key VERB 45 ENTR.
5. Switch the CMC MODE switch to AUTO or HOLD.

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