J.E. WALDO

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DESIGN REFERENCE MISSION II A

Apollo Mission Planning Task Force

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER

DESIGN REFERENCE MISSION II A

Apollo Mission Planning Task Force

Appendices to Volume I

Prepared by the Apollo Mission Planning Task Force
NASA/Manned Spacecraft Center
Grumman Aircraft Engineering Corporation
North American Aviation
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APPENDIX A MISSION GROUND RULES

A.1 INTRODUCTION

In order to construct the mission trajectory and sequence-of-events, it was necessary to first set down a variety of constraints to which the reference mission must conform. These items have become known variously as "ground rules," "guidelines," or "constraints," depending upon their degree of firmness and the degree to which they apply to only a particular lunar landing mission (as opposed to all lunar landing missions). Regardless of the terminology, they represented the starting point for the generation of the DRM IIA, and shall be known herein as simply "ground rules."

These ground rules associated with DRM IIA are presented in this section according to the following breakdown:

- Trajectory
- Spacecraft Systems Operations
- Spacecraft Attitude
- Crew Activity
- CSM-LM Interrelationships
- SC Design Limitations

The order in which these sections appear corresponds roughly to the order in which the DRM IIA was developed; that is, it began with a trajectory which was built around a framework of ground rules. The next steps were to key the resulting trajectory to certain systems operations and attitude considerations, and finally the crew activity was added to perform the resulting operations and events. The next section, CSM-LM interrelationships, presents ground rules that define mission interface requirements between the two modules. The last section in the ground rules, SC design limitations, represent general SC and mission constraints to which all the above operations must conform.

Once the trajectory, sequence-of-events, and associated mission sections have been developed within the framework of the stated ground rules, then the ground rules themselves lose most of their significance. They are presented here chiefly to give the reader a summary of the mission features contained in Volumes I and III. No attempt is made to rank the individual ground rules as to their importance or to their degree of firmness. The reader will note that some of them influence the entire mission while others are associated with a

single operation; some of them are so firm and well understood, that it seems almost unnecessary to restate them here, while others have changed considerably during the course of lunar mission planning, and will undoubtedly change again.

Finally, it should be noted that a few of the "ground rules" are nothing more than assumptions which had to be made in order to develop the mission timeline. That is, in some cases there may have been several alternative ways of performing a certain operation, but one of them had to be chosen in order to proceed with the mission timeline development. In the absence of any clear-cut program preference in these cases, a choice was made based on available data, and the choice became a "ground rule."

A.2 OPERATIONAL TRAJECTORY GROUND RULES

A.2.1 Phase 1.0 - Preflight

A.2.2 Phase 2.0 - Earth Ascent

A.2.2.1 Earth Launch will be from Launch Complex 39, Merritt Island Launch Area (MILA), Cape Kennedy.

A.2.2.2 The range safety launch azimuth limits shall be 72° to 108° based on the earth-fixed heading of the launch vehicle at the beginning of the pitch program.

A.2.2.3 The minimum operational daily launch window shall be 2.5 hours.

A.2.2.4 Operational launch azimuth limits shall be limited to a difference of 26° (e.g., 72° -98°)

A.2.2.5 Launch operations planning for any given day shall consider only one of the two available daily launch windows.

A.2.2.6 For any given monthly launch opportunity, launch windows should be available on at least three days. These launch windows should all be either Atlantic or Pacific injection and should be separated by at least 48 hours.

A.2.2.7 A daylight launch is preferable to a launch during the hours of darkness; however nighttime launches may be considered and are permissible for reference trajectory studies and planning purposes.

A.2.3 Phase 3.0 - Earth Parking Orbit

A.2.3.1 The parking orbit lifetime shall be such that at least ten orbits shall be obtained based on the ARDC 1962 atmosphere. The minimum acceptable perigee altitude shall be 85 nautical miles. The nominal parking orbit for use in trajectory studies shall be a near-circular orbit of 100 nautical miles altitude.

A.2.4 Phase 4.0 - Translunar Injection

A.2.4.1 Translunar injection shall occur no later than 4.5 hours after orbital insertion.

A.2.4.2 Two translunar injection opportunities are required per mission after insertion into an earth parking orbit.

A.2.4.3 Injection shall occur at the earliest opportunity after spacecraft systems have been checked out and the orbit determined.

A.2.4.4 There is no requirement for real time telemetry or tracking during translunar injection. An aircraft shall be positioned to provide real time telemetry record and real time voice relay from the CM to MSFN.

A.2.5 Phase 5.0 - Initial Translunar Coast Through S-IVB Jettison

A.2.5.1 Transposition and docking may take place in daylight or darkness.

A.2.5.2 There shall be no radiation constraints on transposition and docking.

A.2.5.3 Transposition shall nominally be initiated and completed between 15 minutes and 70 minutes after translunar injection. CSM separation for transposition and docking shall not be initiated until at least 10 minutes of tracking data has been obtained by the MSFN. Due to the S-IVB lifetime constraint, transposition and docking must be completed no later than 2 hours after translunar injection.

A.2.5.4 Following translunar injection, and before transposition and docking begins, the launch vehicle high-gain antenna pattern will be oriented to an MSFN station and voice communication will be maintained throughout the period.

A.2.6 Phase 6.0 - S-IVB Jettison to Lunar Orbit Insertion

A.2.6.1 The nominal trajectory shall be the free return type having a nominal vacuum perigee altitude of 25 nautical miles. The free return condition will be established by the separation maneuver at S-IVB jettison, and no midcourse corrections shall be required. The pericynthion altitude of the free return trajectory shall be between 40 nautical miles and 80

nautical miles above the lunar reference radius. The actual pericynthion altitude for any given mission nominal trajectory will be determined by mission optimization. The azimuth at reentry of the circumlunar trajectory shall be between 0 and 180 degrees (posigrade entry). It is preferred to have the free return impact point on water.

A.2.6.2 No midcourse corrections will be made until at least two stations have acquired the spacecraft and provided sufficient tracking data for updating the trajectory.

A.2.7 Phase 7.0 - Lunar Orbit Insertion

A.2.7.1 Lunar Orbit Insertion shall result in a circular orbit of 80 ± 1 n.mi. altitude above the selected landing site radius. The resulting parking orbit shall be such that the CSM would pass directly over the landing site during its fourth orbit and that a maximum out-of-plane condition of the landing site during the maximum LM lunar stay (including an additional nine hour contingency stay) shall be less than 2°.

A.2.8 Phase 8.0 - Lunar Orbit Coast to LM Separation

A.2.8.1 Three passes over the landing site are required prior to initiating the LM Transfer Orbit Insertion (TOI) burn.

A.2.9 Phase 9.0 - CSM Solo Lunar Orbital Operations

A.2.9.1 No trajectory requirements.

A.2.10 Phase 10.0 - LM Descent

A.2.10.1 Phase 10.1 - LM/CSM Separation

A.2.10.1.1 A two-jet, 0.75 fps delta-V, -X axis LM RCS burn thrusting toward the lunar surface shall be applied. Separation shall occur 30 minutes prior to transfer orbit insertion.

A.2.10.1.2 LM separation shall occur five minutes prior to leaving sunlight to give the CSM capability of visual inspection of LM landing gear, descent engine shutdown probes and descent engine skirt prior to the Transfer Orbit Insertion (TOI) maneuver. In addition

continuous MSFN telemetry and voice coverage is required for the LM from 30 minutes prior to LM/CSM separation until 15 minutes after separation.

A.2.10.1.3 A 4-jet, 6-second ullage burn by RCS thrusters shall precede by 5.5 seconds the ignition of the DPS producing transfer orbit insertion.

A.2.10.2 Phase 10.2 - Transfer Orbit Insertion

Insertion is produced by the following descent engine thrust schedule:

3 seconds at 3150 lbs. thrust (30%)
23 seconds at 1050 lbs. thrust (10%)
Remainder at fixed throttle position (FTP) (nominally at 94.0%)

The above thrusts are based on a reference 100% thrust rating of 10,500 lbs. The maneuver shall place LM into coplanar Hohmann transfer descent orbit having a pericynthion 50,000 feet above the landing site elevation.

A.2.10.3 Phase 10.3 - Coast to Initial Point

A 4-jet, 6-second ullage burn by RCS thrusters shall precede by 5.5 seconds the start of braking by the DPS.

A.2.10.4 Phase 10.4 - Braking

The braking phase from 50,000 feet begins with DPS ignition. The descent engine thrust schedule is as follows:

a. Start-up:
   3 seconds at 3150 lbs. thrust (30%)
   23 seconds at 1050 lbs. thrust (10%)
b. Intermediate:
   Constant fixed throttle period with the thrust variation nominally 94.0% at the beginning and increasing linearly such that the thrust level 400 seconds later would be 5% higher than the initial value.

c. Final:

The final 100 seconds of the braking phase is performed at 60% throttle.

A.2.10.5 Phase 10.5 - Final Approach

A.2.10.5.1 The elevation angle to the landing site during this phase (the angle between the Z-axis of LM and the line-of-sight to the landing site) shall not be greater than 55°. This will then guarantee that the landing site shall be visible to the Commander with a margin of at least 10° above the LM window bottom edge.

A.2.10.5.2 The lo-gate condition shall be: Altitude of 500 feet, inertial range to the landing site of 1200 feet (considering a rotating moon the corresponding relative range will be 2340 ft.), and flight path angle of -20° and velocity of 52 fps relative to landing site; the latter corresponds to a 50 fps forward velocity and a 15 fps descent rate. Attitude rates during LM final approach shall not exceed 10 deg/sec. ?

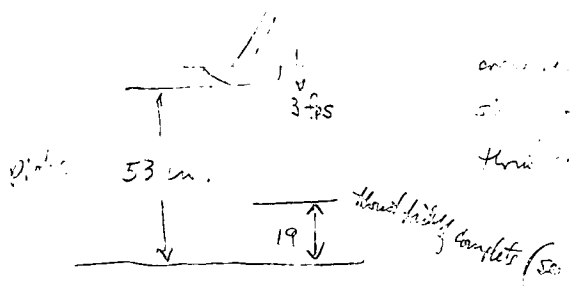
A.2.10.6 Phase 10.6 - Landing

A.2.10.6.1 The LM shall be brought to a pre-touchdown point 100 feet above the landing site with a velocity relative to the landing site of 0 fps forward and 5.0 fps downward.

A.2.10.6.2 The lo-gate-to-touchdown trajectory shall satisfy visibility requirements to the landing site until within 5 seconds of achieving the pre-touchdown point. Manual landing is considered primary.

A.2.10.6.3 From the pre-touchdown point, a vertical descent to the landing site shall be accomplished at a descent rate of 3.0 fps.

A.2.10.6.4 A lunar surface sensing probe contact light will be activated when one of the landing gear pads attains a height of 53 inches above the lunar surface. A subsequent crew reaction time of 0.5 second to activate the descent engine shutdown switch and a shutdown delay time of 0.15 second shall be assumed prior to an exponential thrust decay having a time constant of 0.0436 second (nominally equivalent to a thrust decay time of 0.20 second).



0.5 sec
0.15 sec
0.20 sec
0.85 sec

A 3.2.1.6.5 p A-26

A.2.10.6.5 The LM pitch and roll angles during the landing maneuver shall be maintained to within $\pm 25^{\circ}$. For altitudes between 0 and 100 feet, the maximum pitch and roll angles shall be $\pm 10^{\circ}$.

A.2.10.6.6 The elevation of the sun during the LM landing maneuver shall be within the range of 7° to 20° and the subsolar point shall be east of the landing site.

A.2.11 Phase 11.0 - LM Lunar Stay

A.2.11.1 The planned LM lunar stay shall be no greater than 35 hours.

A.2.11.2 The landing site shall be between $+45^{\circ}$ and -45° selenographic longitude and $+5^{\circ}$ and -5° latitude.

A.2.12 Phase 12.0 - LM Ascent

A.2.12.1 Phase 12.1 - Powered Ascent

The "concentric" flight plan shall be used for the LM ascent phase. Ascent Propulsion Subsystem (APS) propellant shall be assumed to be burned by means of the interconnect, through pulsing +X RCS thrusters to overcome c.g. unbalances. The necessary effective thrust of the APS-RCS thruster combination shall be computed based on the current mass properties c.g. location considering a canted engine to minimize unbalances. The RCS pulsing, using APS propellant through the APS-RCS interconnect, shall begin 10 seconds after lunar liftoff and shall be discontinued 10 seconds prior to the completion of powered ascent. Roll steering shall be used to place the LM into the CSM orbit plane at the 50,000 foot pericynthion of an elliptical orbit having a 30 n. mi. apocynthion.

A.2.12.2 Phase 12.2 - Coast to Concentric Sequence Initiation

No trajectory requirements.

A.2.12.3 Phase 12.3 - Concentric Sequence Initiation

Approximately one-half hour after main ascent burnout, a posi-grade maneuver will be performed by the RCS (2 jets) which will boost the LM into an orbit having a 65 n. mi. apocynthion approximately 180° down range.

A.2.12.4 Phase 12.4 - Coast to Constant Delta Height Maneuver

No trajectory requirements.

A.2.12.5 Phase 12.5 - Constant Delta Height Maneuver

At the 65 n. mi. apocynthion point the ascent trajectory will be circularized using the RCS (2 jets).

A.2.12.6 Phase 12.6 - Coast to Terminal Phase Initiation

No trajectory requirements.

A.2.12.7 Phase 12.7 - Terminal Phase Initiation

The Terminal Phase Initiation (TPI) maneuver shall be performed with the RCS (2 jets) at a preselected elevation angle to the CSM, and shall result in an orbit which intersects the CSM orbit at a point approximately 140° down range from TPI.

A.2.12.8 Phase 12.8 - Terminal Phase Coast

Two RCS midcourse corrections of 30 and 5 fps delta-V (using 2 jets) shall be assumed to result in a change in LM weight during this phase, in addition to expendables. For trajectory computation and planning purposes, no effect on the orbit shall be assumed as a result of these midcourse correction applications.

A.2.12.9 Phase 12.9 - Terminal Rendezvous

Terminal Rendezvous is accomplished manually, utilizing DSKY display of terminal rendezvous control parameters in accordance with the following range, range rate schedule:

Range	Range-Rate (ft/sec)
5 n. miles	100
3 n. miles	25
1 n. mile	10
500 feet	5

In the case of the nominal concentric flight plan, it will not be necessary to exercise the first gate; however, the following three will be used. The RCS (2 jets) will be used for all burns.

A.2.12.10 Phase 12.10 - Docking

At the conclusion of rendezvous a manual maneuver to null range-rate and line-of-sight rates to zero at a point 50 feet directly in front of the CSM docking hatch shall be assumed. Subsequently, a pitchover and +X-axis translation to the soft dock contact point shall follow. A 25 fps delta-V LM RCS expenditure shall be assumed to be applied for docking, in addition to the orientation RCS expenditure and other expendables for this phase.

A.2.13 Phase 13.0 - Coast to Transearth Injection

A.2.13.1 The nominal mission shall extend the lunar parking orbit phase such that the CSM shall make two earth-side passes after jettisoning the LM before transearth injection.

A.2.14 Phase 14.0 - Transearth Injection

A.2.14.1 Injection conditions shall be selected such that the terminal inclination, transit time, and entry corridor constraints are satisfied.

A.2.15 Phase 15.0 - Transearth Coast

A.2.15.1 The transearth transit time shall be less than 110 hours.

A.2.16 Phase 16.0 - Entry

A.2.16.1 Reentry Corridor - The reentry corridor is defined by a negative lift overshoot boundary that guarantees "capture" and an undershoot boundary that permits guided reentry trajectories to targets that are 2500 nautical miles (earth referenced) from the reentry point.

A.2.16.2 Reentry Range - The nominal referenced reentry range from 400,000 feet altitude to touchdown shall not exceed 2500 nautical miles. A spacecraft aerodynamic maneuver capability of at least 1000 nautical miles is required.

A.2.16.3 Return Inclination Limits - The equatorial inclination of the osculating plane, defined by the geocentric radius vector and the inertial velocity vector, shall not exceed 40 degrees at the reentry. All reentry trajectories will be posigrade.

A.2.16.4 Earth Landing Lighting Constraints - There are no natural lighting constraints at earth landing.

A.2.16.5 Cross-range Maneuvering - The nominal reentry trajectory shall not require cross-range maneuver capability.

A.2.17 Phase 17.0 - Parachute Descent

A.2.18 Phase 18.0 Post Landing Through Spacecraft Retrieval

A.2.18.1 Earth Recovery Areas - Recovery of the command module will normally occur in the area bounded by 35°N and 35° S latitudes and 150° W and 170° W longitudes.

A.2.19 General

A.2.19.1 Prior to each powered phase, expendables usage during the previous phases should be considered in computing the spacecraft weight for that phase.

A.2.19.2 Physical constants and conversion factors used in trajectory computations appear in Table VI of "MSC/MSFC Lunar Landing Mission Reference Trajectory, Apollo Mission Planning Task Force, Design Reference Mission II," Volume I, October 1965.

A.3 SYSTEMS OPERATION GROUND RULES

A.3.1 CSM

A.3.1.1 Mission Functional Requirements

A.3.1.1.1 CM-IMU Alignment - TLI - The CM inertial reference alignment for liftoff through translunar injection shall be the same as S-IVB IU alignment.

A.3.1.1.2 CM - Updating of State Vector - The state vector in the CMC shall be updated via MSFN up-data link on the following minimum number of occasions. In each case a minimum of ten minutes of MSFN tracking shall have been obtained prior to the update.

a. Within 30 minutes prior to TLI.
b. Within 30 minutes after TLI
c. Within 60 minutes after each midcourse correction.
d. During every other high bit rate telemetry transmission period between midcourse corrections #2 and #3 and #4 and #5. (Updating and T. V. transmission do not occur during same one-hour periods).
e. During lunar orbits 1, 3, 5, 9, 15, 19, 21, and 24.
f. Within 60 minutes after TEI.
g. Approximately three hours prior to the last transearth midcourse correction.

A.3.1.1.3 Navigation Sighting Schedule - The following navigation sighting schedule shall apply to DRM IIA:

5 star-landmark sightings in the vicinity of the first translunar midcourse correction.
5 star-landmark sightings in the vicinity of the third translunar midcourse correction.
4 landmark sightings in the first lunar orbit
3 landmark sightings in the lunar orbit just prior to LM separation.
9 landmark sightings during CSM solo operations prior to rendezvous and docking, spaced to maintain an accurate knowledge of the orbit ephemeris.
4 landmark sightings after LM jettison and prior to TEI.

A.3.1.2 Subsystem Operational Requirements

A.3.1.2.1 CSM Subsystems Checks in Earth Orbit - A visual or "cockpit" check shall be performed as soon as possible after earth orbit insertion. (All pertinent operating displays will be checked.)

A.3.1.2.2 Guidance and Control Subsystem

A.3.1.2.2.1 The S-IVB Instrument Unit (IU) shall be the primary source of guidance and navigation data for the launch vehicle during the earth ascent phase.

A3.1.2.2.2 The S-IVB guidance subsystem shall be used as the primary control mode through the termination of TLI. Deviations from nominal S-IVB attitudes for CSM earth orbit navigation sightings and IMU alignments, and the attitude required for transposition and docking will be obtained by means of CSM override of the S-IVB attitude control.

A.3.1.2.2.3 Attitude maneuvers subsequent to S-IVB jettison will be accomplished automatically using the G&N via crew DSKY inputs when the G&N subsystem is in operation.

A.3.1.2.2.4 IMU alignments are performed as soon as possible after earth orbit insertion and normally within 15 minutes prior to each orbital navigation sequence, thrusting, and entry.

A.3.1.2.2.5 The IMU shall be in the operate mode for 30 minutes prior to the completion of fine alignment.

A.3.1.2.2.6 PIPA's shall be on at least one hour prior to SPS burns.

A.3.1.2.3 Communications Subsystem

A.3.1.2.3.1 Scheduling of Voice Communications

A.3.1.2.3.1.1 "S" Band voice communications shall be in effect between the CSM and MSFN as follows:

a. For every opportunity during ascent, earth orbit, and throughout transposition and docking.

b. Continuously during the translunar and transearth coast phases.

c. The availability of voice communications shall not constrain the navigation sighting activity.

d. For every opportunity in lunar orbit, except when this would interfere with astronaut sleep periods.

A.3.1.2.3.1.2 VHF/AM voice communications between the CSM and LM shall be in effect during LM checkout, descent, and ascent.

A.3.1.2.3.2 CSM Scheduling of Telemetry

A.3.1.2.3.2.1 Hi-bit rate telemetry shall be transmitted during the ascent phase, earth orbit when CSM-MSFN line of sight exists, TLI through transposition and docking, all SPS delta -V's, the first and last ten minutes of each CSM-MSFN line of sight period in lunar orbit, pre-SPS thrusting including BMAG and IMU alignments, and continuously for one hour out of each consecutive five-hour period during the translunar and transearth coast phases. Passive thermal control shall not be interrupted; therefore, cyclic communication interruptions in telemetry are permissible during the one-hour periods.

A.3.1.2.3.2.2 Lo-bit rate telemetry shall be transmitted continually when CSM-MSFN line of sight exists except when hi-bit rate telemetry is required. During passive thermal control cyclic interruptions in telemetry are permissible.

A.3.1.2.3.2.3 A continuous ten minutes of real time biomedical data for each crewman shall be transmitted during each of the one-hour hi-bit rate telemetry periods scheduled for non-thrusting periods of the translunar and transearth mission phases (ie., 10 min/man/5 hrs).

A.3.1.2.3.2.4 A continuous ten minutes of television shall be transmitted during every other hi-bit rate telemetry transmission period scheduled for non-thrusting periods of the transearth and translunar mission phases (i.e., 10 min/10 hours).

A.3.1.2.3.2.5 Five minutes of real time scientific data shall be transmitted during each of the one-hour high bit rate telemetry periods scheduled for non-thrusting periods of the transearth and translunar mission phases.

A.3.1.2.3.2.6 A check (to include redundant components) of the Telecommunications Subsystem shall be conducted as soon as possible after earth orbit insertion.

A.3.1.2.3.3 CSM-Scheduling of MSFN Updata

A.3.1.2.3.3.1 Updata commands for the telecommunications equipment may be sent by MSFN at any time during the mission when CSM/MSFN line-of-sight exists. Digital updata shall normally be in effect for the onboard computer during the period from 60 minutes before a thrusting maneuver until 30 minutes after the maneuver. Updata for TEI will be transmitted in the last orbital pass before TEI. Updata to the computer will not be accepted during thrusting maneuvers.

A.3.1.2.3.4 CSM Tracking Scheduling During CSM-MSFN Line of Sight - Continuous doppler tracking shall be in effect for all mission phases when CSM/MSFN line-of-sight exists. PRN ranging is required 10 minutes before, during, and 10 minutes following thrusting maneuvers. In addition, PRN ranging will be required intermittently during the coasting phases, approximately 5% of the time.

A.3.1.2.3.5 CSM Scheduling of Data/Voice Recording and Playback

A.3.1.2.3.5.1 Low bit rate telemetry and voice data shall be recorded when CSM-MSFN line-of-sight does not exist.

A.3.1.2.3.5.2 High bit rate telemetry shall be recorded during earth ascent, TLI, during all thrusting maneuvers and entry. Recording shall begin 2 minutes before the thrusting maneuver and continue until 2 minutes after the maneuver.

A.3.1.2.3.5.3 Stored data shall be dumped during coverage from the last MSFN station prior to initiation of translunar injection.

A.3.1.2.3.5.4 A telemetry dump shall be scheduled once per lunar orbit.

A.3.1.2.3.5.5 The CSM will record both CSM and LM lo-bit rate data when the LM and/ or CSM is out of sight of MSFN and LM-CSM line of sight exists.

A.3.1.2.4 Electrical Power Subsystem - (Note: Battery ground rules pertain to the three batteries A, B, and C. Pyrotechnic batteries A and B cannot be charged in flight. Checks of pyro batteries are limited to open circuit voltage readings.)

A.3.1.2.4.1 Pyro batteries shall be checked prior to CM-SM separation, TLI, LOI, and LM separation in lunar orbit.

A.3.1.2.4.2 Batteries A, B, and C shall be recharged for 2 ± .5 hours each as soon as possible after every usage and prior to SM separation.

A.3.1.2.4.3 A general status check of the EPS shall be performed hourly, except during the sleep periods.

A.3.1.2.4.4 A status check of the EPS shall be performed after SM separation and prior to entry.

A.3.1.2.4.5 Fuel cells shall be purged at least once every seven hours as follows: 0_2 purge every 7 hours starting at T-3 hours and H_2 purged every 7 hours starting at T + 30 minutes. These purges are omitted in the timeline during sleep periods.

A.3.1.2.4.6 Fuel cells shall be purged before a delta-V maneuver if waiting to purge until the first opportunity after the delta-V maneuver will result in an elapsed time greater than 7 hours between purges.

A.3.1.2.4.7 The battery charger shall be utilized to the maximum extent possible beginning approximately six hours before the final transearth midcourse correction.

A.3.1.2.4.8 Batteries shall be connected to the main DC power bus before launch and until verification of earth orbit.

A.3.1.2.4.9 Circuits between battery "C" and the post landing bus and between battery busses "A" and "B" and the post landing bus shall be opened prior to the first battery charging and shall remain open until splashdown.

A.3.1.2.4.10 Two of the three entry batteries shall be connected to the main DC power bus before each delta-V maneuver.

A.3.1.2.4.11 Inverters shall be configured at launch and before each delta-V as follows:

Inverter 1 to AC Bus 1

Inverter 2 to AC Bus 2

Inverter 3 "ON" in the idle standby

A.3.1.2.4.12 After transposition and docking the EPS shall be configured for single inverter operation.

A.3.1.2.4.13 After each delta-V the EPS shall be configured for single inverter operation.

A.3.1.2.4.14 AC Load distribution during the mission shall include the following:

Suit compressors and Fuel Cell #1 pumps on A C Bus 1.

Fuel Cell #2 and Fuel Cell #3 pumps on AC Bus 2.

A.3.1.2.5 Environmental Control Subsystem

A.3.1.2.5.1 A general status check of the ECS shall be performed hourly, except during sleep periods.

A.3.1.2.5.2 The first lithium hydroxide (LiOH) filter element in the CSM shall be replaced after 12 manhours of usage. Each element thereafter will have 24 hours ± 15 minutes of usage.

A.3.1.2.5.3 The ECS shall be operated in the maximum cooling mode during prelaunch, launch and for 10 hours prior to entry.

A.3.1.2.5.4 Consecutive meals requiring hot potable water for reconstitution shall be scheduled at least one hour apart.

A.3.1.2.6 Propulsion Subsystem

A.3.1.2.6.1 A status check of the SPS will be conducted every four hours except during sleep periods.

A.3.1.2.6.2 A status check of the SM-RCS (cold fire) shall be conducted every four hours except during sleep period.

A.3.1.2.6.3 A status check of the CM-RCS (cold fire) shall be conducted every 12 hours except during sleep periods.

A.3.1.2.6.4 An additional status check of the CM-RCS (cold fire) shall be conducted two hours prior to SM separation.

A.3.1.2.6.5 Before the CM-RCS is pressurized prior to CM-SM separation, power shall be applied to the fuel and oxidizer valve coils in each of the twelve CM-RCS engines for at least 20 minutes.

A.3.1.2.6.6 An abbreviated check of the service propulsion system, service module reaction control system, and command module reaction control subsystem shall be conducted as soon as possible after earth orbit insertion, consistent with earth orbit constraints.

A.3.1.2.7 Entry Monitor Subsystem

A.3.1.2.7.1 The entry monitor subsystem shall remain on between delta-V's that are separated by less than one hour.

A.3.1.2.7.2 An EMS delta-V check shall be conducted prior to each delta-V.

A.3.1.2.7.3 An EMS test shall be conducted prior to TLI, prior to TEI, and after the third transearth midcourse correction.

A.3.2 LM

A.3.2.1 Subsystems Operation

A.3.2.1.1 Electrical Power Subsystem

A.3.2.1.1.1 Descent Stage Batteries will be used from removal of Mobile Launcher power (nominally 30 minutes prior to launch) until completion of transposition and docking,

when CSM power will be applied to LM. After LM activation in lunar orbit, descent battery power will again be applied and used until 30 minutes prior to launch from lunar surface, except as indicated in paragraph A.3.2.1.1.3.

A.3.2.1.1.2 CSM will furnish LM power from completion of transposition and docking until LM activation in lunar orbit. The maximum power to be furnished by the CSM during this period will be 200 watts.

A.3.2.1.1.3 Ascent Stage Batteries shall be used in parallel with the descent batteries during powered descent and shall be checked out and used as a power source during a 2-minute period during the checkout in lunar orbit and again for 2 minutes during the post landing checkout and for eight additional 2-minute periods during lunar stay. They shall be activated 30 minutes prior to launch from the lunar surface, and used for power from that time until shutdown of LM subsystems after docking.

A.3.2.1.1.4 There shall be open-circuit monitoring capability available for checkout of the pyro batteries.

A.3.2.1.1.5 Batteries in a particular stage will be operated in parallel. All four descent batteries and both ascent batteries will be used simultaneously.

A.3.2.1.1.6 Only one inverter shall be used at a time; however, either inverter may be designated as primary and the other one reserved for backup use.

A.3.2.1.1.7 The descent stage batteries will be supplied with cooling from the primary heat transport subsystem. The ascent stage batteries will have both primary and backup cooling.

A.3.2.1.2 <u>Environmental Control Subsystem</u>

A.3.2.1.2.1 The CSM will furnish oxygen to the LM for the initial cabin pressurization in lunar orbit and up to shortly prior to separation when independent LM cabin maintenance conditions are established.

A.3.2.1.2.2 The LM cabin will be pressurized to 4.8 ± 0.2 psi.

A.3.2.1.2.3 Sufficient oxygen will be provided for four LM cabin repressurizations (to 5.0 psi) and for recharging the PLSS units for a total of 24 manhours of operations. It is noted, however, that due to the pressure requirements at the PLSS oxygen inlet valve, the complete filling of the PLSS units is not possible after the third cabin recharge. See paragraph A.3.2.1.8.2.

A.3.2.1.2.4 The lithium hydroxide (LiOH) canister shall be replaced when the CO_2 partial pressure reaches 7.6 mm Hg (approx. 41 manhours of actual use).

A.3.2.1.2.5 The heat transport subsystem shall remain on at all times after LM activation in lunar orbit until shutdown of subsystem after final docking.

A.3.2.1.2.6 During periods of cabin depressurization, one astronaut or both may connect his suit into the LM suit loop of the atmosphere revitalization section. Suit fans will remain on as required during periods of cabin depressurization.

A.3.2.1.2.7 Cabin fans as required shall be on during periods of pressurization and off during periods of depressurization.

A.3.2.1.2.8 The water supply system shall provide potable water for drinking and reconstitution of meals.

A.3.2.1.2.9 Windows shall be provided with heaters to prevent fogging during any pressurized phases of the mission. Operations of the heaters shall be limited to those windows and phases where observation through the windows is required. The assumed duty cycle of the window heaters will be as follows:

Preseparation - 90 minutes

From separation until 30 minutes after landing.

Lunar stay - 90 minutes after each repressurization and prior to liftoff (one forward window only)

All of ascent until beginning of crew transfer.

A.3.2.1.3 <u>Guidance, Navigation and Control Subsystem</u>

A.3.2.1.3.1 The IMU shall be used for alignment of the AGS and for basic orientation data for the PGNCS.

A.3.2.1.3.2 An IMU fine alignment shall be completed within 15 minutes prior to LM separation, transfer orbit insertion, main powered descent, and CDH. In addition, a lunar surface IMU fine alignment should be completed as soon as possible after touchdown and within 15 minutes prior to liftoff.

A.3.2.1.3.3 The LM rendezvous radar shall track the CSM during the following periods:

Checkout prior to LM insertion, 7 minutes
Coasting descent - 30 minutes
First and last CSM overpasses during stay, 5 minutes each
Prior to lunar liftoff, 3 minutes
From powered ascent burnout until beginning of docking.

A.3.2.1.3.4 The landing radar shall be turned on prior to powered descent as a check on its operation and left on until touchdown. (No data is accepted by the LGC until 25000 feet)

A.3.2.1.3.5 The LM tracking light shall be on during the following phases:

Checkout, 2 minutes
Coasting descent, 30 minutes
From powered ascent burnout until completion of terminal rendezvous.

A.3.2.1.3.6 The IMU shall be in "standby" mode at all times when not in "operate" mode.

A.3.2.1.3.7 The glycol loop shall be on 30 minutes to reach a stabilized temperature prior to operation of the LGC and IMU.

A.3.2.1.3.8 During the pre-separation checkout the IMU shall be in "operate" at least 30 minutes prior to the fine alignment. The IMU should not be in "operate" unless the LGC is in "operate".

A.3.2.1.3.9 In the lunar orbit docked checkout at least 15 minutes shall elapse between coarse alignment and fine alignment to permit test of excessive gyro drift.

A.3.2.1.3.10 The LGC shall be turned on during checkout in lunar orbit. It remains on for all mission phases except that it is placed on standby for the major portion of the lunar stay phase.

A.3.2.1.3.11 The Abort Guidance Section (AGS) shall be in "off" mode during the trans-lunar coast. In lunar orbit coast the AGS shall be placed in "standby" mode for at least one hour prior to the "operate" mode.

The AGS shall be in "operate" mode from the LM preparation checkout phase to the post landing checkout phase. During the lunar stay the AGS shall be placed in the "off" mode. The AGS shall be placed in the "standby" mode for at least an hour prior to the "operate" mode during the pre-launch preparation on the lunar surface.

A.3.2.1.3.12 The Abort Sensor Assembly shall be updated by the IMU as close as feasible to the beginning of planned thrusting maneuvers (5 minutes or less).

A.3.2.1.3.13 The following modes of PGNCS operation shall be used:

(1) Automatic
   (a) Powered flight: 0.3^{o} or 1° deadband, 10 deg/sec max. rate
   (b) Coasting flight except for (c) below: 5° deadband, 3 deg/sec max. rate.
   (c) Ten seconds prior to transfer burn maneuver deadband is changed to 1°.
   (d) Manual yaw available during main thrusting maneuver by yaw controller.

(2) Attitude hold: 0.3^{o} or 5° deadband available by means of LGC DSKY operations, 20 deg/sec max. rate.

(3) Pulse mode: single, minimum impulse per hand controller discretes 0.3^{o} deadband.

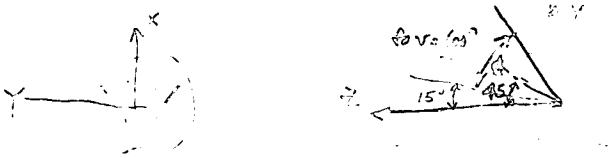
(4) Rate of descent: ± 1 ft/sec discretes per rate of descent select switch during landing maneuver.

(5) Landing point control: $\pm 2^{o}$ azimuth and $\pm 0.5^{o}$ elevation of line-of-sight to landing point per roll and pitch controller discretes, respectively.

A.3.2.1.3.14 LM Tracking Light - The LM tracking light range capability is as follows:

	Visual Range Capability, n. mi.	CSM Sextant Range Capability, n. mi.
Dim	0 - 10	0 - 28
Bright	0 - 130	0 - 400

The LM tracking light will be activated to facilitate optical tracking of the LM by the CSM optics, is flashed at a rate of 60 ± 5/min. with a flash duration of 20 milliseconds. The beacon is visible to the CSM when the line-of-sight vector is within 30° of the LM Z_b-axis.



A.3.2.1.3.15 Inertial Measurement Unit (IMU) - During periods when the LM IMU is in operation, gimbal lock considerations impose limitations upon otherwise allowable orientations and sequences. Gimbal lock problems arise when the IMU outer and inner gimbal axes come within 30° of each other.

During fine IMU alignments, the LM attitude must be inertially constrained so that a suitable star field is in the alignment optical telescope (AOT) field of view. The AOT is a unity powered periscope with a 60-degree field of view. The shaft axis of the telescope is parallel to the X_b - axis, and the optical center line is rotated to set the field of view 15 degrees above the LM vehicle Y_b-Z_b - plane. In this position, the center of the 60-degree field of view will form an angle of 45 degrees with the LM Z_b -axis. By means of a pinion knob, the telescope head assembly can be manually rotated about the shaft axis and 180 degrees for storage. By using detents the three viewing positions (i.e., 0° and $\pm 60^{o}$) are accurately known relative to the body axes. The coverage of two viewing positions overlap by approximately 22 degrees.

A.3.2.1.3.16 Rendezvous Radar (RR) - The overall coverage of the LM rendezvous radar is obtained by using two overlapping regions called "Mode I" (forward sector including the $+Z_b$ - axis), and "Mode II" (overhead sector including the $+X_b$ - axis). The coverage provided by these two modes is specified to cover line-of-sight azimuth angles between -55° to $+55^{o}$ and elevation angles from -70° to 60° for Mode I and $+40^{o}$ to 155° for Mode II. During time-critical phases of the mission, mode switching should be avoided since the target must be reacquired after switching has been completed. The maximum slant range for rendezvous radar tracking is approximately 400 n. mi.

A.3.2.1.3.17 Landing Radar - The LM Landing Radar provides velocity and altitude data during the final portions of powered descent. The landing radar antenna contains a four beam array, three of which measure velocity while the fourth measures slant range between the LM and the lunar surface. The entire beam package has two positions relative to the LM body axis. For altitudes above lo-gate the antenna is in position 1. This places the centerline of the antenna -50.724 degrees from the $-X_b$ axis. For altitudes below lo-gate, the antenna is rotated to position 2. This places the centerline of the antenna +20.576 degrees from the $-X_b$ axis, thereby orienting the slant range beam along the $-X_b$ axis. LM attitudes during the powered descent strongly influence landing radar beam altitude and velocity accuracies.

A.3.2.1.3.18 Continuous MSFN tracking shall be in effect for all mission phases when LM/MSFN line-of-sight exists. It is assumed that MSFN requires at least 10 minutes of continuous tracking to determine the trajectory whenever LM gains line-of-sight or after the completion of LM burns.

A.3.2.1.4 Communications Subsystem

A.3.2.1.4.1 LM-CSM voice communications shall be in effect during LM checkout and all periods of separated LM activity when within CSM line-of-sight. During preseparation checkout, descent, ascent, postlanding checkout, and prelaunch checkout periods communication will be by simplex VHF. During all lunar stay periods communication will be via MSFN relay only except for sleep periods when both simplex VHF and MSFN relay will be available.

A.3.2.1.4.2 LM to CSM data telemetry shall be transmitted at lo-bit rate via VHF during LM orbital operations when not in line-of-sight of MSFN, but within line-of-sight of CSM.

A.3.2.1.4.3 The LM-EVA duplex voice communications shall be available when either astronaut is on the lunar surface. Procedures shall be established to alternate voice communications when both crew men are on the lunar surface.

A.3.2.1.4.4 Only one astronaut at a time may transmit biomedical data to MSFN. Time sharing of biomedical data transmission shall be exercised.

A.3.2.1.4.5 LM-MSFN duplex voice communications shall be available via S-Band whenever LM is in line-of-sight with the earth. Initiation of S-Band may be delayed after LM activation until checkout procedures permit activating and checking-out the S-Band equipment.

A.3.2.1.4.6 The erectable antenna shall be activated as soon as feasible during the first lunar exploration phase, and remains active until 15 minutes prior to liftoff, at which time S-Band will be switched to the steerable antenna. During periods when the erectable antenna is used, the S-Band power amp will not be required except when transmitting TV or hi-bit rate telemetry.

A.3.2.1.4.7 S-Band Steerable Antenna - The steerable antenna is fastened on a two-degree-of-freedom gimbal. The gimballing is defined as follows: The shaft axis is parallel to the LM Y_E axis, the trunnion axis is perpendicular to the shaft axis. Zero shaft angle and zero trunnion angle are when the RF axis (boresight) is parallel to the LM Z_E axis (i.e. when the

trunnion axis is parallel to the LM X_E axis). Positive shaft angle occurs when the RF axis is rotated in the direction from $+Z_E$ toward $+X_E$, and positive trunnion angle occurs when the RF axis is rotated from the X_E-Z_E plane toward the + Y_E axis. The antenna gimbals allow the RF axis to cover the field defined by $-75^o <$ shaft angle $< +255^o$ and $-75^o <$ trunnion angle $< +75^o$. Figure A-1 defines the restricted and unrestricted zones of S-Band communications for both docked and undocked configurations.

A.3.2.1.4.8 S-Band Omni - The two antennas cover equivalent, overlapping regions. The forward S-Band inflight omni antenna covers a 170° cone about a line in the X - Z plane 20° above the +Z axis. The rear antenna covers a 170° cone about a line in the X - Z plane 20° above the -Z axis.

A.3.2.1.5 Mechanical and Structural Subsystem

A.3.2.1.5.1 The landing gear shall be deployed during the LM checkout period prior to separation. An indication of proper extension and lock shall be displayed and a visual check of the landing probes is required.

A.3.2.1.5.2 Both the forward and upper hatches shall permit inflight egress and ingress of astronauts wearing complete protective garments and PLSS back-packs. During lunar surface stay the forward hatch is primary for egress and ingress. The top hatch shall be used only as a back-up. No special provisions are onboard LM to permit ingress or egress from the top hatch.

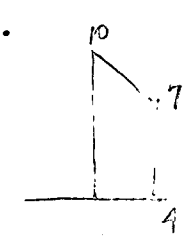
A.3.2.1.5.3 The descent stage storage bays will be accessible from the lunar surface for any safe landing attitude or lunar surface condition in accordance with the LM specification. Where direct access is not feasible, aids for reaching the storage bays will be provided.

Aids will be provided for lowering and raising equipment and sample containers to and from the lunar surface and for carrying scientific equipment during exploration.

A.3.2.1.5.4 The velocity envelope for the landing gear is defined as follows:

(a) At zero ft/sec. horizontal velocity the maximum vertical velocity is 10 ft/sec.

(b) At 4 ft/sec. horizontal velocity the maximum vertical velocity is 7 ft/sec.



A.3.2.1.5.5 That equipment attached to the descent stage which could damage the ascent stage during FITH should be removed at the end of the last EVA.

A.3.2.1.6 Propulsion Subsystem

A.3.2.1.6.1 The first burn of the Descent Propulsion Subsystem (DPS) must be at least 30 seconds duration.

A.3.2.1.6.2 All LM propulsion subsystem firings must be preceded by ullage settling firings of 4 RCS thrusters prior to main engine ignition. Ullage firings of 6.0 seconds duration will be made beginning 5.5 secs prior to DPS ignition and firings of 3.5 secs will be made beginning 3.0 secs before Ascent Propulsion System (APS) ignition. (Only from coasting phases)

A.3.2.1.6.3 There shall be no planned DPS throttle settings between the limits of 60% and maximum thrust as defined by the fixed throttle operating point.

A.3.2.1.6.4 LM RCS engine cumulative operating time shall not exceed 1000 seconds per thruster.

A.3.2.1.6.5 Descent engine shutdown tailoff shall be completed no less than 19 inches above the lunar surface.

A.3.2.1.6.6 Supercritical helium is loaded per nominal mission time requirements. All DPS burns must be made within 1 day of the nominal planned time due to supercritical helium storage limitations.

A.3.2.1.6.7 The APS-RCS interconnect shall not be opened unless the ascent engine is firing.

A.3.2.1.7 Instrumentation Subsystem

A.3.2.1.7.1 The Caution and Warning Electronics Assembly shall be activated at the first practicable time during LM checkout, prior to separation, and shall remain on at all times thereafter.

A.3.2.1.7.2 The Voice Tape Recorder shall have capacity for 10 hours of voice recording. Time signals from the Pulse Code Modulation and Timing Electronics Assembly shall be superimposed on the voice recording. No inflight playback capability exists.

A.3.2.1.7.3 Hi-Bit Rate (HBR) telemetry to MSFN will be transmitted during the orbital phases when within line-of-sight to MSFN, powered descent and ascent mission phases, and periodically during lunar stay.

A.3.2.1.7.4 Telemetry of critical measurements shall be made at Lo-Bit Rate (LBR) to MSFN and shall be transmitted during entire lunar stay phase except when HBR is used.

A.3.2.1.7.5 Telemetry of critical measurements shall be transmitted at LBR to CSM via VHF when not within line-of-sight of MSFN and within line-of-sight of CSM.

A.3.2.1.8 Crew Provisions Subsystem

A.3.2.1.8.1 The waste management section shall provide for transfer of urine, feces, and PLSS condensate from the Extravehicular Mobility Unit to storage containers, which will be off-loaded and stored in the LM descent stage (after lunar surface sampling has been completed). The condensate from the PLSS which is retained for EVA use shall be transferred into the urine storage container used for the ascent phases.

A.3.2.1.8.2 Extravehicular life support equipment and rechargeable consumables (oxygen, water, LiOH, and batteries) shall provide a nominal capability for a total of 24 manhours of separation from the LM. LiOH and batteries shall be replaced after each exploration. The complete oxygen refill will provide 0.92 lb. of oxygen (4800 BTU metabolic). Due to the pressure requirements at the oxygen inlet valve, a full oxygen recharge is not possible after the third cabin recharge. As a result, activities during the fourth exploration period will be limited. Provision shall be made for a single PLSS recharge subsequent to the final exploration for approximately one hour emergency EVA contingency.

A.3.2.1.8.3 The LM has provisions for both astronauts to sleep simultaneously in the following manner: one astronaut will sleep with his head resting on the console and the other will sleep in a sitting position on the engine cover.

A.3.2.2 LM THERMAL

A.3.2.2.1 Rendezvous Radar Thermal Control

Thermal considerations require that the rendezvous radar (RR) antenna dish be pointed away from the lunar surface with the antenna boresight axis oriented parallel to the local vertical when the RR is not being used to acquire and track the CSM during lunar stay. The rendezvous radar antenna can be placed in any orientation for a maximum period not to exceed 9 minutes to accommodate IMU alignment using the central AOT field of view.

A.3.2.2.2 RCS Plume Impingement on LM

The maximum continuous LM RCS X-axis thrusting time is constrained to be 20 sec. and 30 sec. for +X and -X firing, respectively. The maximum CSM RCS -X axis thrusting time is 10 sec. For the case of multiple burns, the allowable firing duration is based on previous firings and the cooldown periods between firings and is defined by:

$$t_b = t_m - \Sigma t_{on} + \frac{1}{60} \Sigma t_{off}$$

where

t_{on} = previous on time, sec.

t_{off} = previous cooldown time, sec.

t_b = allowable firing time, sec.

t_m = 20 sec. for +X LM RCS thrusting
30 sec. for -X LM RCS thrusting
10 sec. for -X CSM RCS thrusting

A.3.2.2.3 Antenna Orientation Due to SM RCS Plume Contamination

Due to the expected SM RCS plume contamination of critical antenna thermal control coatings, antenna travel shall be restricted during certain docked mission phases.

The S-Band Steerable Antenna must remain in the stowed position until preparation checkout. During the pre-separation checkout phase, the antenna may point only in the following areas:

Region I: $+190^{o} <$ shaft angle $< +255^{o}$

$+ 10^{o} <$ trunnion angle $< +75^{o}$

Region II: $- 75^{o} >$ shaft angle $> -10^{o}$

$+ 10^{o} <$ trunnion angle $< +75^{o}$

(See Figure A-1)

A.4 SPACECRAFT ATTITUDE GROUND RULES

A.4.1 CSM

A.4.1.1 Safety and Crew Operations

A.4.1.1.1 Attitude-LM Separation and Jettison - CSM-LM attitude during LM separation and jettison will be constrained by the need to avoid possible subsequent CSM-LM collision.

A.4.1.1.2 Attitude-CM-SM Separation - The Service Module separation attitude and separation time must be scheduled sufficiently in advance to preclude the SM-CM collision and assure that adequate time exists to assume the entry attitude. (SM jettison will normally occur 7 - 10 minutes prior to entry interface at 400,000 ft.)

A.4.1.1.3 Attitude for CSM or LM IMU Alignments, Docked - CSM or LM IMU alignments for the docked configuration shall be accomplished in such a manner that other attitude constraints are not violated.

A.4.1.2 Thrust and Lift Vector Control

A.4.1.2.1 Attitude-Powered Flight - During all powered phases the thrust vector pointing constraint shall take precedence over all other attitude constraints.

A.4.1.2.2 Attitude-Roll Freedom - Except during boost and entry, roll attitude may be chosen to satisfy communications and other constraints compatible with thrust and lift vector pointing.

A.4.1.3 Thermal

A.4.1.3.1 Earth Parking Orbit - The attitude shall be constrained such that the spacecraft X-axis is approximately parallel with the local horizontal and pointed in the direction of flight. Roll attitude about the X-axis shall be arbitrary.

A.4.1.3.2 Translunar coast - The maximum continuous period during which the CSM is constrained for non-thermal control reasons shall not exceed 3 hours. Any hold period

during this phase must be followed by a passive thermal control period 5 times the hold period except the last 3 hours prior to lunar orbit insertion.

The minimum period is described by a .50 hour hold period (following S-IVB separation) followed by a 15-hour passive thermal control period, and subsequent 15-minute hold periods and 1-3/4 hour passive thermal control periods. The last 3 hours prior to lunar orbit insertion are in attitude hold.

A.4.1.3.3 Lunar Orbit - The ECS radiators impose restrictions upon the orientation of the vehicle in lunar orbit. The chordal planes of the radiators must be within 25 degrees of the local vertical when the CSM is within 25 degrees of the subsolar point on the moon. A deviation from this constraint is admissible for a maximum of three consecutive orbits for a total of eight times per mission.

A.4.1.3.4 Transearth Coast - The maximum continuous period is the same as translunar coast except the initial attitude hold period is 2 hours followed by 15 hours of passive thermal control. The minimum period is the same as that described in translunar coast phase.

A.4.1.4 Communications

A.4.1.4.1 Attitude - Voice Communications and Tracking - Attitudes which provide for the capability for up-voice communications and two-way doppler tracking between the CSM and the MSFN must exist at every point in the mission where CSM-MSFN line-of-sight exists.

A.4.1.4.2 Attitude - Hi-Gain Communications, Restoration - The capability to reorient and restore "high-gain" communications with the MSFN must be available throughout all mission phases whenever line-of-sight exists. During the translunar and transearth phases when passive thermal control is normally required, the PTC may be interrupted when necessary for communications, for periods not to exceed three hours. Such interruptions must be followed by passive thermal control periods as specified in the previous section.

A.4.1.4.3 Attitude - Earth Orbit Omni - Communications - While the S-IVB and spacecraft are in earth orbit, body orientations will avoid placement of MSFN stations within the null zone of the CSM and S-IVB omni-directional antennas.

A.4.1.4.4 Attitude-TLI Through Transposition and Docking - During translunar injection, communications with MSFN (using omni-directional antennas) must be available. After deployment of the SLA panels at initiation of transposition and docking, the high-gain antenna is deployed. Continuous hi-bit rate telemetry and voice are required throughout the transposition and docking maneuvers.

A.4.1.4.5 Attitude - Midcourse Communications - Subsequent to transposition and docking, when thermal constraints are not in conflict, attitude must be compatible with high-gain antenna communications. During midcourse phases, high-gain antenna communications must be available at least 50% of the time during normal operations, except during thrusting maneuvers when 100% communications is required subject to thrust vector control (TVC) priority.

A.4.1.4.6 Attitude-Communications CSM-Solo - During LM - CSM separated operations (except during lunar surface stay), the CSM attitude must accommodate simultaneous communications with the earth (over the S-band high-gain antenna) and the LM (using the VHF omni-directional antenna). During CSM astronaut sleep periods, the CSM attitude must be such as to accommodate CSM/MSFN communications.

A.4.1.4.7 Attitude-LM Monitor - CSM orientation will be compatible with the CSM rendezvous radar transponder and visual techniques employed to monitor LM descent and ascent.

A.4.1.5 Navigation and Guidance

A.4.1.5.1 Attitude-Gimbal Lock - Whenever the Apollo inertial platform is in operation, no attitude shall be assumed which will result in gimbal lock.

A.4.1.6 Structural

A.4.1.6.1 Attitude-Structural Constraints - Except just prior to entry, structural considerations shall not impose requirements for special attitudes or attitude sequences. Approximately one hour before the final transearth midcourse correction, the pre-entry heat shield cool-down will be provided by pointing the minus X axis generally sunward so as to keep the CM conical surface in shadow.

A.4.2 LM

A.4.2.1 Safety and Crew Operations

A.4.2.1.1 Astronaut Visibility - LM Separation Phase - During the LM separation phase, the LM orientation profile shall allow a visual check of the descent stage structure including landing gear locking mechanisms, engine, and lunar surface sensing probes, by the astronaut in the CSM.

A.4.2.1.2 Astronaut Visibility - Powered Descent and Ascent - Visibility of the lunar surface during the powered descent braking phase and powered ascent is highly desired although not mandatory. Visibility of the landing site during final approach and landing is required in accordance with the trajectory ground rules. During powered ascent visibility of the lunar surface is desired in the absence of other attitude constraints.

A.4.2.1.3 Astronaut Visibility - Terminal Rendezvous and Docking - For LM/CSM separation ranges greater than 50 feet, visibility of the CSM through the LM forward windows is required during rendezvous and docking. During docking, after the 50 ft. pitchover, visibility of the CSM docking target through the upper LM window is required.

A.4.2.2 Thrust Vector Control

Thrust vector requirements take precedence over all other pointing requirements in preparation for and during all powered flight maneuvers. Rotation about the thrust axis may be used to satisfy other attitude requirements.

A.4.2.3 Communications

A.4.2.3.1 MSFN Voice Communications and Tracking - From LM subsystem activation to jettison, the capability for voice communications, ranging and telemetry between LM and MSFN must be available at every point in the mission where LM-MSFN line-of-sight exists. This communication shall normally be accomplished using the LM S-Band directional antenna; however, during preseparation periods when CSM landmark sightings are being taken (within $\pm 30^{\circ}$ longitude), it may be necessary to switch to the LM omnidirectional antennas to assure LM/MSFN communications.

A.4.2.3.2 VHF LM-CSM Communications - From LM subsystem activation to jettison, the capability for LM-CSM VHF communications must be available at every point in the mission where LM-CSM line-of-sight exists.

A.4.2.4 Navigation and Guidance

A.4.2.4.1 Gimbal Lock - IMU gimbal lock shall be avoided during all operations with the exception of the docking operation where visual cues are adequate for attitude adjustment.

A.4.2.4.2 Rendezvous Radar - Coasting Flight - While LM rendezvous radar tracking data is being used to update LGC, the LM shall be oriented such that the radar view of the CSM is unobstructed by LM structure.

A.4.2.4.3 Rendezvous Radar Bias - In order to perform the LGC-RR angle bias compensation, the LM will be oriented so that the +Z-body axis initially lies within ±30 degrees line-of-sight angle limits, and that attitude will be held within the limit cycle. When the tracking line-of-sight reaches ±30 degrees with respect to the LM Z-body axis, the LM shall be re-oriented such that the +Z-body axis is again within the tracking line-of-sight angle limits. These attitude constraints will apply during the rendezvous radar tracking periods of the concentric flight plan, from orbit insertion to the completion of rendezvous.

A.4.2.4.4 Tracking Light - During all coast periods when CSM tracking of LM is required LM shall be oriented such that the CSM lies within a 30° semi-vertex cone about the LM Z-axis.

A.4.2.4.5 Landing Radar - During the LM powered descent from 40,000 feet until touchdown, the landing radar slant range beam and velocity beams are to be pointed toward the lunar surface. However, no data is accepted by the LGC until 25,000 feet.

A.5 CREW ACTIVITY GROUND RULES

A.5.1 CSM

A.5.1.1 CSM Crew Complement and Positions - The Apollo flight crew shall consist of three crewmen: Commander, Navigator, and Systems Engineer. They shall assume the positions at left hand, center, and right hand couches, respectively, during pre-launch, ascent, translunar injection, transposition and docking, all delta-V maneuvers, and entry.

A.5.1.2 Crew Duties and Training - All crewmen shall be cross-trained and shall assume any duties as required by the work/rest cycle. The Commander and Systems Engineer shall man the LM during lunar orbit operations. The Navigator shall man the CSM during periods of LM separation.

A.5.1.3 Crew Stations

A.5.1.3.1 Crew Manning of Watch Stations - The CSM watch station shall be the right hand couch. Watch station duties shall include monitoring and checking system status, as well as logging flight information. The crewman in the watch station shall be responsible for system management. The watch station shall be manned at all times except when critical operations require the crew elsewhere.

A.5.1.3.2 Crew Duty Station - The duty station shall be any place in the CSM at which crew activity is required other than the watch station.

A.5.1.3.3 Crew Manning of Attitude Control Function - During periods when the automatic attitude control system is operative, a rotational controller shall always be available to to a crewman in case of a failure in the automatic control system.

A.5.1.4 Crew Work/Rest Cycles

A.5.1.4.1 Passive Mission Phases

A.5.1.4.1.1 During the translunar and transearth coast phases, the crew shall adhere to a nominal work/rest cycle of eight hours sleep and sixteen hours work. The crew shall be awake during the checkout, preparation for, and duration of all thrusting maneuvers.

A.5.1.4.1.2 All crewmen shall sleep simultaneously during coast phases.

A.5.1.4.1.3 During sleep periods, the ground will monitor spacecraft systems and will have the ability to awaken the crew if necessary.

A.5.1.4.1.4 All system status will be monitored and telecommunications mode changes will be made by MSFN during sleep periods.

A.5.1.4.2 Crew Work/Rest Cycle - Preparation for Lunar Orbit - Prior to and subsequent to lunar orbit, the crew shall assume a work/rest cycle compatible with the cycle to be used in lunar orbit. The aim of this work/rest cycle transition is to assure 8 hours sleep for each crewman each 24-hour period during the lunar operations phase.

A.5.1.4.3 Navigator Work/Rest Cycle - Lunar Orbit - During lunar orbit, the Navigator shall assume a sleep pattern consistent with his tasks and also with the requirements of a maximum of eighteen hours without sleep and as near as possible of eight hours rest per 24-hour period.

A.5.1.5 Crew Nourishment Schedule

Each crewman shall be provided three hot meals and one snack each 24-hour period. Meals are scheduled nominally between four and six hours apart.

A.5.1.6 Total Crew Utilization of the Pressurized Garment Assembly (PGA)

Except for brief individual periods for eating and personal hygiene, all crewmen shall be in their PGA's with the helmet on during pre-launch and through transposition and docking, from LOI through transearth injection, and during entry.

A.5.1.7 Minimum Crew Utilization of PGA

At least one crewman shall be in a PGA at all times.

A.5.1.8 Atmospheric Control - Partial Utilization of PGA

Partially suited modes; that is, with helmet and/or gloves off shall be for a minimum time. If the partially suited mode is utilized, sufficient fully suited or unsuited mode time must be permitted to remove moisture from the cabin atmosphere.

A.5.1.9 Normal Requirements for Pressurizing PGA

The PGA is pressurized during the integrity check at initial CSM entry, at each PGA donning, and during any CSM depressurization.

A.5.1.10 Crew Stations During Docking

During docking, the astronauts shall remain in their protective harnesses or couches until an initial structural connection of the docking mechanism is completed.

A.5.1.11 Waste Management

For purposes of generating timelines, the following schedule shall be assumed: Urination, once every four hours; defecation, once per day; and personal hygiene, once per day.

A.5.2 LM

A.5.2.1 LM Crew Complement and Positions

The LM flight crew shall consist of two crewmen: Commander andSystems Engineer. They shall assume the positions at left hand and right hand flight stations respectively, during all maneuvers from LM separation through docking maneuvers.

A.5.2.2 Crew Duties and Training

LM crewmen shall be cross-trained to assume any duties required by the work/rest cycle, and will assist one another as required during periods of peak activity including landing, docking, and lunar exploration.

A.5.2.3 Crew Manning of Watch Duty

The LM watch duty shall include monitoring and checking system status, as well as maintaining CSM and MSFN communications. The crewman in the watch station shall be responsible for system management. The watch station shall be manned at all times except when both crewmen are scheduled to sleep between lunar explorations, when both crewmen are scheduled to be on the lunar surface, or when specific operations require the crew elsewhere.

A.5.2.4 LM Crew Work/Sleep Cycles

Maximum awake time shall not exceed eighteen hours for any crewman. The initial sleep period on the lunar surface shall be at least six hours. A minimum sleep period of four hours will be provided in every case. Both crew members will be awake during periods

of LM checkout, LM descent and LM ascent.

A.5.2.5 LM/CSM Crew Work/Sleep Cycles

The CSM work/sleep cycles shall be adjusted before and after LM operations to be compatible with LM work/sleep cycles. During the LM operations the Navigator's work/sleep cycles shall be compatible with the work/sleep cycles of the LM. The Navigator will be awake until after the first pass of the CSM over the landing site following the LM touchdown and prior to the last CSM pass over the landing site prior to liftoff.

A.5.2.6 Crew Nourishment Schedule

Each crewman shall be provided three main meals during each 24-hour period. Meals are scheduled nominally between four and six hours apart.

A.5.2.7 Waste Management

Procedures shall be established to minimize contamination of the lunar surface by crew or equipment. An effective means shall be provided for confinement and disposal of wastes during the lunar stay.

A.5.2.8 Utilization of PGA

During LM operations both astronauts will wear helmets and gloves except for brief individual periods of eating and personal hygiene. Gloves may be changed in preparation for extravehicular activities.

A.5.2.9 Spacesuit Operations

The maximum pressurized suit time to which a crewman will be normally scheduled is three hours.

A.5.2.10 Alarm Monitoring

Both crewmen shall be able to hear the master alarm during sleep periods.

A.5.2.11 Lunar Orbit Checkout

The initial inflight checkout of LM will be performed after the astronauts enter the LM in lunar orbit. Pre-separation checkout will require approximately 1-3/4 hours which includes the RCS "Hot Fire" checkout. From LM/CSM separation to transfer orbit insertion, approximately 30 minutes are required to perform the necessary checkout, visual inspection, and pre-thrusting operations.

A.5.2.12 Lunar Stay Checkout

A limited checkout (approximately 30 minutes) of critical subsystems including shutdown operations will be performed after lunar landing. Preparation for first exploration, including checkout of suit and PLSS units, takes approximately 1-1/4 hours. Periodic subsystem status checks will be performed during each internal activity period. Following the last EVA-period, a complete checkout (approximately 1 hour) including the "Hot Fire" checkout of the RCS jets plus all of subsystems in the ascent stage will be performed prior to launch from the lunar surface.

A.6 CSM AND LM INTERRELATIONSHIPS

A.6.1 Transposition and Docking

The LM docking lights shall be turned on during deployment of the SLA panels at the beginning of transposition. The lights shall be turned off upon LM/SLA separation.

A.6.2 Tracking

CSM and LM attitudes are constrained by the tracking devices (i.e., optics, radar, etc.) during periods of separation LM and CSM activity. The LM rendezvous radar must acquire and track the CSM transponder and the CSM optics must acquire and track the LM beacon. Attitudes during tracking phases must be compatible with communications requirements.

A.6.3 Communications

In order to maintain a communications capability whenever line-of-sight exists between the CSM and LM and a MSFN station, body orientations should avoid placement of the station within the null zones of the communications system as discussed earlier. In addition, while the LM and CSM are separated, attitudes should be favorable for VHF communications between the two vehicles.

A.6.4 Thermal

See paragraphs A.3.2.2.2 and A.3.2.2.3

A.6.5 Rendezvous and Docking

A.6.5.1 Both the CSM and LM shall be capable of performing the rendezvous and docking maneuvers required. The passive vehicle shall be attitude stabilized.

A.6.5.2 During docking maneuvers, attitude of the CSM and LM shall be constrained such that proper alignment of the two vehicles is achieved. In the docked configuration, the CSM and LM positive X axes are joined such that the LM positive Z axis and the CSM negative Z axis make an angle of $60^{\circ} \pm 10^{\circ}$ as measured from CSM negative Z toward CSM positive Y axis.

A.6.5.3 When docking is performed in sunlight, the docking interface of the passive vehicle should be in direct sunlight. The angle between the X axis of the active vehicle and sun should be greater than 90° to avoid glare interference with visibility from the

active vehicle.

A.6.5.4 During terminal rendezvous and docking, attitude must be constrained such that, for LM/CSM separation ranges greater than 50 feet, visibility of the CSM through the LM forward windows is required during rendezvous and docking. During docking, after the 50 foot pitchover, visibility of the CSM docking target through the upper LM window is required.

A.6.6 CSM/LM Pressurization

CSM oxygen shall be used to pressurize the docking tunnel and the LM cabin prior to crew transfer from CSM to LM. The LM shall pressurize the docking tunnel prior to crew transfer from the LM to the CSM.

A.6.7 LM Jettison

LM shall be left in attitude hold mode with subsystems operating at the time the last crewman transfers to the CSM prior to LM jettison. This will allow continuing telemetry to examine subsystem equipment operation time above the nominal mission. One of the S-Band omni antennas shall be used for this purpose.

A.7 SPACECRAFT DESIGN LIMITATIONS

A.7.1 CSM

A.7.1.1 Launch Window

The spacecraft is designed with the capability to be launched on any day of the month, (consistent with natural environment considerations), during the single daily launch window that provides optimum performance.

A.7.1.2 CSM Mission Duration

The CSM is designed for a mission duration not exceeding 14 days from earth liftoff to earth landing.

A.7.1.3 Single Crew Member Operation

The Command Module (CM) design is such that a single crew member can, while in lunar orbit, perform all essential CM operations for at least two days.

A.7.1.4 Earth Landing Design

The CM is designed for a primary earth landing on water and emergency landing on land.

A.7.1.5 Spacecraft Retrieval Design

The CM shall provide a habitable environment and provisions for the crew for two days after landing. CM is capable of floating for seven days after landing.

A.7.1.6 Launch Vehicle/CSM Guidance During Earth Ascent

The launch vehicle guidance system is used to guide the vehicle until the termination of translunar injection (TLI). In addition, CM G&N has the capability to assume the guidance function subsequent to S-II ignition.

A.7.1.7 Astronaut Control Capability During Earth Ascent

The astronaut can take over control of the S-IVB reaction jets for attitude control from earth orbit insertion to separation of the CSM from the S-IVB/LM.

A.7.1.8 S-IVB Design Capability

The S-IVB attitude control function is available for 6.5 hours after launch.

A.7.1.9 Spacecraft Sterilization

Sterilization of the Apollo spacecraft or launch vehicle is not required.

A.7.1.10 LM-CSM Rendezvous Capability

Both the CSM and LM are capable of performing the rendezvous and docking maneuvers required. The passive vehicle is attitude stabilized.

A.7.2 LM

A.7.2.1 LM Mission Duration

The LM is capable of meeting its nominal design performance level for a 48-hour mission following separation in lunar orbit to soft dock. In addition, certain subsystems functions are required during the period from pre-launch to separation, and after rendezvous and docking with the CSM.

A.7.2.2 LM Lunar Stay Design

The LM is designed to accommodate lunar surface day or night extremes, but not on the same mission. Subsystems will not be required to be modified for such accommodation, but expendables may vary depending on the particular mission to be flown.

A.7.2.3 Manual Control Capability

Provision is made for LM rendezvous, docking and landing maneuvers to be controlled manually. Manual backup control is available during other phases for contingency operations.

A.7.2.4 LM Pressurization During Lunar Stay

The LM is designed so that it can be left unoccupied with the cabin unpressurized on the lunar surface during periods of exploration. For the case of worst thermal environment (landing with a 90° sun elevation angle), it may be required to limit the maximum unpressurized period, and further to require a pressurized period of equal duration, in order to maintain cabin and equipment temperatures within operating limits.

A.7.2.5 LM Sterilization

Sterilization of the LM is not required.

A.7.2.6 LM Consumables

LM consumables shall be loaded for a 48-hour mission from LM separation in lunar orbit to initial (soft) docking.

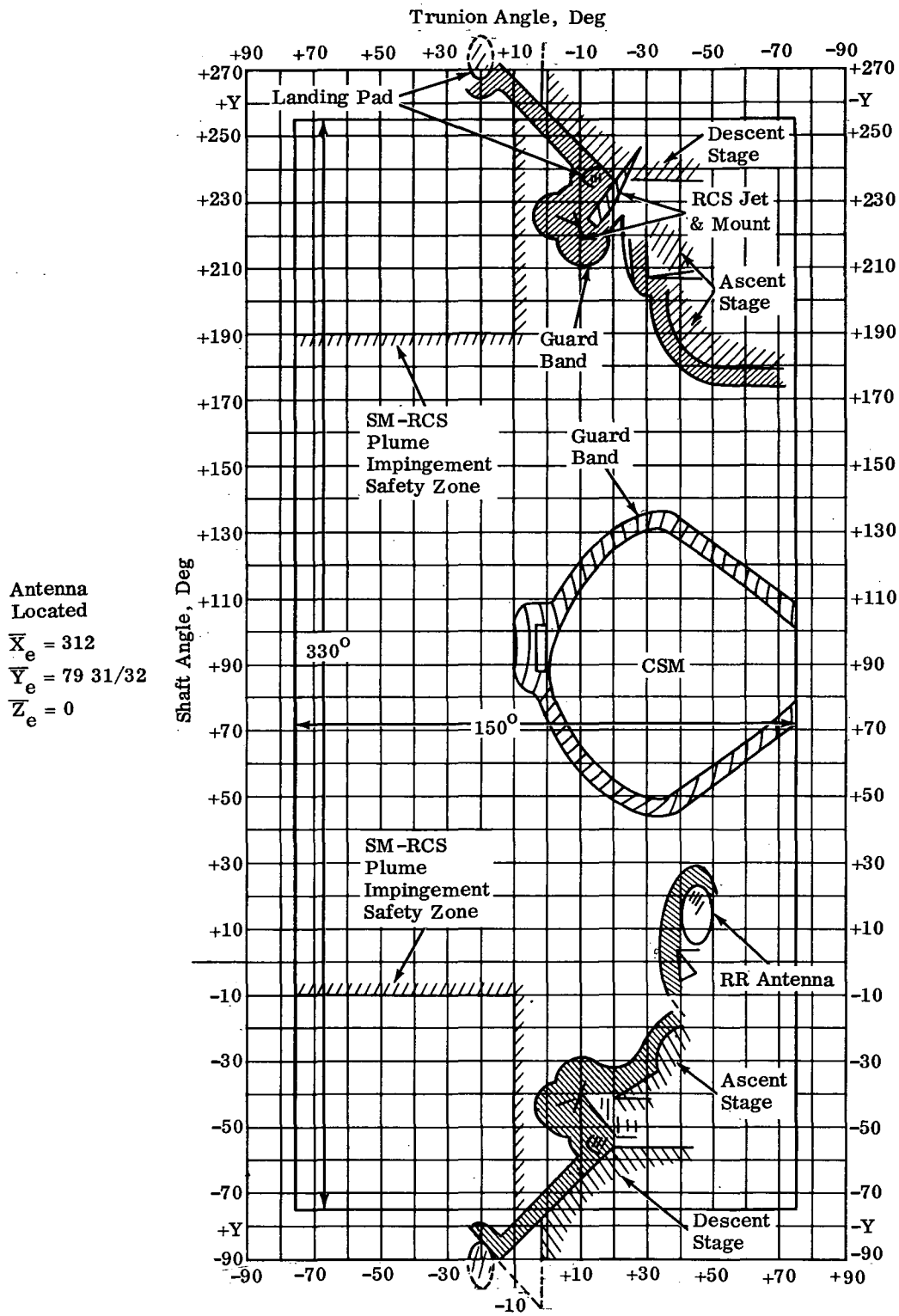


Figure A-1 LM S-Band Steerable Antenna Angular Coverage on Projection of Sphere

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APPENDIX B MISSION COMMUNICATIONS AND LIGHTING

The CSM and LM both provide S-Band voice, telemetry at hi and lo-bit rates, ranging, tracking and television for MSFN receivers. It is to be noted, however, that the LM can not transmit television except from the lunar surface. In addition to these capabilities, the CSM provides the updata, recorded data and voice playback, and scientific data transmission.

Both the CSM and LM have mutual VHF voice communication capabilities and the LM has the capability of transmitting lo-bit rate telemetry to the CSM to be stored on tape, for later playback to MSFN receiving stations.

For recovery operations, the CSM provides HF two-way voice and beacon transmission communications.

The launch vehicle Instrument Unit provides the capabilities of telemetry, tracking, ranging, and updata at S-Band, as well as telemetry at VHF and tracking at C-Band. The three launch vehicle stages have VHF telemetry capabilities and range safety destruct.

Tables B-1 and B-2 show the Manned Space Flight Network (MSFN) capabilities to support the spacecraft and launch vehicle communication functions. Table B-1 illustrates the ground based station capabilities and Table B-2 illustrates the ship and aircraft capabilities. It should be noted that the ground based stations have identical capabilities except that Madrid, Canberra, and Goldstone stations have the ability to receive television from the lunar surface.

Table B-3 shows the geodetic locations of the ground base stations and the supporting ships. Table B-4 shows the time history of acquisition and loss of spacecraft communications with ground based station and supporting ships during the lunar mission.

The mission illumination timeline is presented in Table B-5.

CALL SIGN	STATION	S-BAND							VHF		HF	C BAND
		VOICE	SC, SIVB & ALSEP TLM	TRACKING & RANGING	UP DATA	TV	ANT. DISH (FT) 30	ANT. DISH (FT) 85	VOICE	SIVB TLM	VOICE/ BEACON	SIVB TRACKING
MLA/CNV	CAPE KENNEDY	X	X	X	X		X		X	X		X
BDA	BERMUDA	X	X	X	X		X		X	X		X
GBM	GRAND BAHAMA	X	X	X	X		X		X	X		X
GTI	GRAND TURK								X	X		X
ANG	ANTIGUA	X	X	X	X		X		X	X		X
ACN	ASCENSION	X	X	X	X		X		X	X		X
CYI	GRAND CANARY	X	X	X	X		X		X	X		X
MAD	MADRID	X	X	X	X	X		X				
CRO	CARNARVON	X	X	X	X		X		X	X		
CNB	CANBERRA	X	X	X	X	X		X				
GWM	GUAM	X	X	X	X		X		X	X		
HAW	HAWAII	X	X	X	X		X		X	X		X
CAL	PT. ARGUELLO								X			X
GDS	GOLDSTONE	X	X	X	X	X		X				
GYM	GUAYMAS	X	X	X	X		X		X	X		
TEX	CORPUS CHRISTI	X	X	X	X		X		X	X		

TABLE B-1 MSFN GROUND STATION CAPABILITIES

CALL SIGN	STATION	S-BAND								VHF		HF	C BAND
		VOICE	S/C, SIVB & ALSEP TLM	TRACKING & RANGING	UP DATA	TV	ANT DISH (FT) 30	ANT DISH (FT) 85	VOICE	SIVB TLM	VOICE/ BEACON	SIVB TRACKING	
S-1	INSERTION-SHIP NO. 2	X	X	X	X		X		X		X	X	
S-2	INJECTION-SHIP NO. 2	X	X	X			12'		X		X	X	
S-3	INJECTION-SHIP NO. 3	X	X	X	X		X		X		X	X	
S-4	REENTRY-SHIP NO. 4	X	X	X			12'		X		X	X	
S-5	REENTRY-SHIP NO. 5	X	X	X			12'		X		X	X	
A/C	INSTRUMENTATION A/C (8)	X	X	X					X	X			
RECOVERY FORCES				X					X		X		

TABLE B-2 MSFN SHIP AND AIRCRAFT CAPABILITIES

TABLE B-3

TRACKING STATIONS & LOCATIONS

Station Name	Geodetic Latitude (Degrees)	Geodetic Longitude (Degrees)
Cape Kennedy	28.508	-80.527
Bermuda	32.351	-64.658
Atlantic Ship	26.00	-47.00
Indian Ocean Ship	-25.00	53.00
Carnarvon	-24.908	113.724
Pacific Ship	4.4	183.9
Hawaii	22.128	-159.667
Point Agruello	34.583	-120.561
Goldstone	35.342	-116.873
Guaymas	27.963	-110.721
Corpus Christi	27.654	-97.378
Ascension	-7.955	-14.328
Madrid	40.455	-4.167
Guam	13.583	144.925
Re-entry Ship No. 1	27.0	173.0
Re-entry Ship No. 2	12.5	159.3

TABLE B-4 MANNED SPACE FLIGHT NETWORK COVERAGE

EARTH LAUNCH/PARKING ORBIT

STATION	ACQUISITION*			LOSS*		
CAPE AREA	00	00	50**	00	07	26**
BERMUDA	00	06	00**	00	12	19
ATLANTIC SHIP	00	09	24	00	17	00
INDIAN OCEAN SHIP	00	38	00	00	45	15
CARNARVON	00	51	57	00	59	06
PACIFIC SHIP	01	08	55	01	16	40
HAWAII	01	17	10	01	23	40
POINT ARGUELLO	01	26	43	01	32	55
GOLDSTONE	01	27	35	01	33	41
GUAYMAS	01	28	15	01	35	22
CENTRAL TEXAS	01	31	19	01	38	27
CAPE KENNEDY	01	35	06	01	42	00
TRANSLUNAR COAST						
BERMUDA	01	38	39	01	48	58
ASCENSION	01	46	46	02	35	00
MADRID	01	50	33	10	19	55
GOLDSTONE	09	53	18	18	50	31
CANBERRA	13	24	25	28	21	36
MADRID	27	14	10	35	25	20
GOLDSTONE	34	32	00	43	24	56
CANBERRA	37	56	29	52	39	49
MADRID	51	25	59	59	41	03
GOLDSTONE	58	40	26	63	13	07
CANBERRA	62	04	47	63	13	07
LUNAR ORBIT COAST						
GOLDSTONE - CSM/LM	63	50	27	65	07	26
CANBERRA - CSM/LM	63	50	27	65	07	26
GOLDSTONE - CSM/LM	65	53	31	67	09	32

** Uses 5° mask for acquire & loss

*Time in hrs., min. & sec. from liftoff

TABLE B-4 MANNED SPACE FLIGHT NETWORK COVERAGE (continued)

LUNAR ORBIT COAST

STATION	ACQUISITION*			LOSS *		
CANBERRA - CSM/LM	65	53	31	67	09	32
GOLDSTONE - LM	67	55	42	69	12	02
GOLDSTONE - CSM	67	55	42	69	12	12
CANBERRA - LM	67	55	42	69	12	02
CANBERRA - CSM	67	55	42	69	12	12
CANBERRA - CSM	69	58	22	71	14	29
CANBERRA - LM	69	59	45	79	14	57
CANBERRA - CSM	72	00	39	73	16	46
CANBERRA - CSM	74	03	14	75	19	21
CANBERRA - CSM	76	05	38	77	21	45
MADRID - LM	78	08	00	86	44	43
MADRID - CSM	78	08	00	79	24	08
CANBERRA - CSM	78	08	01	79	14	57
MADRID - CSM	80	10	24	81	26	31
MADRID - CSM	82	12	47	83	28	54
MADRID - CSM	84	15	11	85	31	16
GOLDSTONE - LM	85	25	39	95	00	32
GOLDSTONE - CSM	85	25	39	85	31	16
MADRID - CSM	86	17	35	86	44	43
GOLDSTONE - CSM	86	17	35	87	33	40
GOLDSTONE - CSM	88	19	58	89	36	03
CANBERRA - LM	88	55	53	103	52	45
CANBERRA - CSM	88	55	53	89	36	03
GOLDSTONE - CSM	90	22	20	91	38	26
CANBERRA - CSM	90	22	20	91	38	26
GOLDSTONE - CSM	92	24	43	93	40	49
CANBERRA - CSM	92	24	43	93	40	49
GOLDSTONE - CSM	94	27	07	95	00	32
CANBERRA - CSM	94	27	07	95	43	13
CANBERRA - CSM	96	29	31	97	45	36
CANBERRA - CSM	98	31	54	99	47	59

*Times in hrs., min. & sec. from liftoff

TABLE B-4 MANNED SPACE FLIGHT NETWORK COVERAGE (continued)

STATION	LUNAR ORBIT COAST ACQUISITION*			LOSS*		
CANBERRA - CSM	100	34	17	101	50	22
CANBERRA - CSM	102	36	41	103	52	45
MADRID - LM	102	39	21	105	53	35
MADRID - CSM	102	39	21	103	52	45
MADRID - CSM	104	39	04	105	55	08
MADRID - CSM	106	41	27	107	57	31
MADRID - LM	106	41	49	107	57	31
MADRID - CSM/LM	108	43	50	109	59	54
CANBERRA	112	35	14	126	11	43
GOLDSTONE	112	35	14	117	46	32
MADRID	124	49	57	134	05	16
GOLDSTONE	132	09	06	141	55	02
CANBERRA	136	23	27	150	13	04
	TRANSEARTH COAST					
MADRID	148	51	37	158	20	24
GOLDSTONE	156	13	11	166	12	14
CANBERRA	160	40	42	174	17	52
MADRID	172	58	46	182	53	41
GOLDSTONE	180	26	06	191	01	43
CANBERRA	185	25	24	198	35	44
GUAM	186	37	43	200	21	01
CARNARVON	188	08	25	200	05	29
MADRID	198	17	35	199	34	43
RE-ENTRY SHIP 1	200	20	09	200	27	09
RE-ENTRY SHIP 2	200	26	09	200	41	46

*Times in hrs., min. & sec. from liftoff

TABLE B-5 MISSION ILLUMINATION TIMELINE

LIGHTING	ENTER	EXIT
EARTH PARKING ORBIT		
EARTH PENUMBRA	000 51 18	000 51 26
EARTH UMBRA	00 51 26	001 28 44
EARTH PENUMBRA	001 28 44	001 28 52
TRANSLUNAR COAST		
MOON PENUMBRA	062 44 54	062 45 23
MOON UMBRA	062 45 23	
LUNAR ORBIT COAST		
MOON UMBRA		063 24 32
MOON PENUMBRA	062 24 32	063 24 43
MOON PENUMBRA	064 41 36	064 41 47
MOON UMBRA	064 41 47	065 27 05
MOON PENUMBRA	065 27 05	065 27 16
MOON PENUMBRA	066 44 00	066 44 11
MOON UMBRA	066 44 11	067 29 40
MOON PENUMBRA	067 29 40	067 29 50
MOON PENUMBRA	068 46 35	068 46 45
MOON UMBRA	068 46 45	069 32 42
MOON PENUMBRA	069 32 42	069 32 53
MOON PENUMBRA	070 49 43	070 49 54
MOON UMBRA	070 49 54	071 35 23
MOON PENUMBRA	071 35 23	071 35 34
MOON PENUMBRA	072 52 24	072 52 35
MOON UMBRA	072 52 35	073 38 04
MOON PENUMBRA	073 38 04	073 38 14
MOON PENUMBRA	074 55 17	074 55 27
MOON UMBRA	074 55 27	075 41 02
MOON PENUMBRA	075 41 02	075 41 13
MOON PENUMBRA	076 58 03	076 58 14

TABLE B-5 (Cont'd)

LIGHTING	ENTER			EXIT		
MOON UMBRA	076	58	14	077	43	49
MOON PENUMBRA	077	43	49	077	44	00
MOON PENUMBRA	079	00	56	079	01	07
MOON UMBRA	079	01	07	079	46	35
MOON PENUMBRA	079	46	35	079	46	46
MOON PENUMBRA	081	03	42	081	03	53
MOON UMBRA	081	03	53	081	49	22
MOON PENUMBRA	081	49	22	081	49	33
MOON PENUMBRA	083	06	29	083	06	40
MOON UMBRA	083	06	40	083	52	09
MOON PENUMBRA	083	52	09	083	52	20
MOON PENUMBRA	085	09	16	085	09	27
MOON UMBRA	085	09	27	085	54	55
MOON PENUMBRA	085	54	55	085	55	06
MOON PENUMBRA	087	12	02	087	12	13
MOON UMBRA	087	12	13	087	57	42
MOON PENUMBRA	087	57	42	087	57	53
MOON PENUMBRA	089	14	49	089	15	00
MOON UMBRA	089	15	00	090	00	36
MOON PENUMBRA	090	00	35	090	00	46
MOON PENUMBRA	091	17	36	091	17	47
MOON UMBRA	091	17	47	092	03	21
MOON PENUMBRA	092	03	21	092	03	32
MOON PENUMBRA	093	20	22	093	20	33
MOON UMBRA	093	20	33	094	06	08
MOON PENUMBRA	094	06	08	094	06	19
MOON PENUMBRA	095	23	09	095	23	20
MOON UMBRA	095	23	20	096	08	55
MOON PENUMBRA	096	08	55	096	09	05
MOON PENUMBRA	097	25	56	097	26	06
MOON UMBRA	097	26	06	098	11	41
MOON PENUMBRA	098	11	41	098	11	52
MOON PENUMBRA	099	28	42	099	28	53

TABLE B-5 (Cont'd)

LIGHTING	ENTER			EXIT		
MOON UMBRA	099	28	53	100	14	28
MOON PENUMBRA	100	14	28	100	14	39
MOON PENUMBRA	101	31	29	101	31	40
MOON UMBRA	101	31	40	102	17	04
MOON PENUMBRA	102	17	04	102	17	15
MOON PENUMBRA	103	34	15	103	34	26
MOON UMBRA	103	34	26	104	20	01
MOON PENUMBRA	104	20	01	104	20	12
MOON PENUMBRA	105	37	02	105	37	13
MOON UMBRA	105	37	13	106	22	48
MOON PENUMBRA	106	22	48	106	22	59
MOON PENUMBRA	107	39	49	107	40	00
MOON UMBRA	107	40	00	108	25	34
MOON PENUMBRA	108	25	34	108	25	45
MOON PENUMBRA	109	42	35	109	42	46
MOON UMBRA	109	42	46	110	27	57
MOON PENUMBRA	110	27	57	110	28	08
MOON PENUMBRA	111	44	59	111	45	09
MOON UMBRA	111	45	09			
TRANSEARTH COAST						
MOON UMBRA				112	22	22
MOON PENUMBRA	112	22	22	112	22	28
EARTH PENUMBRA	198	56	26	198	58	27
EARTH UMBRA	198	58	27	199	58	52
EARTH PENUMBRA	199	58	52	199	59	48

APPENDIX C COORDINATE AND ATTITUDE REFERENCE SYSTEMS

C.1 GENERAL

Several coordinate and orientation systems are used in this report to describe vehicle position, velocity and attitude. These are also recommended for general use by the Apollo project. There are four sets of position coordinates; a rectangular set and a spherical set referenced to earth, and a similar pair referenced to the moon. There are two sets of velocity coordinates; one set with respect to the earth and one with respect to the moon. There are five sets of attitude coordinates; two referenced to earth, two referenced to the moon, and one referenced to the vehicle. Table C-1 summarizies the position and attitude systems used throughout the report.

C.2 POSITION COORDINATES

C.2.1 General

The position coordinate systems used in the Design Reference Mission IIA are diagrammed in Figure C-1. Figure C-1(a) shows the earth-referenced coordinates and Figure C-1(b) shows the moon-referenced coordinates. The rotating spherical coordinate system is the one primarily used in this report.

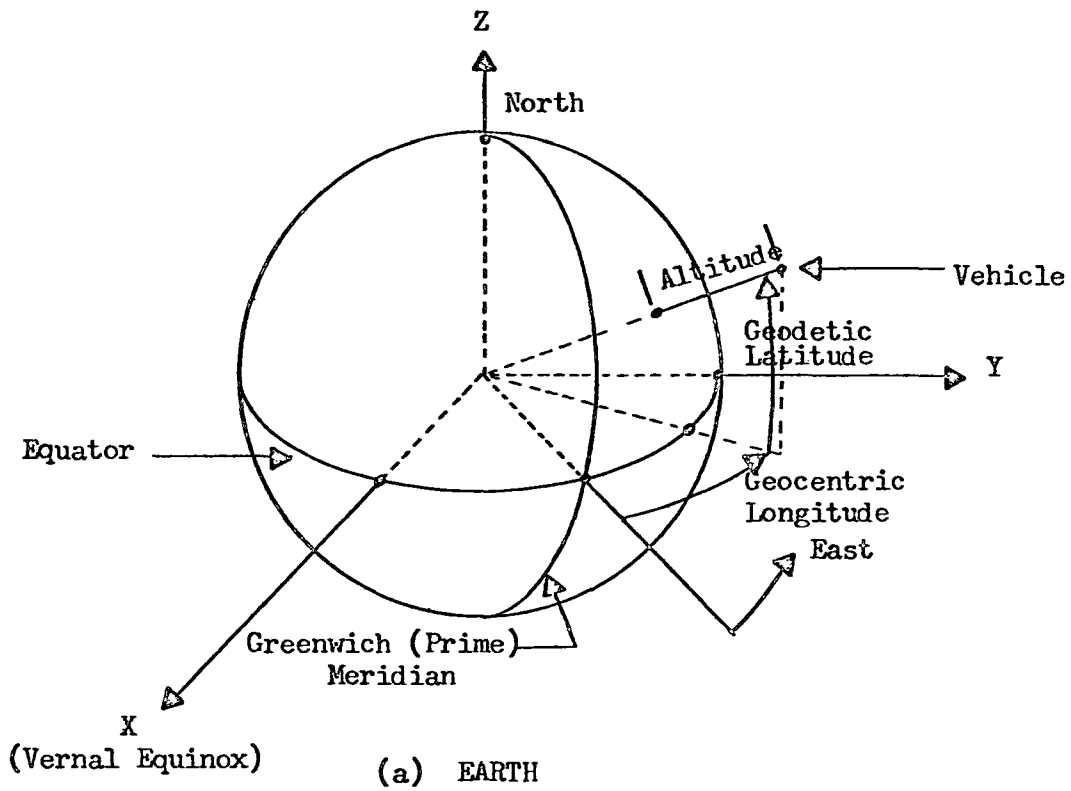
C.2.2 Rectangular Coordinates

The rectangular coordinate systems have been used in this report to provide more graphic illustrations of spacecraft position. The earth-centered axes are right-handed and orthogonal, X, Y, and Z in the usual order. The reference plane (X, Y) and the referenced direction (X) are defined by the mean earth equator and equinox of the nearest Besselian year of launch (1970.0). The Z axis is positive north of the equatorial plane.

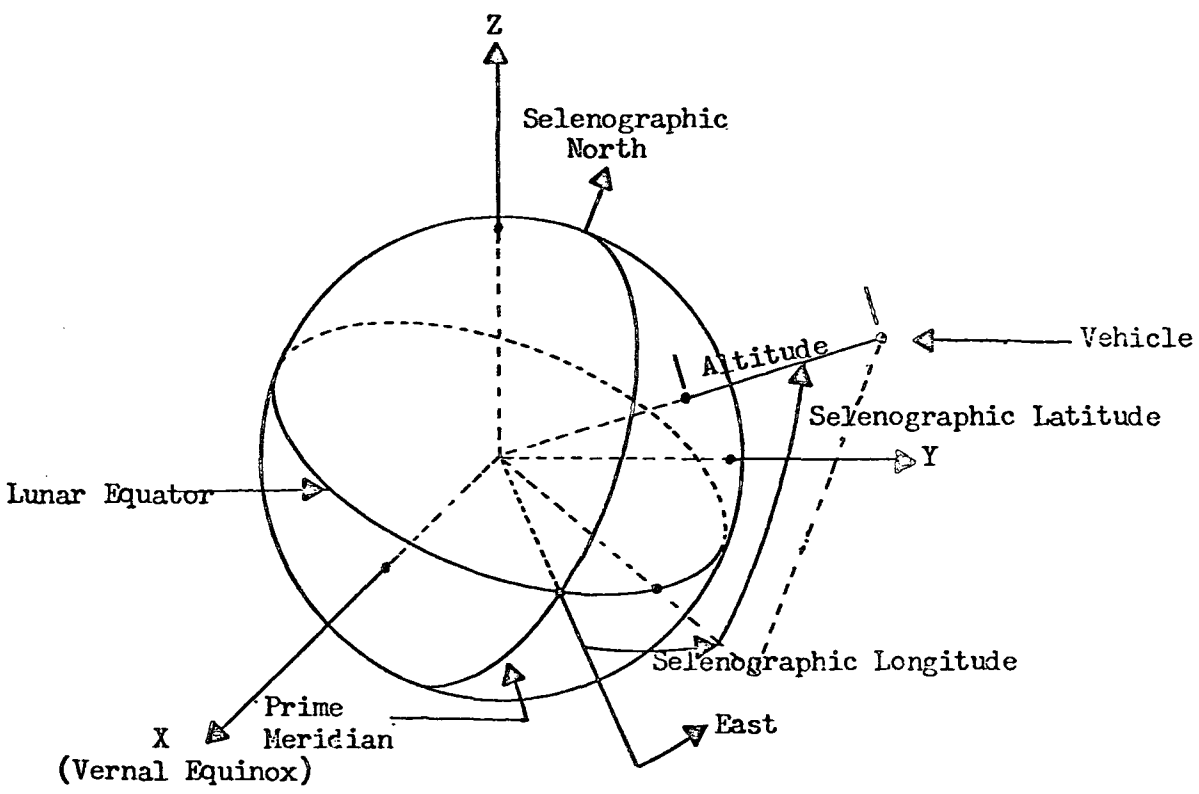
The moon-centered rectangular axis set is right-handed and parallel to the earth set. The X and Y axes lie in a plane through the center of the moon parallel to the earth equatorial plane. The Z axis is positive north of the X-Y plane. The X axis is directed toward the vernal equinox.

C.2.3 Spherical Coordinates

The origin of the earth system is the center of the earth. The position of any point in the earth-centered rotating spherical coordinate system is given by an altitude, a geodetic



(a) EARTH



(b) MOON

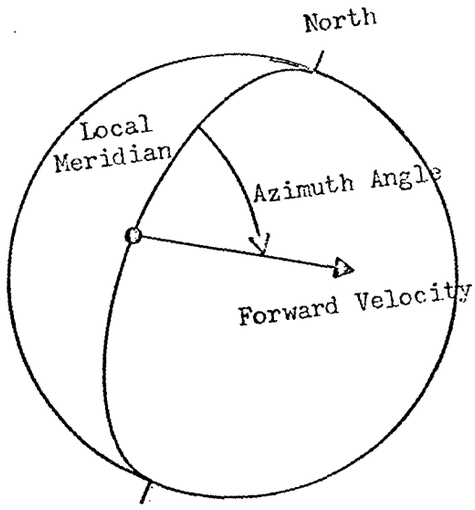
Figure C-1 Spacecraft Position Coordinate System

latitude, and geocentric longitude. The altitude of a point is its distance from the center of the earth minus the earth radius as defined by the spheroid. The latitude of the point is the angle between a normal to the spheroid at the sub-vehicle point and the earth equatorial plane. The longitude is the angle in the equatorial plane between the projection of earth-center-to-vehicle line and the line from earth center out through the 0° (prime) meridian. Latitude is measured positive northward from the equator. Longitude is measured positive eastward from the 0° meridian.

The origin of the lunar system is the center of the moon. The position of any point in the moon-centered rotating spherical coordinate system is given by an altitude, a selenographic latitude, and a selenographic longitude. The altitude of a point is its distance from the center of the moon minus the lunar radius as defined by a spheroid. The latitude of the point is the angle between the moon-center-to-vehicle line and the lunar equatorial plane. The longitude is the angle in the equatorial plane between the projection of the moon-center-to-vehicle line and the line from the moon center out through the 0° (prime) meridian. Latitude is measured positive northward from the equator and longitude is measured positive eastward from the 0° meridian.

C.3 VELOCITY COORDINATES

The velocity magnitudes, while in the earth's sphere of influence, are inertial with respect to the central force field body. While in the lunar sphere of influence, the velocity magnitude is relative to the lunar landing site. That is, at earth liftoff the velocity of the vehicle is described as that due to the rotation of the earth. However, during LM descent and ascent, for example, a described LM inertial velocity of 60 ft/sec forward at the lo-gate point of powered descent is therefore actually 75 ft/sec forward relative to the lunar surface since the moon rotates at 15 feet per second opposite to the direction of the LM motion during descent. Figure C-2 shows the method of describing the velocity vector direction, whether the vector is inertial or relative. The velocity vector is always oriented with respect to local vertical and local horizontal in the trajectory plane. The flight path angle is the smallest angle between the velocity vector and the local horizontal. It is positive for a positive altitude rate. The azimuth angle is the angle between the forward velocity vector and the plane of the local meridian. The azimuth angle is positive when the velocity vector is east of the meridian and negative when the velocity vector is west of the meridian. Therefore, the azimuth angle is 0° when the velocity vector is pointing north and 180° (+ or -) when the vector is pointing south.



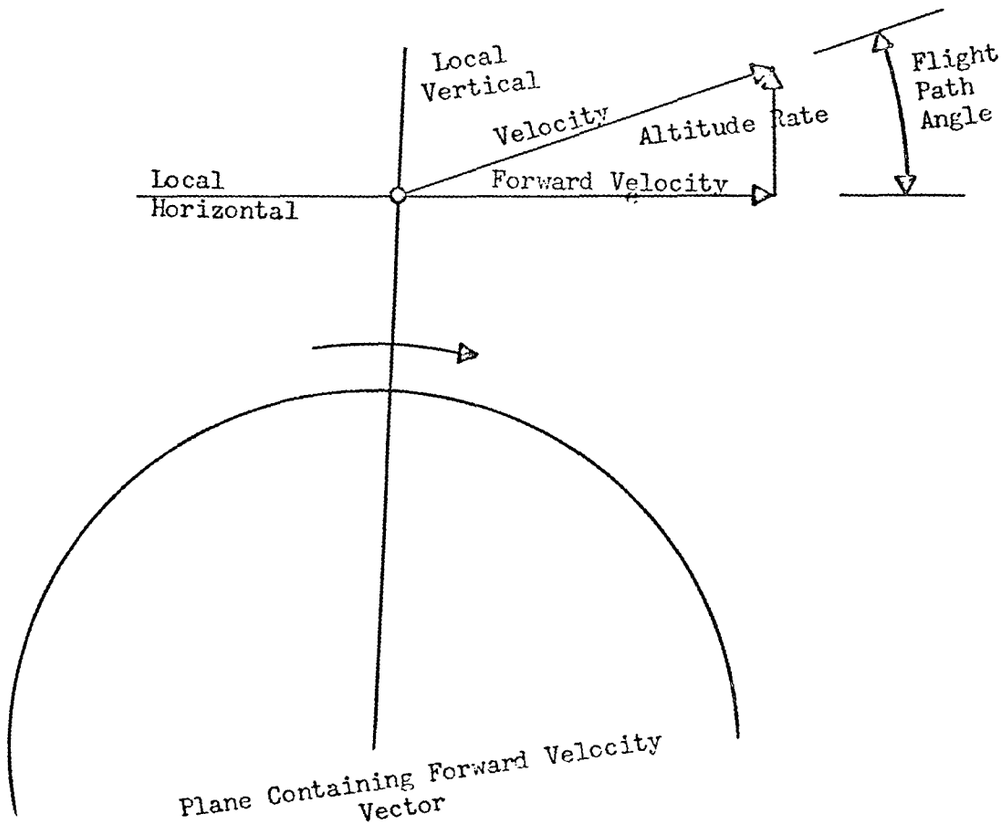


Figure C-2 Spacecraft Velocity Coordinate System

This system is used for all phases and for all vehicles. The local horizontal, local vertical and meridian are referenced to the earth or moon depending on the sphere of influence the vehicle is within.

C.4 BODY COORDINATES

C.4.1 Launch Vehicle

The origin of the coordinates is on the longitudinal axis, 100 inches below the gimbal reference plane. The X_B axis lies along the longitudinal axis of the vehicle, positive in the normal direction of positive thrust acceleration. Position I defines the positive Z direction. Position 1 is located 45° from Fin D towards Fin A. The Y axis completes a standard right-handed system. See Fig. C-3. Launch complex 39 will be used for Saturn V launchings. The positive Z axis of the erected vehicle will be directed approximately 90° east of north for this launch complex.

C.4.2 CSM and SLA

The origin of the coordinates is on the longitudinal axis, 1000 inches below the mold line of the heat shield main structure ablator interface. The X axis lies along the longitudinal axis of the vehicle, positive in the normal direction of positive thrust acceleration. The benchmark defining the positive Z axis is an alignment target at the top of the Service Module. The Y axis completes a standard right-handed system. See Figure C-3.

C.4.3 LM

The origin of the coordinates is located 200 inches below the LM ascent stage base. The X axis lies along the longitudinal axis (centerline of the transfer tunnel) of the LM, positive in the nominal direction of positive thrust acceleration. The positive Z axis is not defined by a physical benchmark; however, the center of the LM exit hatch serves as a reference benchmark. Thus, the positive Z axis is parallel to the center line of the exit hatch. The Y axis completes a standard right-handed system. See Figure C-4.

C.5 INERTIAL ATTITUDE COORDINATES

C.5.1 General

The SC attitudes throughout the mission are defined by a rotation order from an inertial reference frame X_I, Y_I, Z_I. The order of rotation is defined in Fig. C-6 and is designated

Notes:

The Launch Vehicle Uses Position Designations in Lieu of Y and Z Axes.

Position I Corresponds to Z Axis, Position II to the -Y Axis, III to the -Z Axis, and IV to the Y Axis.

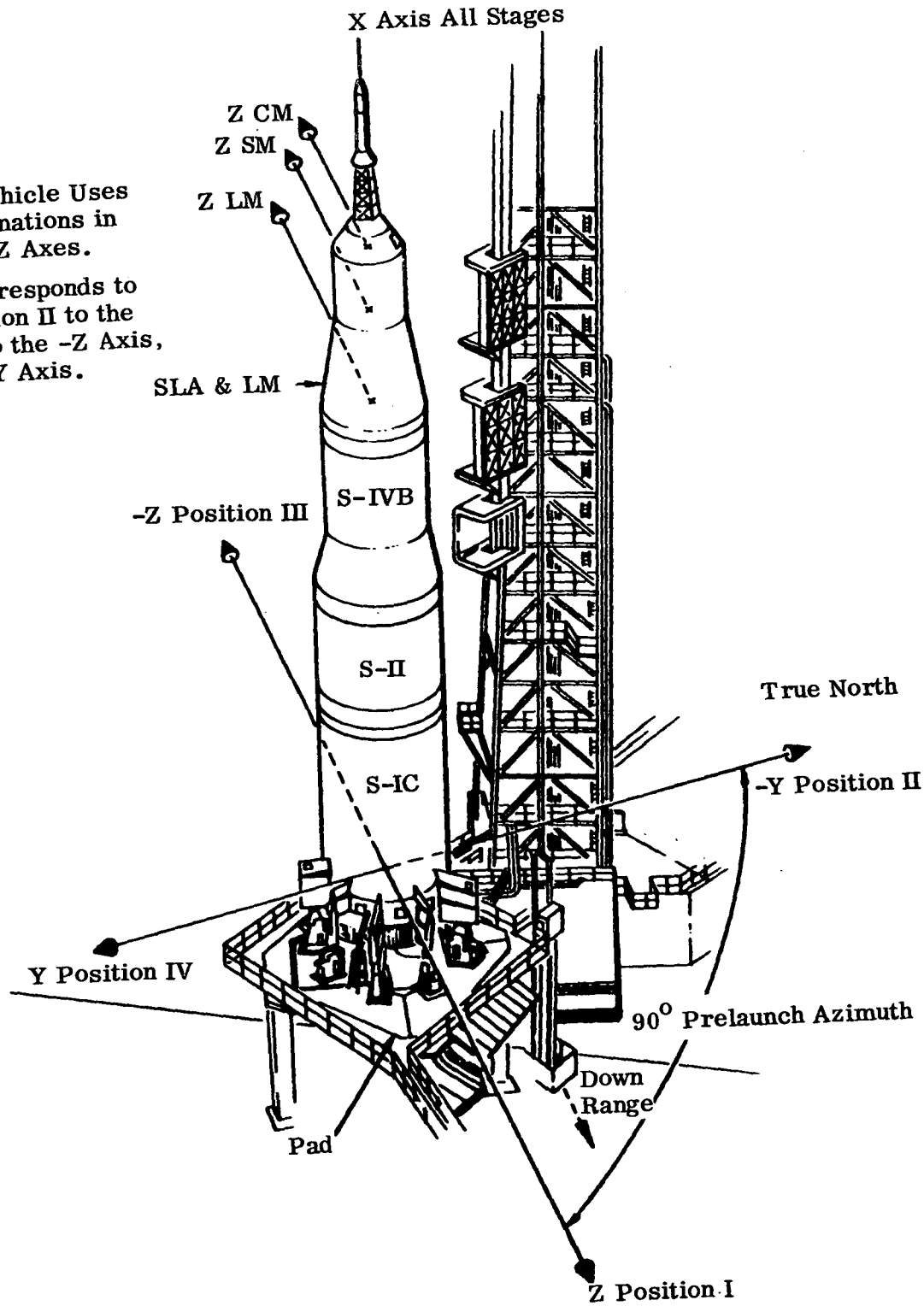


Figure C-3 Saturn V Attitude Launch Configuration

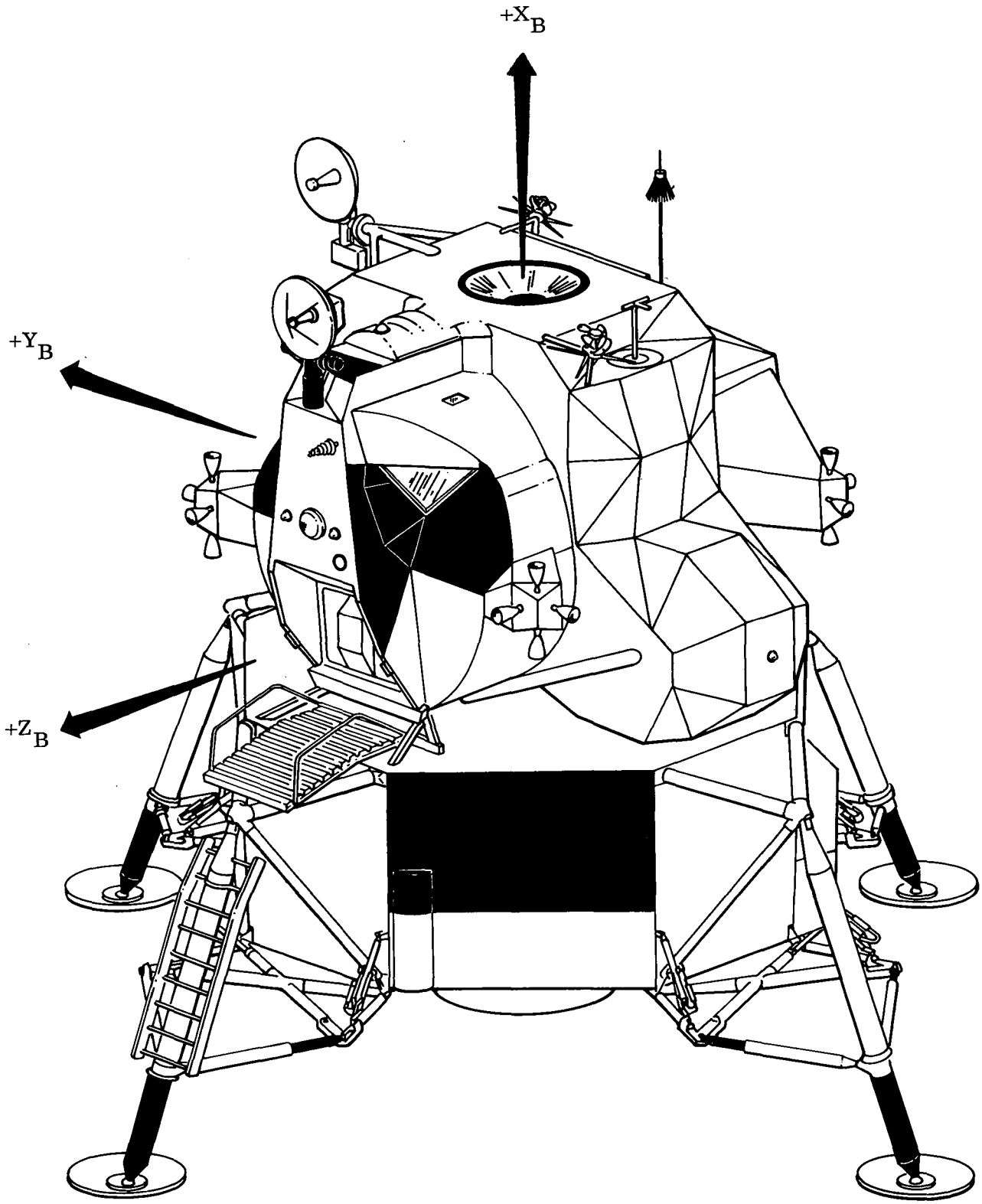


Figure C-4 LM Body Coordinates

θ, ψ, and ϕ. The inertial reference frame for the various mission phases is discussed in the following paragraphs. Differences between the CSM and LM systems are noted in the figure. Although the order of rotation is the same, the orientation of the pilot within the CSM and LM reference frames is different. This results in a pilot-oriented rotation order difference; i.e., pitch, yaw, roll for the CSM and pitch, roll, yaw for the LM.

C.5.2 Launch to TLI

The inertial reference frame (see Fig. C-5) for spacecraft attitude is defined, at time of liftoff (S-V launch), by the upward local vertical direction (X_I), the launch azimuth direction (Z_I), and the normal direction (Y_I) which completes a right-handed orthogonal system.

C.5.3 TLI through LOI

The inertial reference frame (see Fig. C-7) for spacecraft attitude is defined with respect to the mean equinox and mean equator plane of the nearest Besselian year of launch (1970.0). The orthogonal axes are specified by the mean equinox (X_I), a direction (Z_I) normal to (X_I) in the mean equator plane, and a direction (Y_I) southward normal to the equator plane.

C.5.4 Post LOI to LM Liftoff

The inertial reference frame (see Fig. C-5) for spacecraft attitude is defined at the landing site (at the planned time of LM landing) by the local vertical (X_I), a vector (Z_I) at the landing site within the CSM orbit plane pointing in the direction of motion, and the normal (Y_I) which describes a right-handed orthogonal system. This reference is maintained from the first IMU alignment in lunar orbit until LM IMU alignment prior to LM liftoff.

C.5.5. LM Liftoff to TEI

The inertial reference frame (see Fig. C-5) for spacecraft attitude is defined at the launch site (at the planned time of LM launch) by the local vertical (X_I), a vector (Z_I) at the launch site parallel to the CSM orbit plane pointing in the direction of motion, and the normal (Y_I) which describes a right-handed orthogonal system. This reference is maintained from the LM IMU alignment prior to LM liftoff to the last IMU alignment prior to transearth injection.

C.5.6 TEI Through Landing

The inertial reference frame for this phase is the same as for the translunar phase and is repeated for convenience. The inertial reference frame (see Fig. C-7) for spacecraft

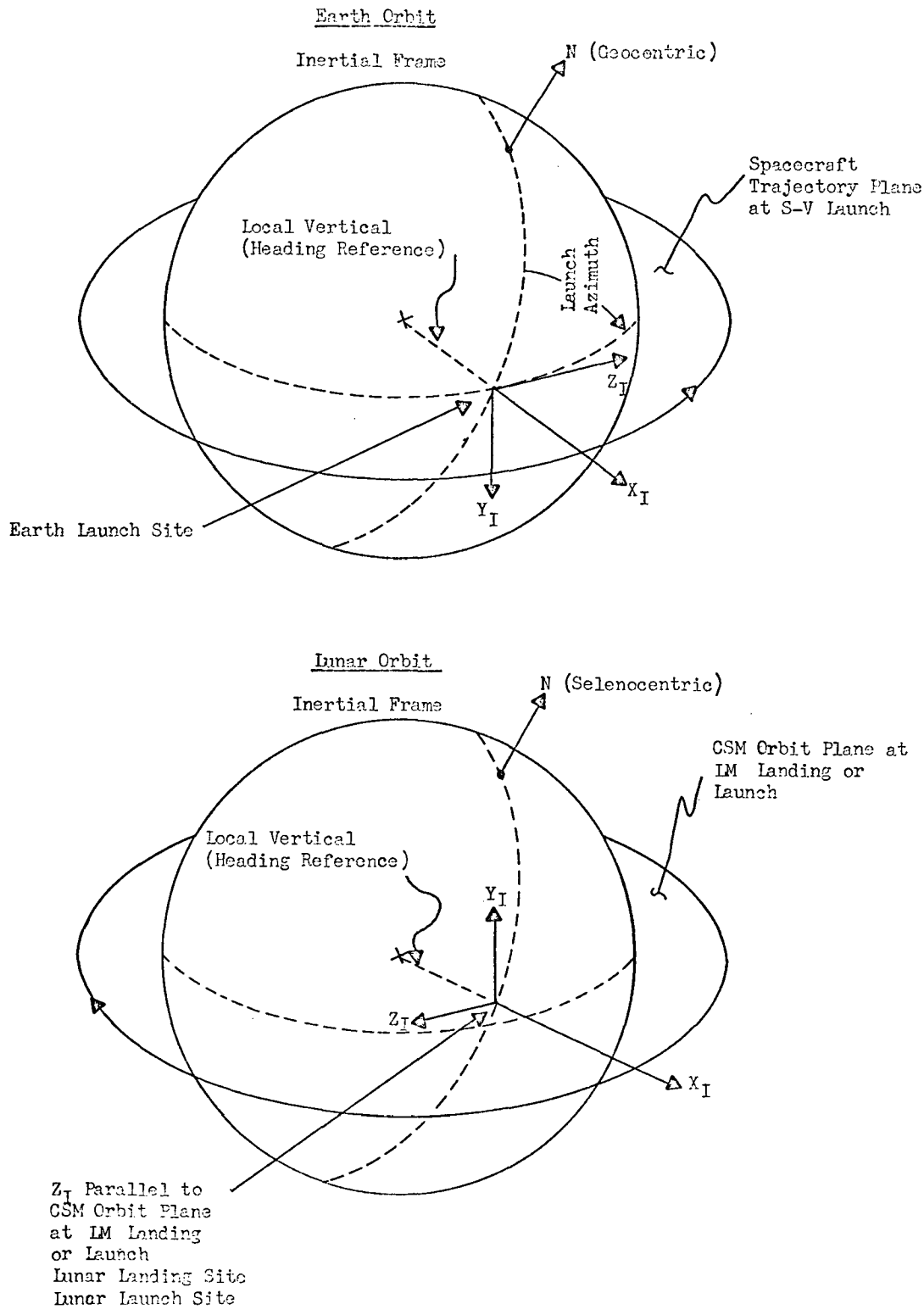
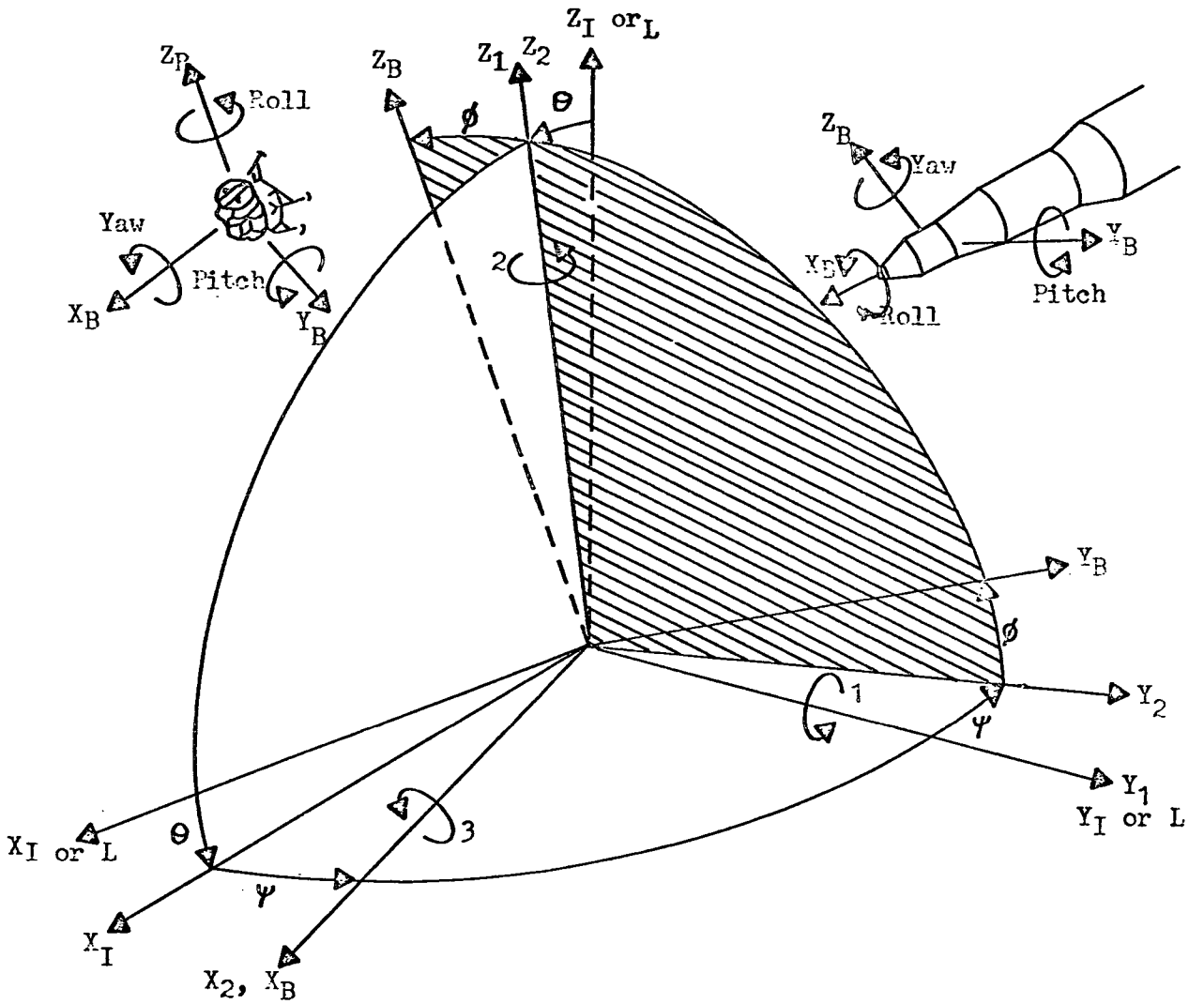


Figure C-5 Inertial Reference Frame



Order of Rotation	Symbol	S/V CSM	LM	Rotation About
1	θ	Pitch	Pitch	Y_B
2	ψ	Yaw	Roll	Z_B
3	ϕ	Roll	Yaw	X_B

Note: Subscripts

I = Inertial
L = Local
B = Body

Figure C-6 Spacecraft Attitude Coordinate System

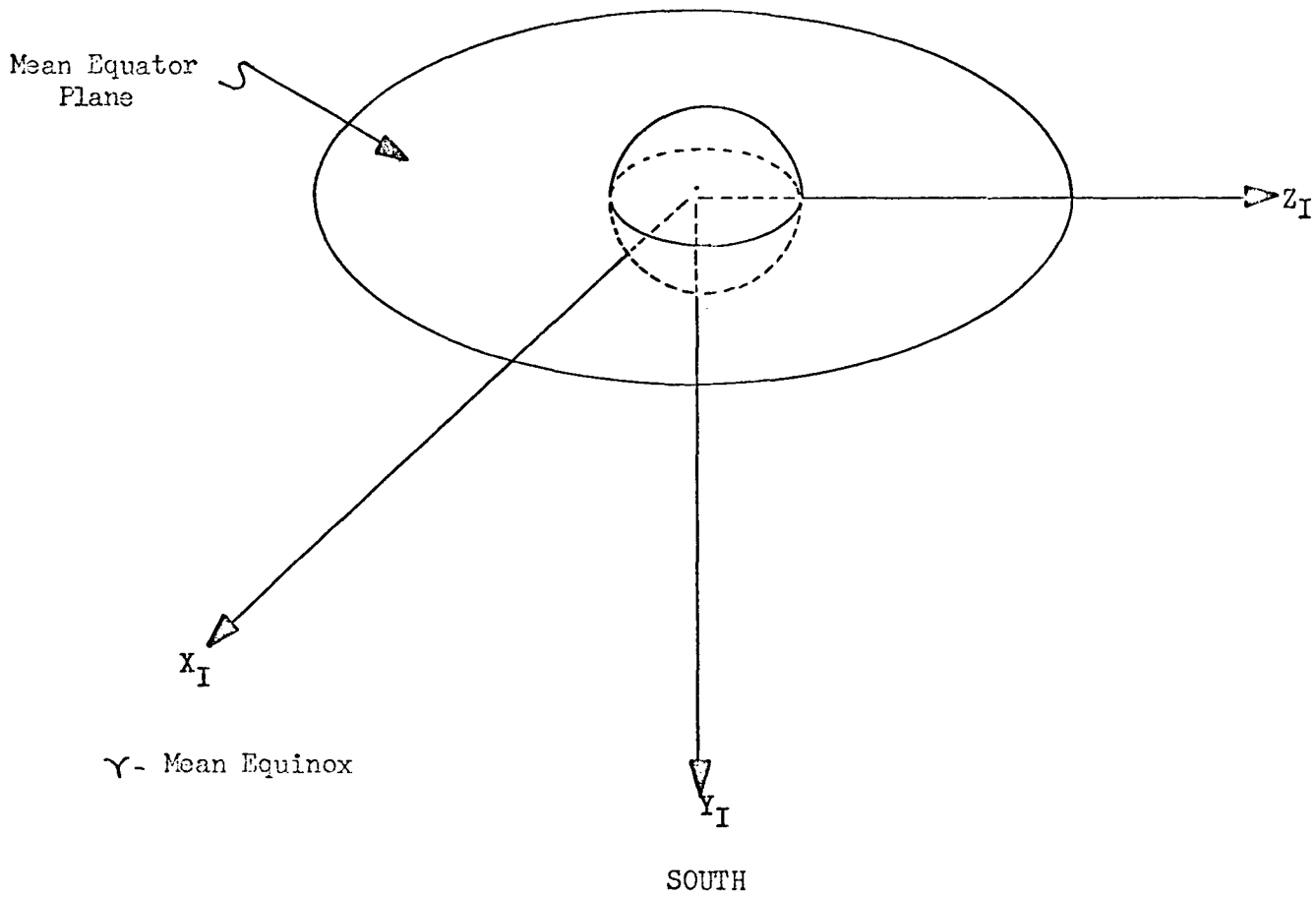


Figure C-7 Cislunar Inertial Frame

attitude is defined with respect to the mean equinox and mean equator plane of the nearest Besselian year of launch (1970.0). The orthogonal axes are specified by the mean equinox (X_I), a direction (Z_I) normal to (X_I) in the mean equator plane, and a direction (Y_I) southward normal to the equator plane.

C.6 LOCAL ATTITUDE COORDINATES

C.6.1 General

A local attitude coordinate system is provided which is more pilot-oriented than is the inertial system. The local system is referenced to the local horizontal-local vertical of the earth or moon as defined in the following paragraphs.

C.6.2 Earth Region of Influence

The local reference frame is illustrated in Fig. C-8 and is further defined by Fig. C-9. The spacecraft heading reference (X_L) is directed along the spacecraft velocity component in the local horizontal plane, the local vertical direction (Z_L) is toward the earth center, and the normal direction (Y_L) completes the right-handed orthogonal system. Spacecraft attitude is identified in this frame as θ, ψ, ϕ (see Fig. C-6). The earth region of influence extends out to within 36,630 nm of the moon's center and all mission phases occurring in this region (including transearth and translunar) will be defined in this coordinate system.

C.6.3 Lunar Sphere of Influence

The local reference system is the same as for the earth region of influence except centered at the moon and will be repeated here for clarity. The local reference frame is illustrated in Fig. C-8 and is further defined by Fig. C-9. The spacecraft heading reference (X_L) is directed along the spacecraft velocity component in the local horizontal plane, the local vertical direction (Z_L) is toward the lunar center, and the normal direction (Y_L) completes the right-handed orthogonal system. Spacecraft attitude is identified in this frame as θ, ψ, ϕ (see Fig. C-6). Although the order of rotations and the axes of the CSM and LM are the same, the orientation of the pilot within the two reference frames is different. This results in a pilot-oriented order of pitch, yaw, roll for the CSM and pitch, roll, yaw for the LM. The lunar sphere of influence is the volume within 36,630 nm of the lunar center. All mission phases within this volume will be defined in this coordinate system.

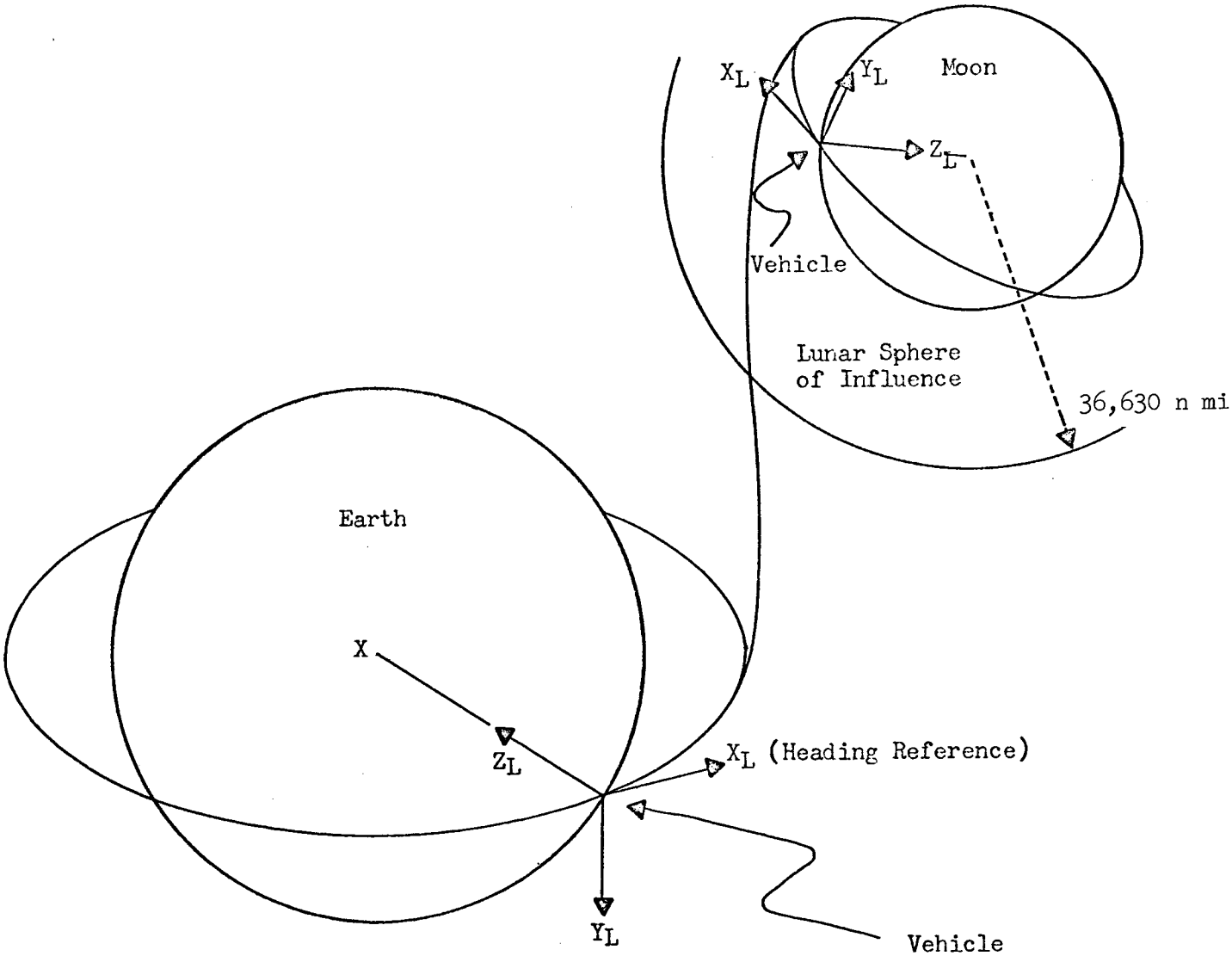


Figure C-8 Local Reference Frame - Orientation

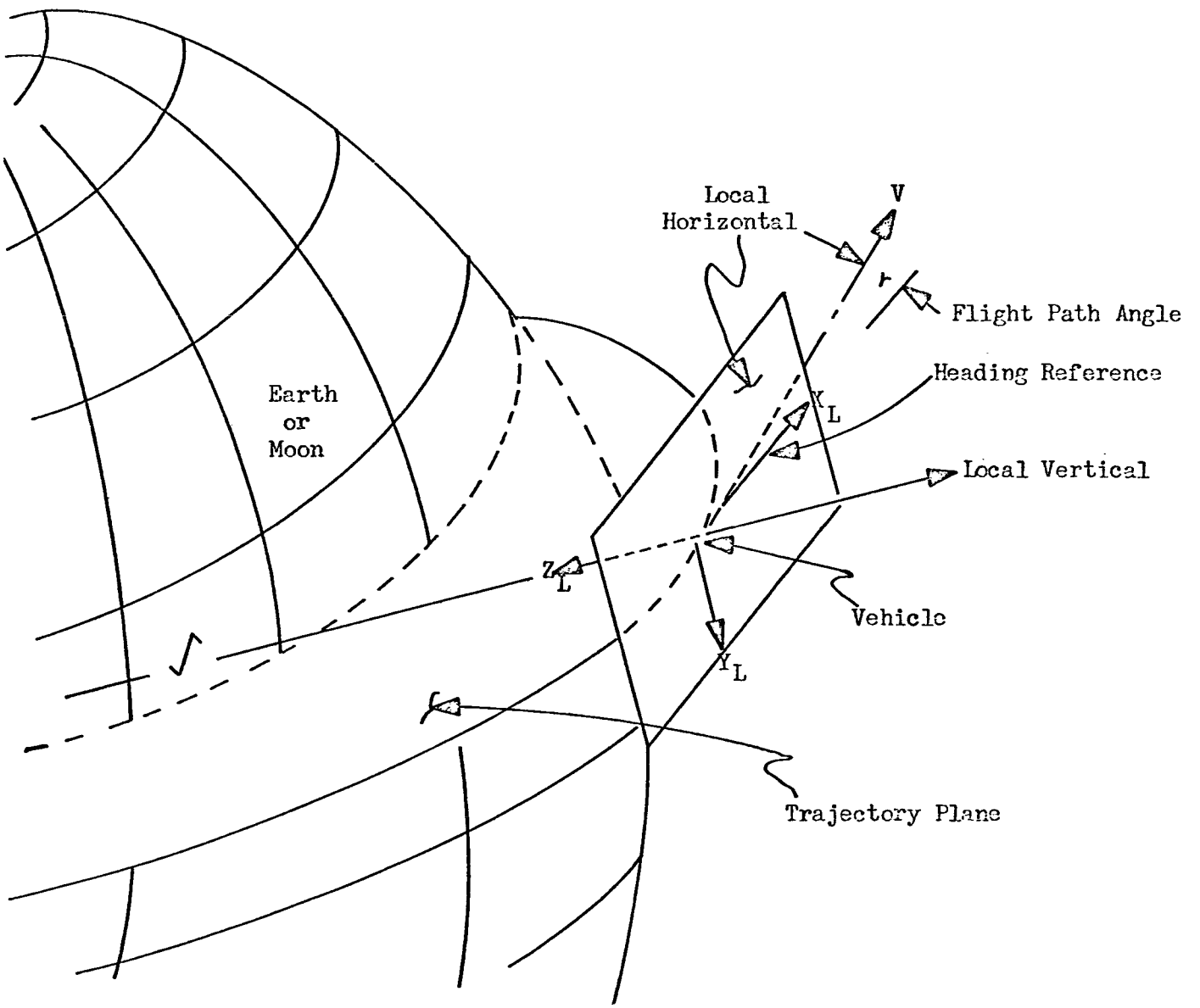


Figure C-9 Local Reference Frame - Velocity

C.7 AZIMUTH-ELEVATION SYSTEM

C.7.1 General

Azimuth-elevation angles to various points of interest are provided. The azimuth (AZI) and elevation (ELV) angles are expressed in terms of Command and Service Module body reference frame X_B, Y_B, Z_B (see Fig. C-10). The AZI angle is measured in the spacecraft X_B-Y_B plane, positive from $+X_B$ toward $+Y_B$. The ELV angle is measured from the X_B-Y_B plane toward the line-of-sight and is positive toward the $-Z_B$ axis. For the LM the azimuth and elevation angles are related to the LM body coordinates (see Fig. C-4). The AZI angle is measured in the LM Z_B-Y_B plane positive from $+Z_B$ towards $+Y_B$. The ELV angle is measured from the Z_B-Y_B plane towards the line-of-sight and is positive towards the $+X_B$ axis.

C.7.2 Earth Direction

The azimuth-elevation angles will define the direction to either the MSFN station in communucation with the SC or the earth's center, depending upon the mission phase. In earth orbit and the transposition and docking phase, the two angles will provide the direction to the proper MSFN station. During the remaining portion of the mission, direction to the earth's center will be presented.

C.7.3 Landmark Direction

The azimuth-elevation angles will define the direction to either the moon or lunar landmark, depending upon the mission phase. During all mission phases other than lunar orbit, the two angles will represent the direction to the lunar center. While in lunar orbit the direction to the lunar landmark will provided. For the purpose of this reference system, the lunar landing site is considered a lunar landmark.

C.7.4 Sun Direction

The azimuth-elevation angles will define the direction toward the sun for all mission phases.

C.7.5 CSM-LM Direction

The azimuth-elevation angles will define the direction from one vehicle (CSM or LM) toward the other (LM or CSM) during the lunar orbital phase while the two vehicles are separated.

C.7.6 LM Shaft - Trunnion System

The LM shaft-trunnion angles (see Fig. C-11) are used primarily to define motion of the S-Band and rendezvous radar antennas. However, this coordinate system has been used to define line-of-sight directions in a manner consistent with the radar terminology.

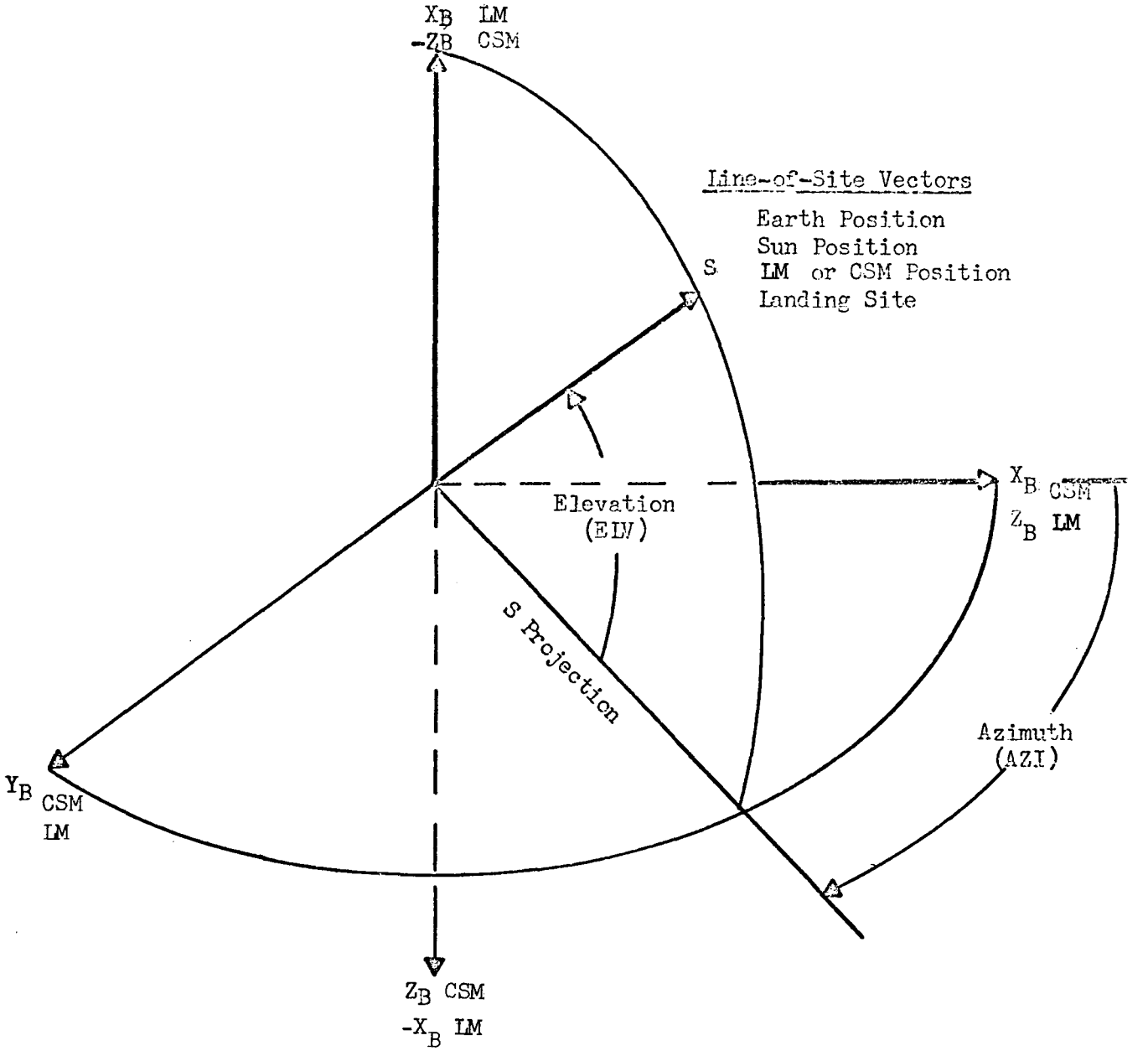


Figure C-10 Azimuth and Elevation Relative to Body Reference Frame

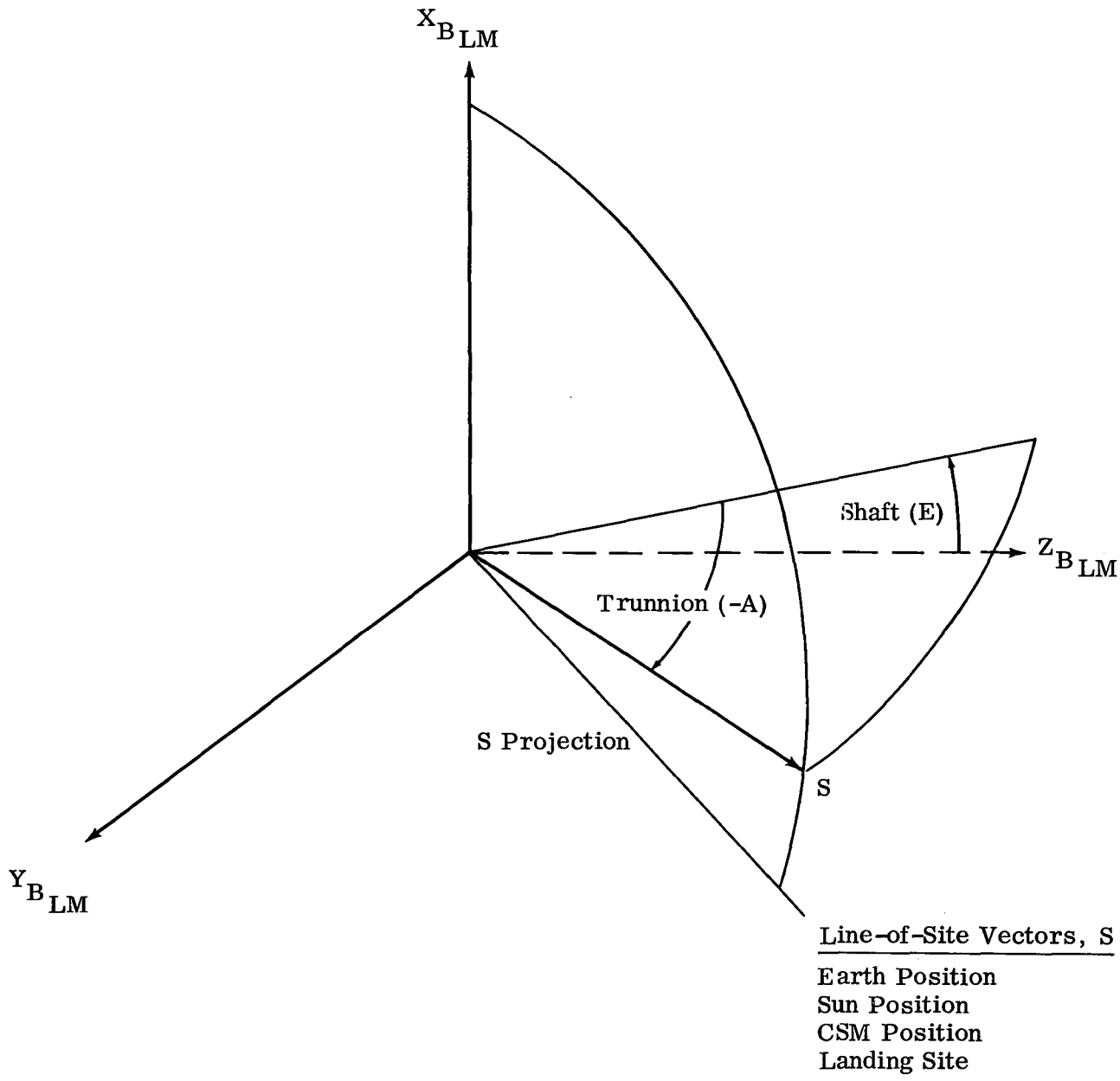


Figure C-11 LM Shaft and Trunnion Angle System

TABLE C-1 COORDINATE AND ATTITUDE REFERENCE SYSTEM SUMMARY

ITEM	MISSION PHASE USED	REFERENCE SYSTEM		COORDINATES	
		ORIGIN	REFERENCE PLANE AND DIRECTION	TYPE	DESCRIPTION
POSITION	ALL PHASES	EARTH CENTER	EQUATORIAL PLANE AND VERNAL EQUINOX	RECTANGULAR	X - POSITIVE TOWARDS VERNAL EQUINOX Y - NORMAL TO "X" IN EARTH EQUATORIAL PLANE Z - NORMAL TO EARTH EQUATORIAL PLANE, POSITIVE NORTH
		MOON CENTER	PARALLEL TO EARTH CENTERED SYSTEM		
	EARTH ORBIT AND MIDCOURSE	EARTH CENTER	EARTH EQUATORIAL PLANE AND PRIME MERIDIAN	SPHERICAL	LATITUDE - GEODETC LONGITUDE - GEOCENTRIC ALTITUDE - ABOVE SPHEROID
	LUNAR ORBIT AND MIDCOURSE	MOON CENTER	MOON EQUATORIAL PLANE AND PRIME MERIDIAN		LATITUDE - SELENOGRAPHIC LONGITUDE - SELENOGRAPHIC ALTITUDE - ABOVE SPHEROID
VELOCITY	WITHIN EARTH REGION OF INFLUENCE	VEHICLE	TRAJECTORY PLANE, LOCAL VERTICAL, LOCAL NORTH	POLAR	VELOCITY MAGNITUDE FLIGHT PATH ANGLE - IN-PLANE vs LOCAL HORIZONTAL AZIMUTH - IN LOCAL HORIZONTAL PLANE vs LOCAL NORTH
	WITHIN LUNAR SPHERE OF INFLUENCE	VEHICLE			
ATTITUDE	EARTH AND LUNAR ORBIT	VEHICLE	X_I - LOCAL VERTICAL AT SITE Y_I - COMPLETES ORTHOGONAL SYSTEM Z_I - AZIMUTH OF ORBIT PLANE	INERTIAL	IN THE FOLLOWING ORDER: θ - ROTATION ABOUT Y_I ψ - ROTATION ABOUT Z_I ϕ - ROTATION ABOUT X_2
	MIDCOURSE	VEHICLE	X_I - VERNAL EQUINOX Y_I - TOWARD SOUTH POLE Z_I - IN EARTH EQUATORIAL PLANE		
	WITHIN EARTH SPHERE OF INFLUENCE	VEHICLE	X_L - VELOCITY VECTOR PROJECTION ONTO HORIZONTAL PLANE Y_L - IN LOCAL HORIZONTAL PLANE Z_L - LOCAL VERTICAL TOWARDS CENTER OF SPHERE	LOCAL	IN THE FOLLOWING ORDER: θ - ROTATION ABOUT Y_L ψ - ROTATION ABOUT Z_1 ϕ - ROTATION ABOUT X_2
	WITHIN LUNAR SPHERE OF INFLUENCE	VEHICLE			
	ALL PHASES	CSM	BODY AXES X_B, Y_B, Z_B	AZIMUTH AND ELEVATION	AZIMUTH - IN X_B - Y_B PLANE ELEVATION - FROM X_B - Y_B PLANE TO LINE-OF-SIGHT
	LEM ACTIVE PHASES	LM			AZIMUTH - IN Z_B - Y_B PLANE ELEVATION - FROM Z_B - Y_B PLANE TO LINE-OF-SIGHT

APPENDIX D SPACECRAFT ATTITUDE

D.1 INTRODUCTION

This appendix contains a complete description of the CSM and LM attitudes for the entire DRM IIA Lunar Landing Mission. The description begins with the preflight phase and continues through splashdown. To insure completeness in the topic of spacecraft attitude, both written descriptions and tabular sequences are provided.

The written description contains both definitions of vehicle attitudes and discussions of attitude constraints. The discussion describes typical vehicle attitudes for each mission phase and the nature and priorities of constraints considered in developing the particular attitude sequence. The constraints are discussed quantitatively in the form of attitude envelopes satisfying subsystem and mission requirements. Material on all known constraints is presented to support the attitude sequence.

The tabular attitude timeline (Table D-1) contains a listing of all tpyes of attitude functions performed by the CSM and LM for all mission phases. These attitudes are grouped by mission phase, with phases 1 through 9 and 13 through 18 containing CSM attitudes, and phases 10 through 12 containing LM attitudes. The attitudes in the timeline are not printed out uniformly in time, but on a maneuver or event basis. The attitude data are printed out at the beginning and end of each event which is attitude critical; these include delta -V's, navigation sightings, IMU alignments, thermal cycling, etc. The attitude data are also printed out at the beginning and end of each rotational maneuver and for large or complex maneuvers intermediate points are also given. Sunrise-sunset and earthrise-earthset times are printed for the thermal and communications analysis needs.

D.2 MISSION ATTITUDE DESCRIPTION

The process of developing spacecraft attitude histories requires the identification, parametric analysis, and integration of time dependent geometric constraints imposed by environmental and subsystem performance factors. To establish the appropriate balance between these factors and to clarify the actual character of the problem of total mission attitude planning, a basic spacecraft attitude management philosophy was derived and applied to the development of attitude sequence data for the Design Reference Mission IIA.

This philosophy considers both operational and performance factors in maximizing the potential for satisfying mission requirements.

Attitude Management Philosophy

The following guidelines were synthesized through integration and correlation of ground rules and analysis results and are the fundamental basis for spacecraft attitude data presented herein:

Rigorous spacecraft attitude planning

Minimize propellant usage within defined constraints

Balanced propellant utilization

Minimize attitude maneuver complexity

Maximize margins from specific pointing constraints

Rigorous Attitude Planning

Rigorous attitude planning must be accomplished for every lunar landing mission. There is no time within the mission in which there is not at least one constraint upon the vehicle attitude. During many phases of the mission several environmental and subsystem constraints are imposed simultaneously. Some of these constraints severely limit the vehicle attitude while others allow some margin of flexibility. In addition, many of the attitude maneuvers are time critical in that there are a large number of closely spaced maneuvers which must be performed at specified times or intervals. Further, these time critical attitude maneuvers usually occur during periods of high crew task loading. Thus, considering these factors collectively, attitude planning must be carefully coordinated with crew operations and subsystem demands in the development of an attitude sequence for each mission.

Minimize Propellant Usage

One of the major considerations in the development of an attitude timeline is the requirement for RCS propellant. The amount of propellant required depends upon: (1) the maneuver rates, (2) the types of maneuvers, and (3) the number of maneuvers. Most maneuvers performed by the CSM, with the exception of transposition and docking, are accomplished at 0.2 degrees per second (12 degrees per minute). This slow rate conserves RCS propellant and minimizes fuel slosh dynamic instability associated with higher maneuver rates. When higher rates are used the rate is specified in the timeline.

The attitude sequence developed minimizes the number of attitude maneuvers requiring the most RCS propellant (pitch and yaw) and emphasizes the use of roll maneuvers and

vehicle attitude holds which require smaller quantities of propellant. In addition, optimum usage of switching between local and inertial attitude holds is used, to minimize the RCS propellant quantity, by reducing pitch maneuvers.

Balanced Propellant Utilization

The SM Reaction Control System consists of four quads, each of which contains independent propellant tanks. Due to the arrangement, propellant for pitch and yaw maneuvers is consumed from the respective pitch and yaw tanks whereas roll maneuvers may use any of the four depending on which reaction jets are selected. As a result pitch and jaw will tend to unbalance the remaining propellant unless pitch and yaw maneuvers are alternated to balance the utilization. Roll maneuvers, on the other hand, can be performed using propellant evenly from among the four RCS quad tank systems without special maneuver or jet selection procedures. As a result, a high proportion of planned roll maneuvers can be expected to deplete the propellant tanks more uniformly than a high proportion of pitch or yaw maneuvers.

Minimize Sequence Complexity

System capabilities and crew tasks have been integrated into the attitude management concept. For instance, local attitude holds are utilized only when the CSM PGNCS is required to be in operation (first 3 lunar orbits, navigation sightings, etc.). During all other phases when the SCS is used for stabilization, only inertial attitude holds are specified. Preplanned attitude management employs switching between local and inertial attitude holds at the proper time which enables the spacecraft to accumulate a reorientation equivalent to a pitch maneuver. By anticipating future attitude requirements, the proper orientation can usually be obtained by a combination of an attitude hold and a roll maneuver. The objective of this sequence is to minimize the number of operationally more complex three axis maneuvers and to minimize RCS propellant consumption. The proposed attitude management philosophy may also be used to advantage by the Navigator in acquiring lunar landmarks and to help the Systems Engineer point the high-gain antenna toward earth.

Maximize Margins

The specific attitude maneuvers and pointing characteristics discussed are not necessarily unique requirements. In many instances, tolerance of flexibility exists within the constraint envelope; however, in some cases the precise attitude or maneuver is a definite requirement. Within DRM IIA, the selected attitude usually places the vehicle as near as possible to the center of the acceptable attitude constraints envelope to allow for control tolerances and possible future reductions in defined limits.

Terminology Used

Throughout the written description, frequent reference is made to terms such as "Z axis, north of the orbit plane," "above the velocity vector," etc. These terms are defined as follows: The "A axis north of the orbit plane" has the A axis in the hemisphere containing the lunar north pole, where the hemisphere is bounded by the lunar orbit plane. The "A axis toward the earth" has an acute angle between the A axis and the vehicle-earth vector. The "A axis above the negative velocity vector" implies that the A axis is pointing away from the earth or moon, as appropriate (referenced to the local horizontal), and an acute angle is formed by the axis and the negative velocity vector.

The detailed attitude description of the vehicle is organized by mission phase. The last digit of the paragraph number corresponds to the mission phase number to maintain continuity of all facets of mission content for reader clarity.

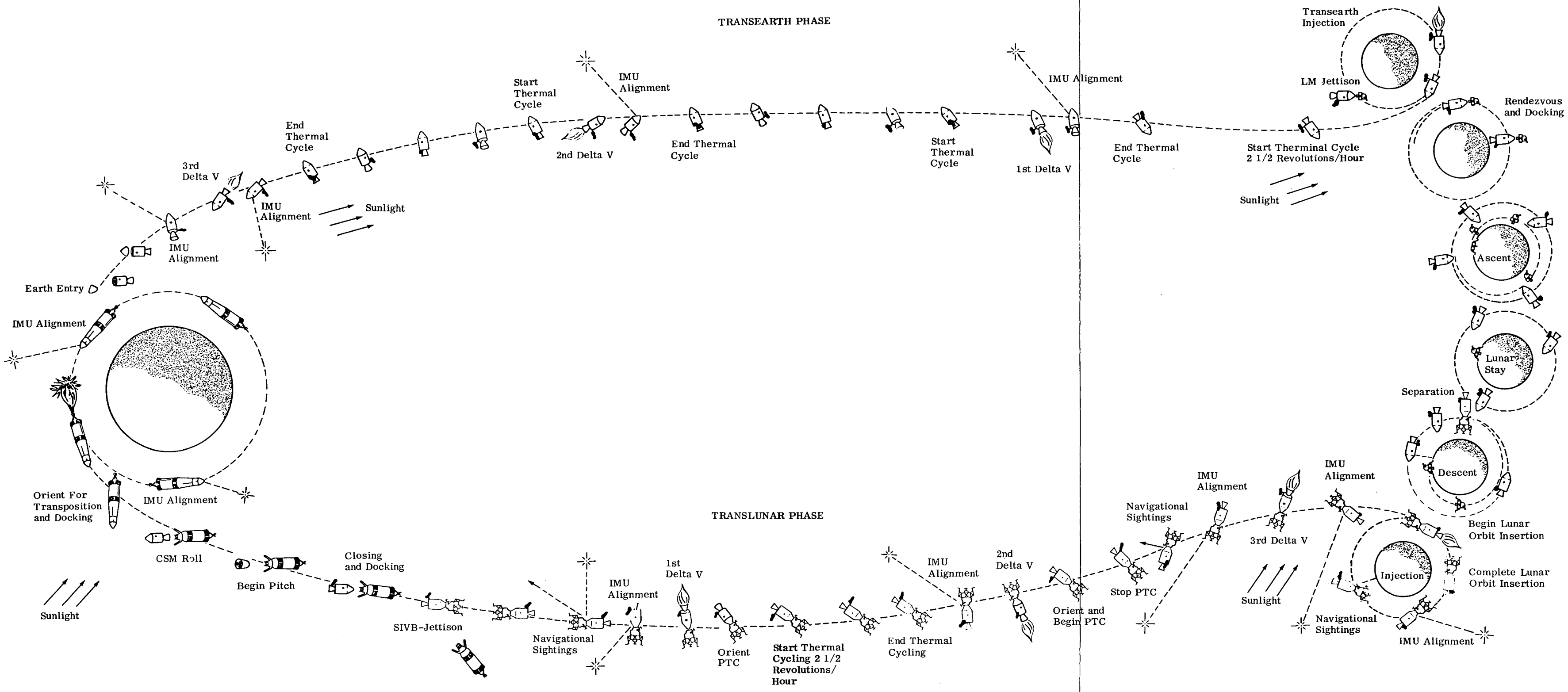


Figure D.2-1 DRM-II A Attitude Illustration

ATTITUDE PROFILE SUMMARY

D.2.1 PHASE 1.0 PREFLIGHT

The attitude orientation of the Saturn V vehicle on the launch pad is with the plus Z axis (Position I) of all booster stages pointing downrange 90 degrees east from true north and with the plus X axis of the vehicle pointing toward the positive velocity direction (up). The LM, CM, and SM minus Z axes are pointed downrange with the plus X axis pointed toward the positive velocity direction (up). The pre-launch attitude configuration of the Saturn V vehicle is shown in Figure D.2.1-1.

D.2.2 PHASE 2.0 EARTH ASCENT

Launch occurs at Cape Kennedy from Complex 39, Pad A, located at a geodetic latitude of 28 degrees, 38 minutes, 50.9 seconds north, and a longitude of 80 degrees, 38 minutes, 08.1 seconds west. As shown in Figure D.2.2-1, the launch profile of the Saturn V includes S-IC boost, S-II boost, and the S-IVB insertion into earth parking orbit.

During the launch to earth orbit phase, the attitude of the spacecraft is, of course, dictated by the boost trajectory requirements. However, the following CSM system requirements, sensitive to vehicle attitude, are observed.

1. The CSM IMU is aligned to the same reference as the S-IVB IMU, with the inner gimbal axis normal to the orbit plane. As a result, during the launch pitch maneuver, gimbal lock is avoided.

2. Communication between the CSM and the MSFN is maintained through the unified S-Band System. The S-Band omni antenna patterns exhibit the weakest gain along the nose (plus X) and tail (minus X) of the vehicle. Since these regions are not generally pointed at an MSFN station, communications are virtually assured during the launch phase.

S-IC Boost

Following S-IC ignition and launch vehicle liftoff, a roll program is performed such that a launch vehicle pitch acheives the desired trajectory launch azimuth. Since the DRM IIA launch azimuth is defined as 90 degrees, no roll program is required. After 12 seconds of vertical flight during S-IC boost, a pitch rate is initiated and maintained to S-IC shutdown, 159 seconds after liftoff. The pitch maneuver program is performed following the roll program and places the vehicle in the proper earth orbit trajectory plane. Depending upon

Notes:

The Launch Vehicle Uses Position Designations in Lieu of Y and Z Axes.

Position I Corresponds to Z Axis, Position II to the -Y Axis, III to the -Z Axis, and IV to the Y Axis.

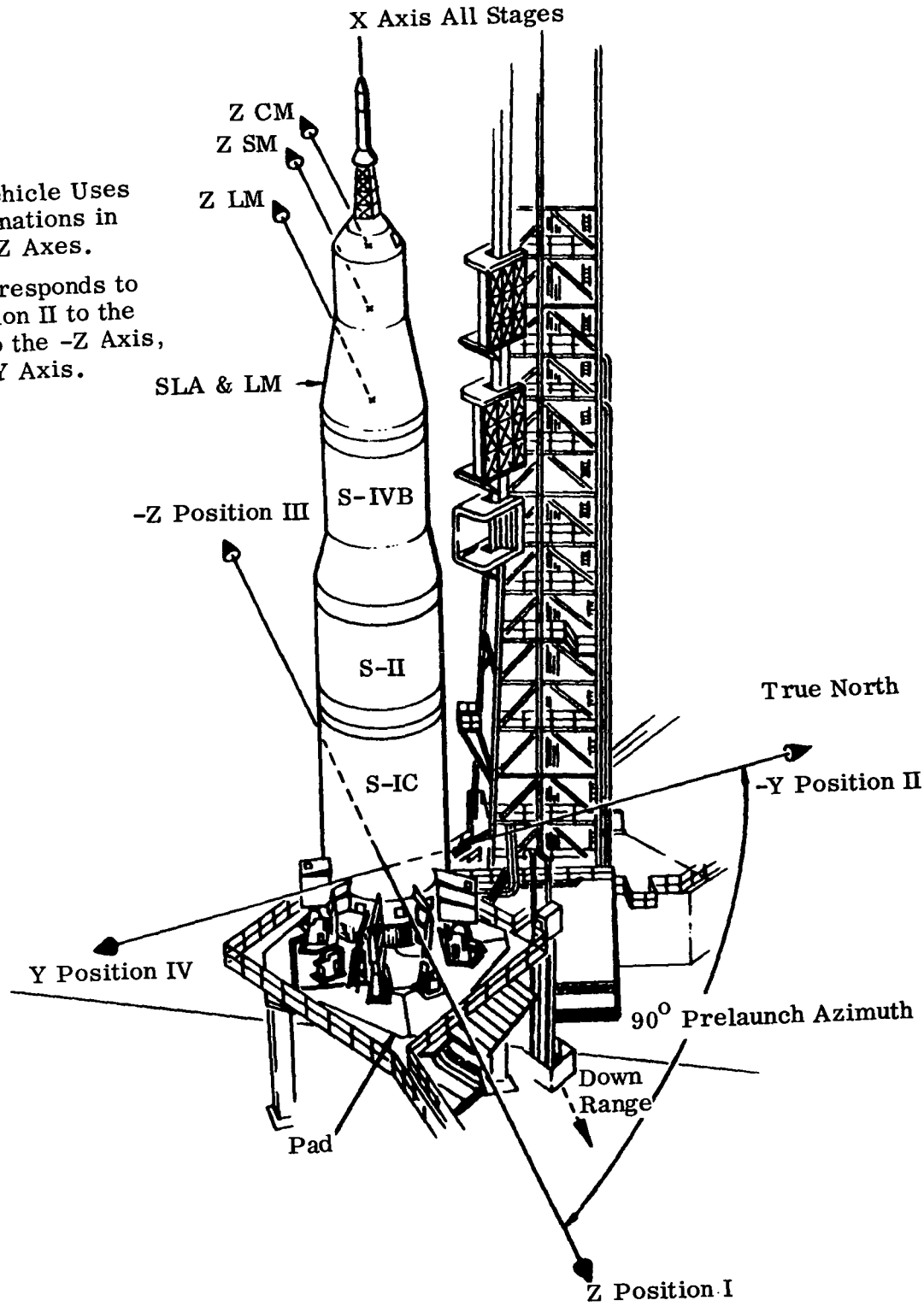


Figure D.2.1-1 Saturn V Attitude Launch Configuration

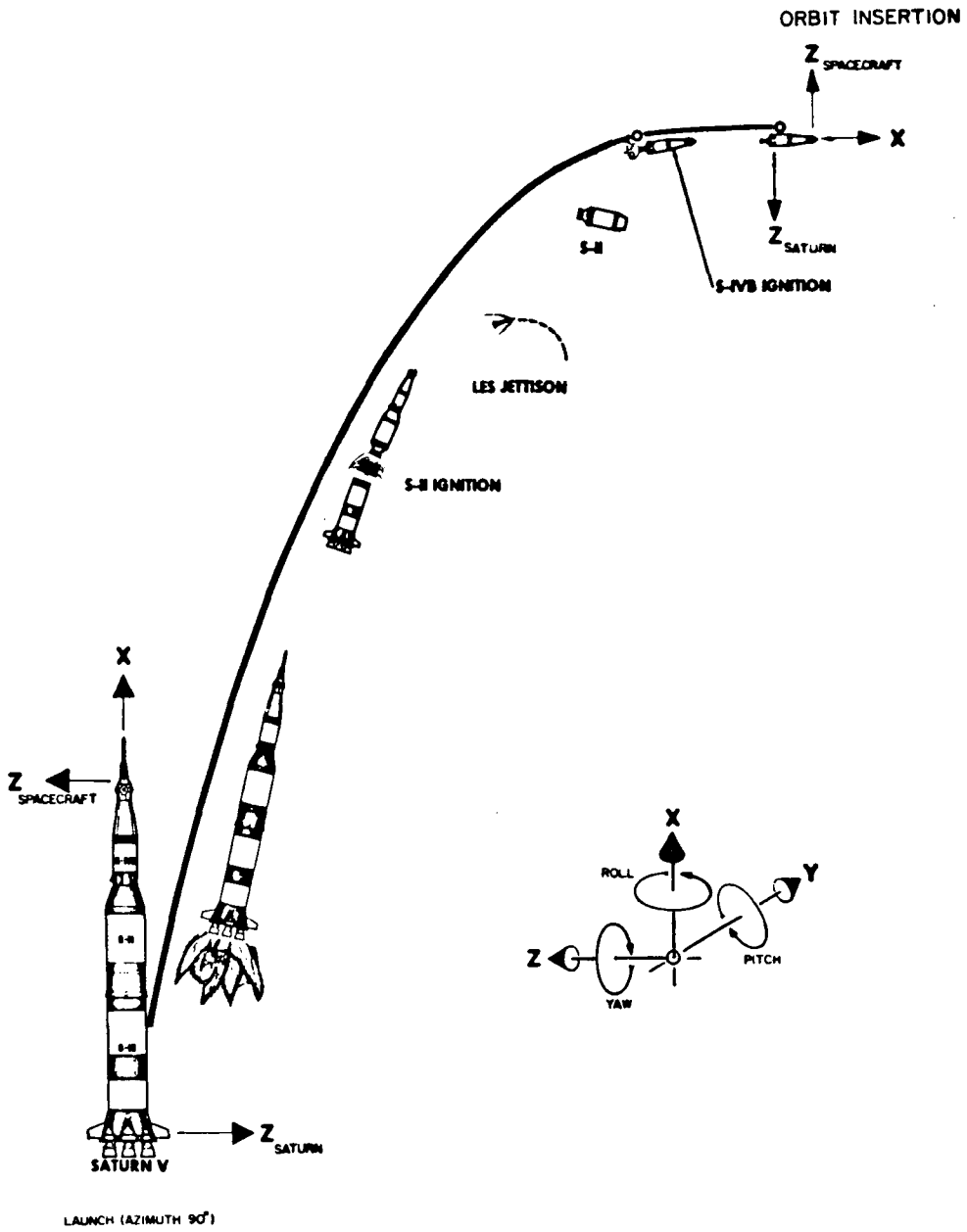


Figure D.2.2-1 Saturn V Attitude Configuration and Booster Events

the time of launch, the earth-fixed heading (launch azimuth) varies between 72 degrees east of north and 108 degrees east of north. This azimuth selection meets range safety requirements and precludes Bermuda and Carribean island overflights.

S-II Boost

At 162 seconds after liftoff the S-II stage has reached full thrust after which the S-IC/S-II interstage is jettisoned at 189 seconds. The LES is jettisoned at 194 seconds. S-II shutdown occurs at 536 seconds from launch.

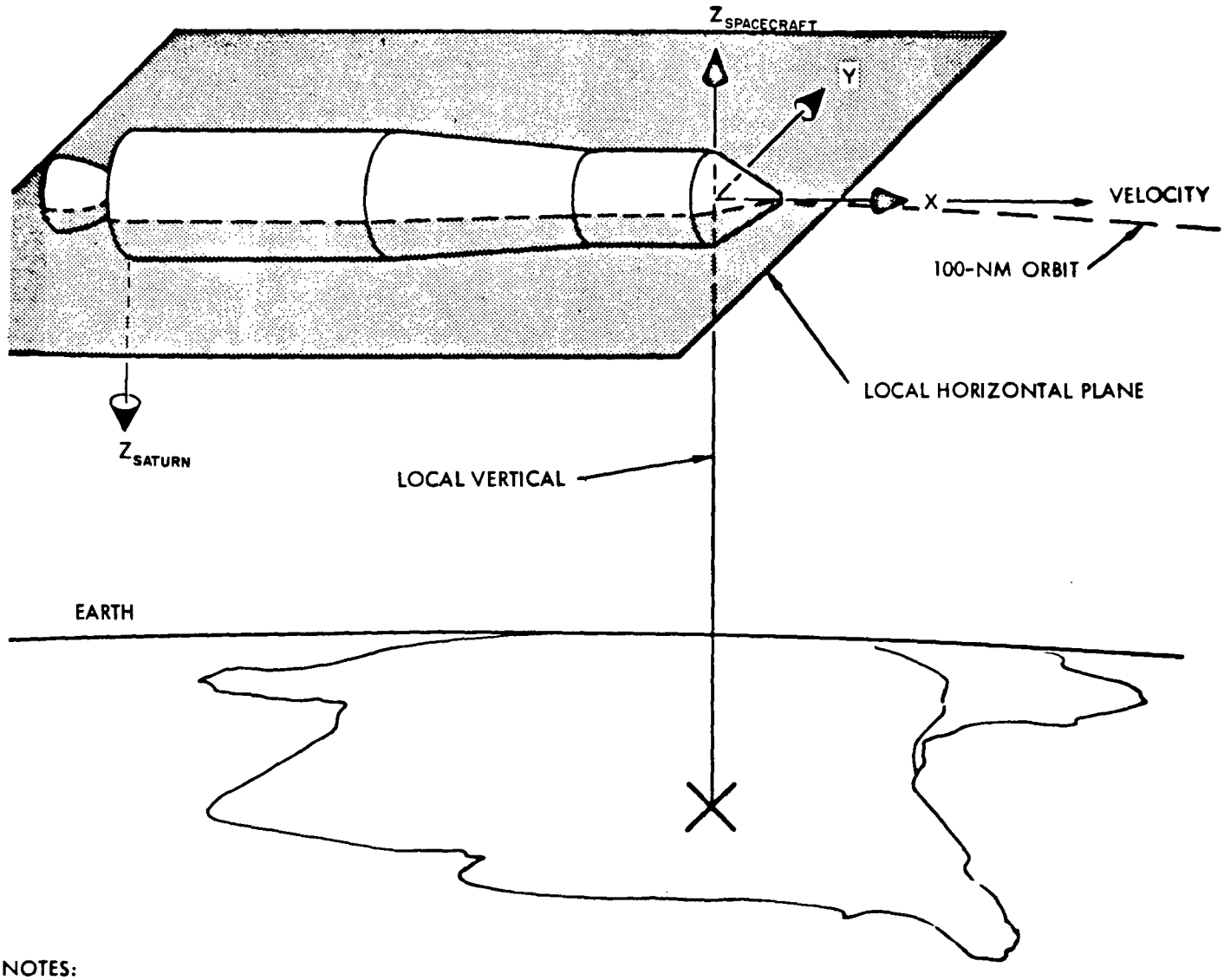
S-IVB Boost

S-IVB thrust is initiated at 536 seconds from liftoff for the final thrust to earth orbit insertion. The duration of this initial S-IVB burning time is 146 seconds. The S-IVB follows a pitch profile to an altitude of about 100 nautical miles. When earth orbit insertion is completed, the spacecraft XZ plane nominally coincides with the trajectory plane. The spacecraft X axis is approximately along the velocity vector and the plus Z axis is pointed away from earth toward the zenith as shown in Figure D.2.2-2.

D.2.3 PHASE 3.0 EARTH PARKING ORBIT

S-IVB earth-orbit insertion cutoff occurs approximately 700 seconds after liftoff resulting in a near-circular orbit of 100 nautical miles. The vehicle remains in a near-circular orbit for a duration of 1 hour, 23 minutes, 45 seconds. The spacecraft plus X axis is approximately in the local horizontal and pointed in the direction of flight. This relative attitude is maintained by a constant X axis pitch rate of approximately 0.067 deg/sec. The pitch rate is maintained in a 1 degree deadband through the S-IVB guidance and control system. During each orbit, general attitude constraints are imposed on the spacecraft to perform Inertial Measurement Unit (IMU) alignments and navigation sightings which will be performed in such a manner to maintain S-Band communications. However, navigation sightings are not performed during the earth orbit phase of DRM IIA for the following reasons: (1) the time required to perform necessary crew tasks and attitude maneuvers requires more than one earth orbit; (2) the earth landmarks are in darkness during the time available for navigation sightings.

When the spacecraft first achieves earth orbit, the SC XZ plane is approximately in the orbit plane and the X axis is parallel to the velocity vector. This local attitude is maintained for about 4.5 minutes, at which time a 70 degree roll maneuver is initiated. This



NOTES:

SPACECRAFT X Z PLANE IS IN THE TRAJECTORY PLANE

X AXIS IS ALONG THE VELOCITY VECTOR

Z AXIS IS TOWARD THE ZENITH

Figure D.2.2-2 Earth Orbit Insertion Completed

roll maneuver is performed so that the sun is not in the optics field during IMU fine alignment. At the completion of the first IMU fine alignment, the vehicle is returned to the original local attitude with the plus Z axis of the SC pointing up parallel to local vertical. This local attitude is maintained until the vehicle alignment for translunar injection.

Figure D.2.3-1 illustrates the sequence, duration and location of attitudes employed during the earth orbit phase of the DRM IIA. The following general attitude constraints are imposed on the vehicle during earth orbit.

(1) IMU Alignment

In earth orbit, two IMU alignments are performed: one after earth orbit injection and one performed within 15 minutes of the second S-IVB burn for translunar injection. IMU alignments are made to establish a precise inertial reference from which to effect guidance and control of the vehicle in the event backup control is required. To perform an IMU alignment the vehicle roll attitude is such that the spacecraft shaft drive axis is at least 50 degrees above the local horizon as shown in Figure D.2.3-2. The vehicle attitude at earth orbit insertion satisfies this condition and therefore no attitude maneuver is required for the first IMU alignment. If, however, a condition should arise as in the DRM IIA, where the sun appears in the optical field of view, a roll maneuver of about 70 degrees would be performed to point the optics away from the sun. Since the vehicle follows a programmed pitch attitude throughout the orbit, the vehicle plus X axis is approximately in the direction of flight. This attitude enables continuous earth communications via unified S-Band during MSFN/vehicle-line-of-sight periods.

As required to perform an IMU alignment, the scanning telescope is used to select stars. The scanning telescope having a 60-degree optical field of view is servo-driven to scan within a 100-degree mechanical field. A star is selected within the telescope field and the star is acquired by the sextant. The sextant has a 1.8-degree optical field of view and a magnification power of 28. The shaft axes of the scanning telescope and the sextant are electrically slaved. The star is identified and its position is recorded by pressing the mark button. The sextant is next aligned to a second star which is also within the scanning telescope field of view. After "marking" the second star, based on the two sequential measurements, the computer establishes the platform inertial reference.

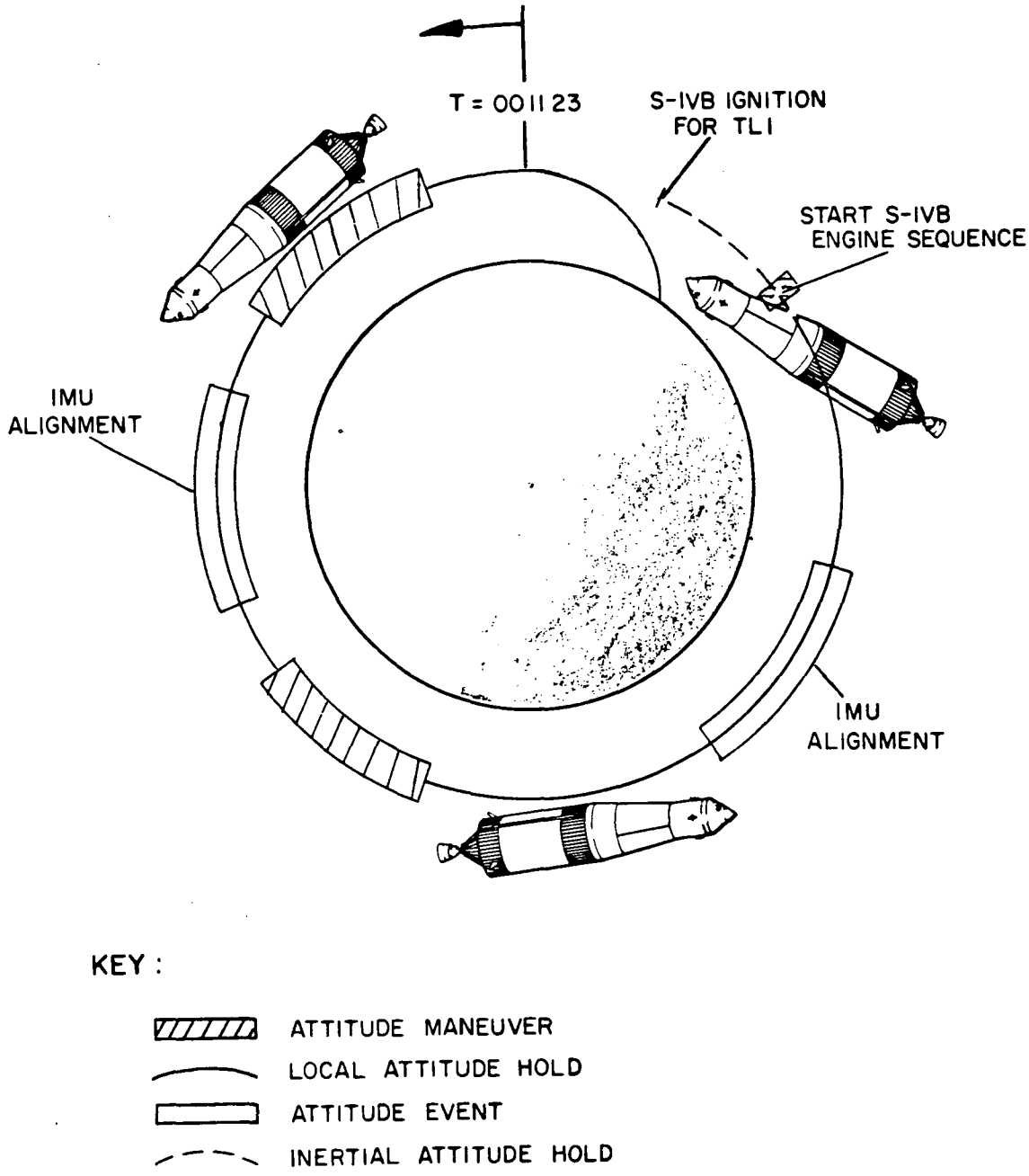
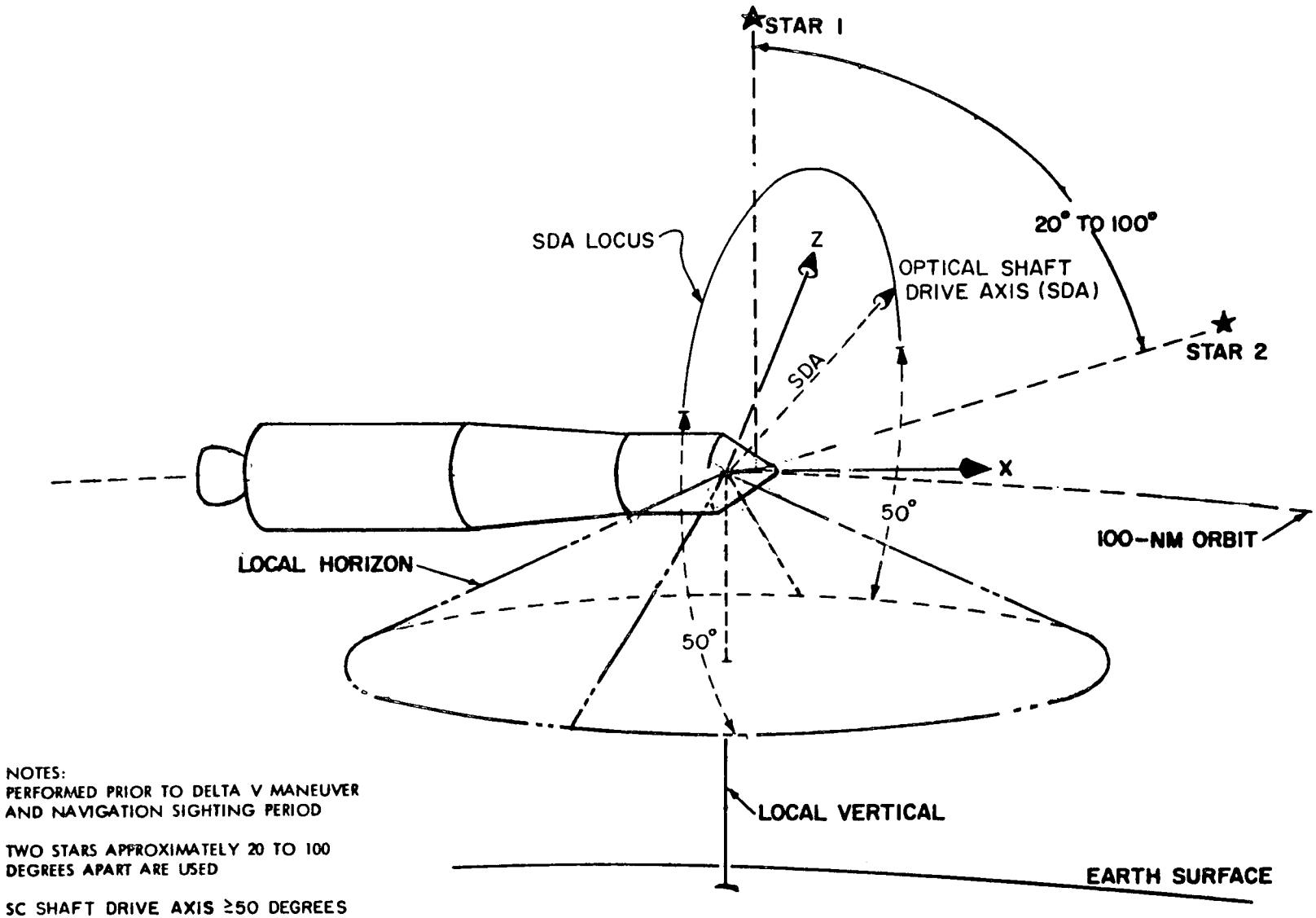


Figure D.2.3-1 Earth Orbit Attitude Sequence



NOTES:
PERFORMED PRIOR TO DELTA V MANEUVER AND NAVIGATION SIGHTING PERIOD

TWO STARS APPROXIMATELY 20 TO 100 DEGREES APART ARE USED

SC SHAFT DRIVE AXIS ≥50 DEGREES ABOVE LOCAL HORIZON

Figure D.2.3-2 IMU Alignment in Earth Orbit

To avoid S-IVB platform gimbal lock the vehicle is limited to maneuvers which do not carry the vehicle X axis out of the plane of the orbit by more than 45 degrees.

Within these limitations, the CSM IMU platform inner gimbal axis is aligned normal to the orbit plane in order to also avoid gimbal lock of the CSM platform. For the IMU alignment just prior to translunar injection, the primary consideration is to align the platform plus X axis to the predetermined thrust direction.

(2) Navigation Sightings

Although the primary mode of navigation is Manned Space Flight Network (MSFN) for the earth orbit phase of the mission, a period will be allotted for other Block II missions to perform earth orbit navigation sightings to check out the Guidance and Navigation system. The navigation sighting is preceded by an IMU alignment with about four optical fixes being performed on earth landmarks. Earth landmark sightings must be performed on sunlit side of the earth and the landmarks must be within the region denoted in Figure D.2.3-3.

While a navigation sighting is being made during the earth orbit phase, the spacecraft plus X axis is in the direction of positive velocity and the plus Z axis is near the local vertical, pointing toward earth as shown in Figure D.2.3-3. As a result, to perform a navigation sighting, the vehicle is rolled 180 degrees from the IMU alignment attitude. This roll maneuver is controlled by the astronaut through the S-IVB guidance and control system. Consideration has been given to holding the plus X axis 20 degrees below the positive velocity vector to increase the optical coverage of the earth's surface. However, due to the possibility of low S-Band antenna gains near the plus X axis, acquisition of communications could be delayed and therefore a local horizontal attitude is maintained.

Navigation sightings are taken on predetermined landmarks about the earth, near but not on the plus Z axis flight-trace because of the optics blind zone (see Figure D.2.3-3). The optics blind zone is a result of a high line-of-sight angular rate of the landmark, with reference to the spacecraft and optics drive mechanism. The scanning telescope, having a large field of view, is used for tracking. The latitude and longitude for each landmark is entered into the CMC (Command Module Computer). Using the scanning telescope a landmark is identified and tracked. When centered on the optics cross hairs, the landmark is marked. At least two marks per sighting are made by depressing the mark button for each sighting. Orbital parameters are computed and stored in the CMC memory.

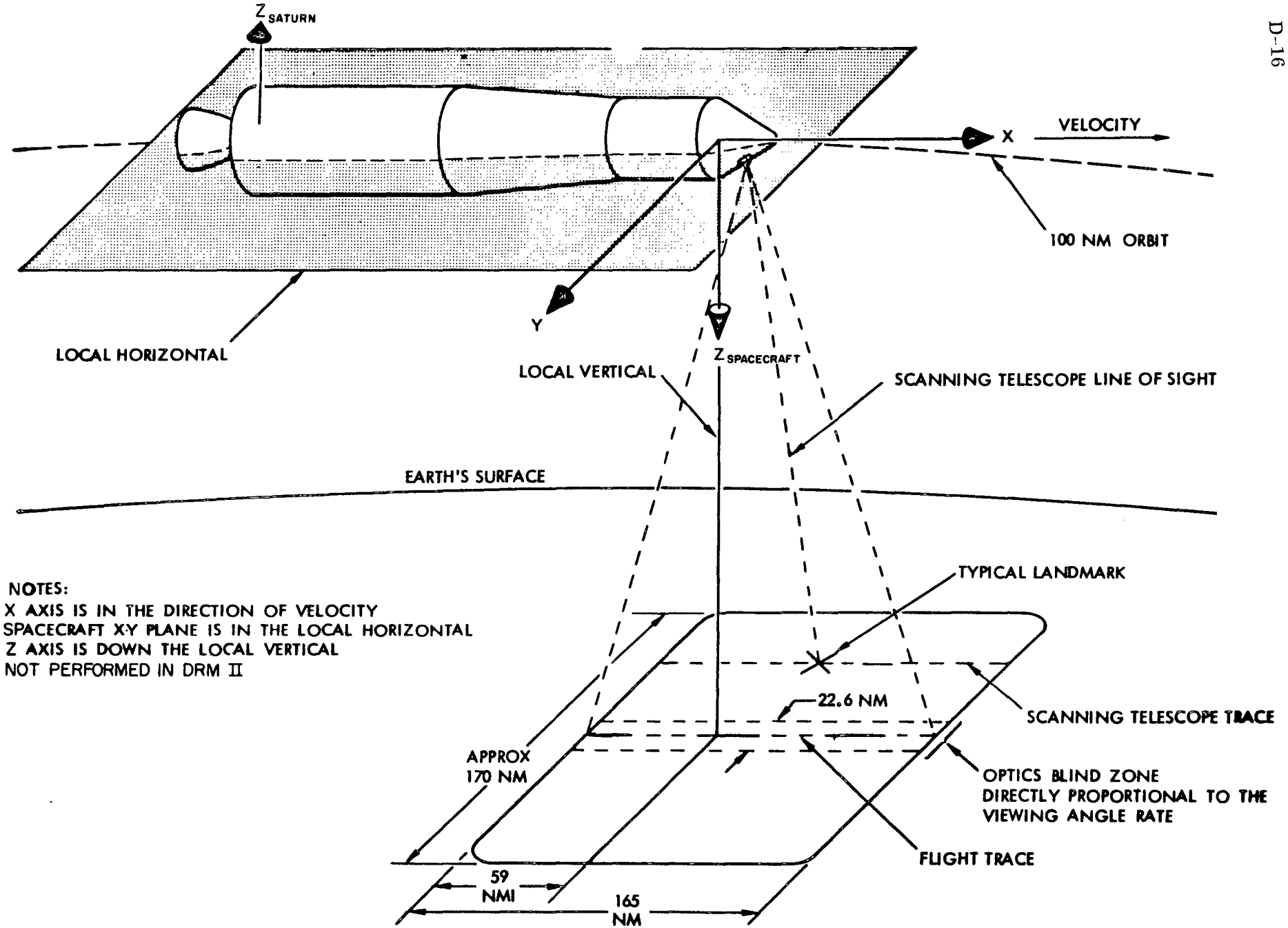


Figure D.2.3-3 Navigation Sightings Earth Orbit

(3) Communications

Throughout earth orbit, the spacecraft attitude must be compatible with unified S-Band communications whenever line-of-sight exists to a suitable configured ground station. Omni limits shown in Figure D.2.3-4 are based on an antenna gain greater than negative 3 db. Since for most of the earth orbit phase the S-IVB is constrained in a preprogrammed pitch attitude, roll orientations required for navigation sightings and IMU alignments are compatible with CSM S-Band omni communication requirements.

D.2.4 PHASE 4.0 TRANSLUNAR INJECTION

Translunar injection occurs at the first opportunity after earth orbit checkout of the spacecraft. The S-IVB burns for 5 minutes, 42 seconds terminating at an altitude of 161 nautical miles.

Before the S-IVB engine is restarted for translunar injection, the vehicle plus X axis is oriented 4 degrees below the local horizontal in the orbit plane and the spacecraft plus Z axis pointing up. At S-IVB shutdown, the spacecraft XZ plane is still in the vehicle orbit plane with the plus X axis 4 degrees above the earth local horizontal and the plus Z axis up as shown in Figure D.2.4-1.

D.2.5 PHASE 5.0 INITIAL TRANSLUNAR COAST THROUGH S-IVB JETTISON

Transposition and Docking

The configuration of the vehicle after translunar injection consists of the S-IVB with the Lunar Excursion Module (LM) and the Command and Service Module (CSM). Immediately following translunar injection the MSFN begins tracking the vehicle and performs computation of the translunar trajectory. About three minutes after translunar injection the S-IVB orients for the transposition and docking phase. This orientation consists of a X axis negative pitch away from earth of 60 degrees followed by a positive 165 degree roll. Just prior to transposition and docking, the spacecraft LM adaptor (SLA) is deployed followed by deployment of the CSM high-gain antenna. Approximately 17 minutes after translunar injection, the transposition and docking maneuver begins at an altitude of 2500 nautical miles.

The CSM must separate from the S-IVB using the SM RCS jets and, while coasting to the necessary separation distance, perform a roll to achieve axial indexing as shown in Figure D.2.5-1. The CSM will then perform a 180° pitch maneuver, acquire CSM high-

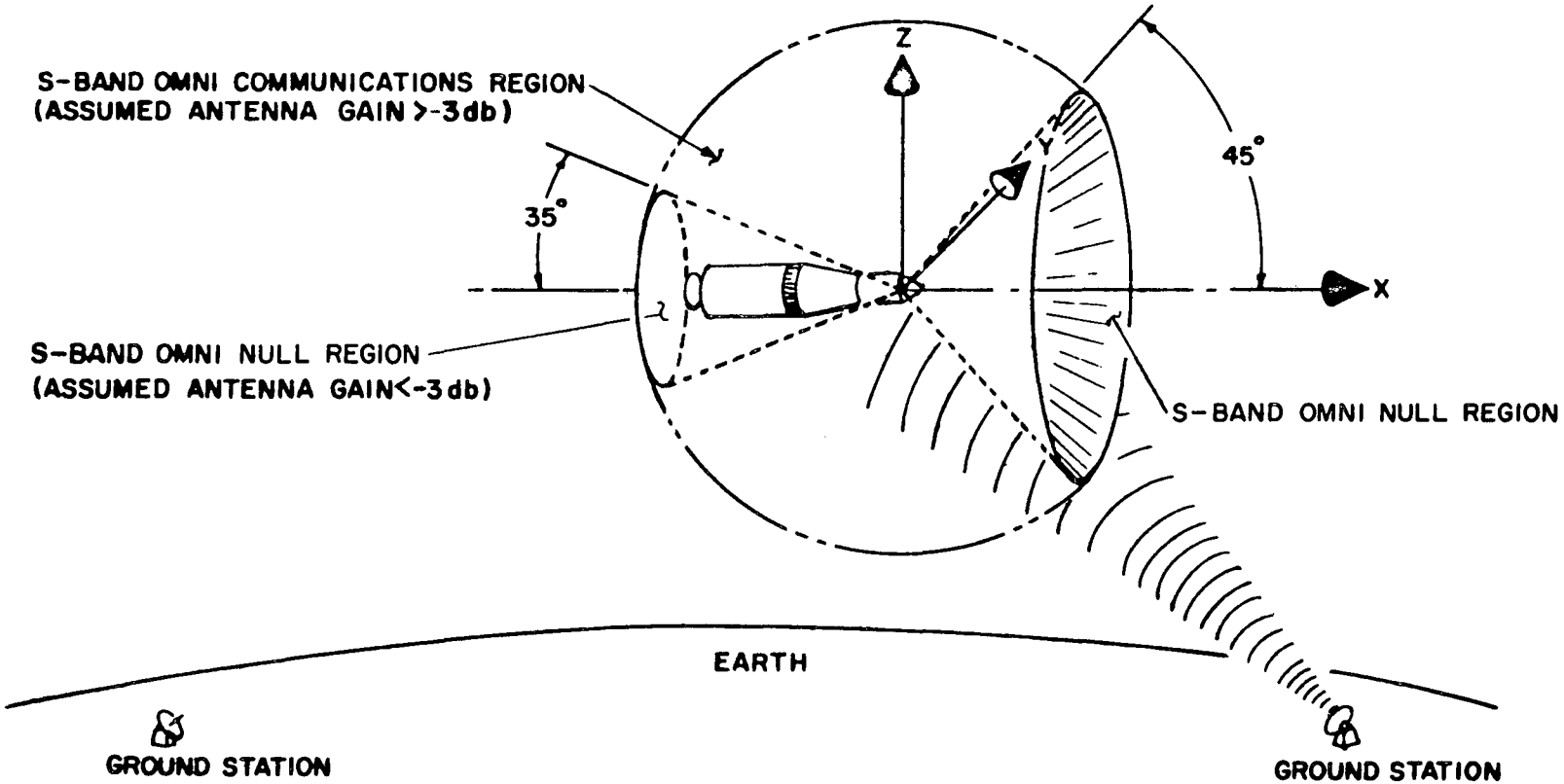
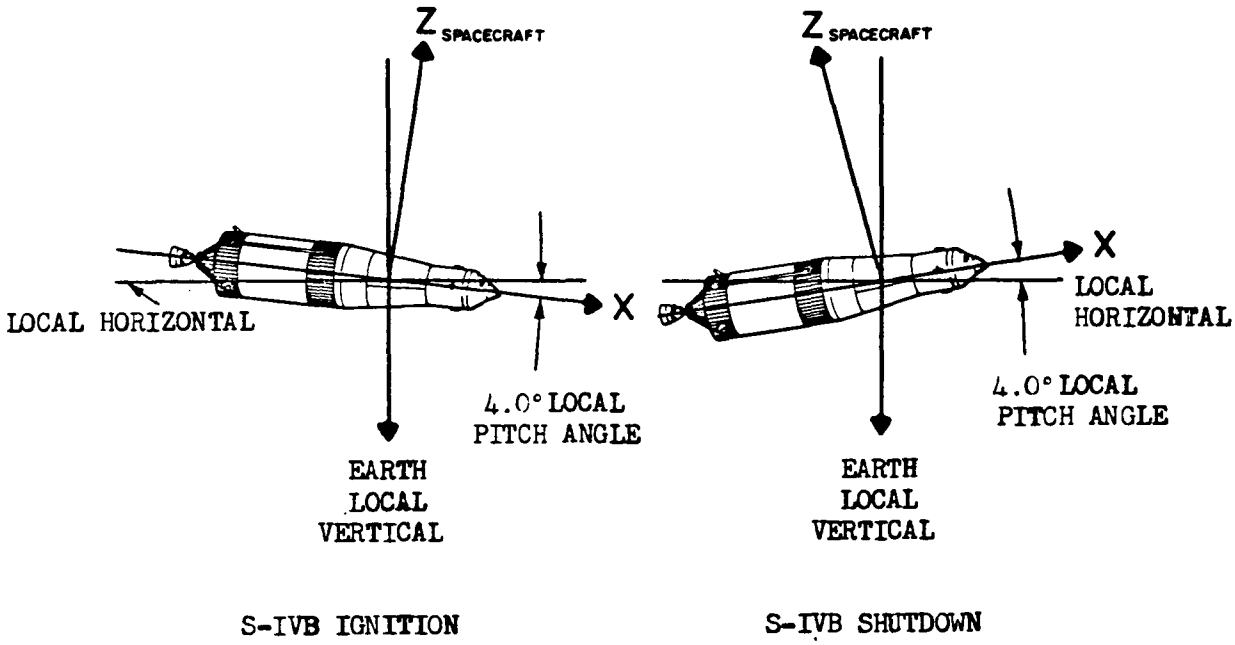


Figure D.2.3-4 Unified S-Band OMNI Communications, Earth Orbit



- AT IGNITION THE SPACECRAFT X Z PLANE IS IN THE ORBIT PLANE WITH PLUS X AXIS 4.0° BELOW THE LOCAL HORIZONTAL (THRUST DIRECTION) AND PLUS Z IS UP (ACCEPTABLE PRE-IMU ALIGNMENT ATTITUDE)
- AT S-IVB CUTOFF THE SPACECRAFT X Z PLANE IS IN THE ORBIT PLANE WITH PLUS X AXIS 4.0° ABOVE THE LOCAL HORIZONTAL.

Figure D.2.4-1 Translunar Injection

gain communications, close and dock onto the LM protruding from the S-IVB, and finally withdraw the LM from the S-IVB. This maneuver is completed within ten minutes. Figure D.2.5-1 illustrates the attitude sequence for the transposition and docking phase.

Currently there are three primary constraints imposed on the CSM which influence the procedures for attitude during transposition and docking. The constraints must be compatible with each other and are described as follows:

(1) Communication Requirements

Prior to and during transposition and docking, the S-IVB is inertially constrained such that its high-gain antenna coverage pattern contains an MSFN station. In addition, initial orientation of the composite vehicle must be adjusted in pitch such that at final CSM closing and hard docking the SLA panels do not obstruct the line-of-sight between the CSM high-gain antenna and the MSFN station.

To provide adequate S-IVB high-gain antenna coverage, the minus Z axis of the CSM is pointed approximately 40 degrees from the MSFN station toward the minus velocity vector. This will allow the S-IVB high-gain antenna pattern to sweep through the MSFN station during transposition and docking. Thus the angle between the minus Z axis and the MSFN is smallest (greater antenna gain) at the greatest slant range. The turnaround maneuver performed by the CSM involves a roll-pitch sequence rather than a pitch-roll sequence. The roll-pitch sequence avoids placing the CSM S-Band omni antenna null zone region at the MSFN station during the 180-degree pitch maneuver. Upon completion of the CSM pitch maneiver, but prior to translation docking, the astronaut manually acquires the MSFN with the CSM high-gain antenna. The final docking orientation has the line-of-sight of the CSM high-gain antenna to the MSFN in the CSM plus Z, minus Y quadrant, which permits CSM high-gain communications.

(2) Guidance Platform Gimbal Lock

The S-IVB is constrained in pitch and roll by communications and has a ± 45-degree limit* in yaw due to guidance platform gimbal lock constraints. Since the CSM also has its guidance platform in operation, the CSM positive X axis is also restricted by the CSM IMU to within ± 70 degrees of the trajectory plane. The platform gimbal alignment with the inner

*This limit is based on a presumed favorable alignment of the inner gimbal axis of the S-IVB stable member platform.

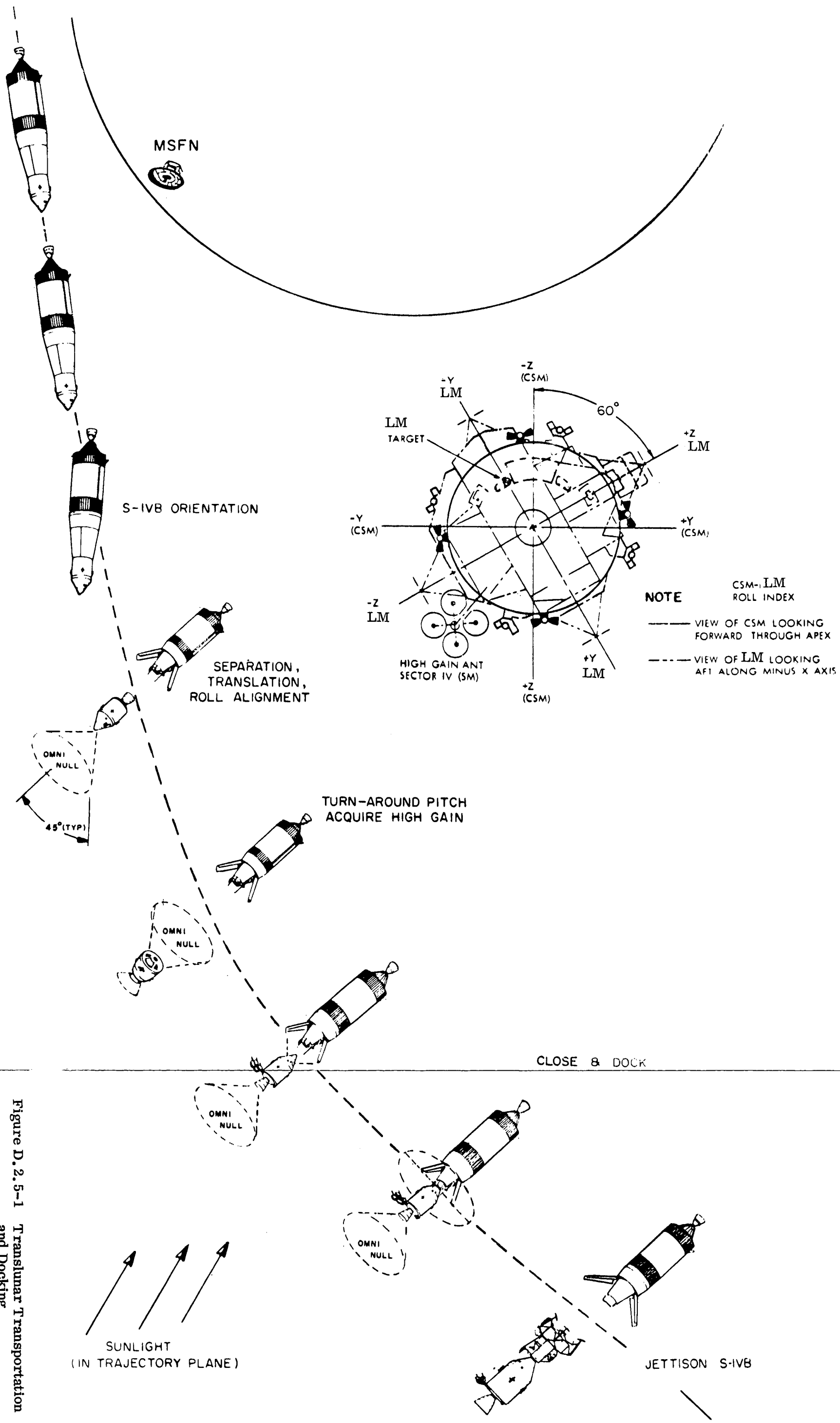


Figure D.2.5-1 Translunar Transportation and Docking

gimbal axis normal to the trajectory plane permits the CSM maximum freedom to maneuver its X axis within the trajectory plane and also maximum freedom to roll about the CSM X axis. Therefore, the sequence of maneuvers indicated in Figure D.2.5-1 complies with guidance platform alignment restrictions.

(3) Visibility Restrictions

The CSM positive pitch maneuver is performed during transposition and docking to permit the crew to most rapidly acquire a view of the target vehicle (LM/S-IVB) through the CM windows. To enhance docking visibility, it is required that the docking interface be illuminated by the sun. Therefore, during final docking, the angle between the CSM minus X axis and the vehicle sun line must be less than 90 degrees.

S-IVB Jettison

Final docking and the necessary crew procedures to secure the LM with the CSM are completed approximately 1 hour from initiation of the transposition and docking maneuver. The S-IVB jettison is performed by a SM RCS delta velocity along the CSM minus X axis at a rate of 6 feet per second. Since the jettison velocity of 6 feet per second affects the trajectory, the S-IVB translunar injection velocity vector must be biased to account for the separation velocity vector. The DRM IIA trajectory accounted for this separation velocity by applying it along the velocity vector. As a result, the separation velocity vector used for trajectory computation is incompatible with the spacecraft attitude at the time of S-IVB jettison.

D.2.6 PHASE 6.0 S-IVB JETTISON TO LUNAR ORBIT INSERTION

During the translunar phase of the mission, attitude constraints are imposed on the spacecraft to perform the following maneuvers and mission operations: 1) navigation sightings, 2) IMU alignments, 3) midcourse corrections, 4) maintenance of continuous communications, 5) thermal attitude control. Ullage maneuvers are not required for the translunar phase thereby avoiding a requirement for propellant settling. The nearly full SPS tanks together with screens which inhibit propellant movement away from the tank outlet, negates the requirement for propellant settling.

About 20 minutes after S-IVB jettison the spacecraft is oriented for a series of five earth-star navigation sightings. The desired orientation requires that the optical shaft drive axis point at the earth landmark. After remaining in the final navigation sighting attitude for about 25 minutes, the spacecraft is maneuvered to the IMU fine alignment attitude. The alignment attitude is approximately the same as the midcourse correction attitude so at the

end of the alignment only a small (less than 2 degree) maneuver is made to the MC attitude. This attitude is than held throughout the SPS firing.

Immediately after the MC the spacecraft is oriented to the passive thermal control attitude, which places the X axis normal to the vehicle-sun line. A slow roll (2.5 rev/hr) is then initiated. The spacecraft remains approximately in this rolling attitude until just before the second MC. At mission time 50 hr. 47 min. the thermal cycling is stopped and a coarse IMU alignment is performed. At the completion of the coarse alignment the spacecraft is maneuvered to the fine IMU alignment attitude. Again, this alignment attitude is approximately the second MC attitude, so at the completion of the fine alignment a small maneuver is made to the MC attitude. This attitude is held through the SPS firing.

Following the MC the spacecraft is oriented to the passive thermal control attitude and a roll rate initiated. This thermal cycling attitude is maintained until mission time 60 hrs. and 33 minutes. The spacecraft is then oriented for a series of five earth-star navigation sightings. At the completion of the navigation sightings the final inertial attitude is held and a coarse IMU alignment performed. The spacecraft is then oriented for a fine IMU alignment. At the completion of the fine alignment a small attitude change is made to place the spacecraft in the third MC attitude. This attitude is maintained through the SPS firing and up to mission time 62 hours and 37 minutes. At this time the spacecraft is oriented for the fine IMU alignment prior to lunar orbit insertion (LOI). At the completion of the fine alignment a small attitude change is made to place the spacecraft in the proper attitude for the initiation of LOI. This attitude is held inertially fixed until SPS ignition.

Fig. D.2.6-1 illustrates the attitude sequence for the translunar phase of the DRM IIA. A description of attitude constraints observed for the translunar phase is presented below.

(1) Navigation

Although ground based transponder ranging (MSFN-CSM PRN) is the primary navigation mode, optical sightings are performed during the translunar phase to check out optical navigation which is a back-up to ground based navigation. For translunar optical navigation, both a star and landmark must be sighted through the CSM optics. It is further required that the shaft drive axis of the optics mechanism be pointed at a landmark and that the sextant line of sight to a star be within 50 degrees of the shaft drive axis. The shaft drive axis is in a fixed direction with respect to the CSM, 32.5 degrees from the CSM plus Z axis towards the plus X axis in the CSM body XZ plane. Either earth surface landmarks or lunar

surface landmarks are used, depending upon which is in the nearest vicinity of the spacecraft. The objective is to determine spacecraft velocity and position in order to verify a satisfactory trajectory. For the translunar phase of the DRM IIA, two series of navigation sightings are performed and are described as follows:

a. First Series of Navigation Sightings

After the CSM/LM is separated from the S-IVB and prior to the first midcourse correction, a series of optical navigation sightings are performed. The spacecraft is oriented to establish an attitude satisfactory for earth landmark sightings and communications as shown in Fig. D.2.6-1. Navigation sightings are performed during intervals of approximately 4 minutes.

b. Last Series of Navigation Sightings

Preceding the third translunar midcourse correction a series of optical navigation sightings is performed to check out the navigation equipment prior to lunar orbit insertion (See Fig. D.2.6-2). Since most of the lunar surface visible from the SC is in darkness, navigation sightings are performed on earth landmarks.

(2) IMU Alignment

Translunar IMU alignments are performed prior to SPS translation maneuvers. Four IMU alignments are performed during the translunar phase, prior to each of three translunar midcourse corrections and a fourth performed within 15 minutes of SPS ignition for lunar orbit insertion.

An IMU alignment prior to an SPS delta-V imposes certain constraints upon spacecraft attitude. (See Fig. D.2.6-3). The IMU platform X axis is aligned approximately to a predetermined direction of thrust (IMU coarse alignment). The only requirement placed upon attitude for a coarse IMU alignment is that two reference stars are contained in the optical field of view and that the sun is not in the field of view. Since the 37 reference stars are essentially uniformally distributed about the celestial sphere, all translunar coarse IMU alignments can be performed in the same inertial attitudes as the preceding mission event, i.e., navigation sightings, thermal cycling. Following the coarse IMU alignment the spacecraft is then maneuvered to the desired direction of thrust. The IMU platform is realigned using sequential sextant sightings of two stars within the optics field of view (IMU fine alignment). Following the fine IMU alignment, the spacecraft is held inertially fixed in the narrow deadband while final preparations are made for the midcourse correction.

(3) Midcourse Corrections

Due to navigation and maneuver execution errors, the spacecraft is expected to deviate from the desired trajectory. To accommodate these deviations, midcourse correction (velocity changes) are planned using the SPS. Three SPS translation maneuvers are expected for translunar midcourse phase. As a reference for mission planning purposes, SPS ignitions for translunar midcourse corrections are assumed typically to occur at the following times: The first correction is to occur as soon as possible after transposition and docking and the navigation sighting sequence. This opportunity exists 3 hours after translunar injection for the DRM IIA. The second correction takes place near the boundary of earth-moon's sphere of influence, about 50 hours from translunar injection. The third (final) midcourse correction is performed as close to lunar orbit insertion as possible and occurs about one hour prior to lunar orbit insertion. The duration of an SPS MC burn is typically one to ten seconds.

The sequence of operations prior to a midcourse correction includes the following: The IMU is aligned to the predetermined thrust direction; the spacecraft X axis is oriented in the direction of thrust; a preferred roll orientation is permitted to assure high-gain communitions; and finally, SPS ignition occurs. (See Figure D.2.6-4.) IMU alignments are discussed under previous topics.

(4) Passive Thermal Control

Passive Thermal Control (PTC) is utilized to maintain a satisfactory temperature balance for spacecraft critical subsystems and components, i.e., RCS quads, SPS feed lines, and heat shield. The PTC attitude specifies a continuous roll about the vehicle X axis during extended periods of cislunar coast and will normally be interrupted only for midcourse correction operations. To maintain the proper thermal balance, the YZ plane of the CSM must be within 20 degrees of the line-of-sight to the sun. Orientations for the PTC attitude occur after the first and second midcourse corrections. The time from the third midcourse correction to lunar orbit injection is sufficiently short so that thermal constraints are not required. In addition, this period has a high density of attitude operations, thus precluding continuous heating or cooling on any fixed region of the spacecraft. As a result,no orientation for PTC occurs between the final midcourse correction and lunar orbit insertion.

To achieve the PTC attitude, the SC is maneuvered to an attitude that places the vehicle X axis normal to the vehicle-sun line. An orientation of the vehicle X axis about the sun vector may be chosen to maximize the time of communications via the CSM high gain antenna.

This condition will be discussed in the subsequent communications paragraph. After stabilizing the vehicle in the desired attitude for PTC (vehicle is stabilized after 15 minutes of attitude hold in the 0.5° deadband) there remains a residual drift about all 3 axes due to the minimum impulse capability of the RCS jets. Both the direction and magnitude of the residual rates are random variables and therefore cannot be deterministically specified prior to the mission. As a result, specification of the required roll rate to meet the ± 20-degree PTC deadband requirement cannot be explicitly stated since the required roll rate is a function of the residual drift-rate vector. Upon initiating the X axis roll, the combination of vehicle residual drift rates and the X axis roll cause the principal axis (X axis) to precess about an inertially fixed angular momentum vector (See Figure D.2.6-5). The direction of angular momentum vector, being a function of both the vehicle inertias and the angular velocities imparted to the spacecraft, is not easily predicted.

The magnitude of the precession angle ρ (angle between momentum vector and X axis) is largest for high residual pitch or yaw drift rates for a given roll rate. On the other hand the magnitude of the precession angle may be reduced by increasing the X axis roll rate. At the present time there is no plan to either measure or control the vehicle residual drift rates and therefore the X-axis roll rate will be initiated such that for worst case conditions (maximum residual drift rates) the ± 20-degree thermal deadband requirement is satisfied. To meet this requirement the translunar roll rate must be 1 to 2.5 revolutions per hour. The DRM IIA passive thermal control roll rate is assumed to be 2.5 revolutions per hour.

(5) Communications

Communications between the spacecraft and earth are provided by S-Band high-gain equipment for the translunar phase. The capability to receive voice from the MSFN and to track with two-way doppler must be available at all times during this phase of the mission. The high-gain antenna located on the aft end of the CSM is used for sending and receiving the high data rate modes whereas the omni antennas generally provide adequate gain for emergency voice communications and tracking. RF antenna beamwidths and the associated antenna gains may be varied to meet gain and station coverage requirements. A significant null zone region exists for high-gain communications (Fig D.2.6-6). If communications are interrupted by vehicle attitude maneuvers, capability to reacquire high-gain communications with MSFN must be available throughout the translunar phase of the mission.

During PTC periods, the high-gain antenna (HGA) will automatically track an MSFN station except when the earth-vehicle line passes into the null zone region. This condition could prevail for each revolution of the spacecraft and therefore HGA reacquisition might be required upon each revolution. With the spacecraft X axis constrained within $90^\circ \pm 20^\circ$ of the vehicle sun line, there exists freedom for the X axis to be oriented about the vehicle-sun line within these specified limits. Taking advantage of this freedom, an X axis orientation is chosen to minimize HGA interruption periods. Uninterrupted high-gain antenna communications result if the angle between the minus X axis and the earth is less than 29 degrees. This condition exists when the angle between the vehicle-sun vector and the vehicle-earth vector is between 70 degrees and 110 degrees and the vehicle precession angle is less than 4 1/2 degrees. These conditions prevail for the translunar phase of both DRM I and IIA. A roll rate of 2 1/2 RPH causes a 4-degree precession angle resulting in a maximum angle of 21 degrees between the vehicle minus X axis and the vehicle-earth line. Thus continuous high gain antenna communications are available for the entire translunar phase of the DRM IIA.

The aforementioned conditions may also be related in terms of the LM lunar landing site. Due to the landing site sunlight requirements uninterrupted high-gain antenna communications cannot be assured if the lunar landing sites are more than 9-degrees west of the earth moon line. The likelihood of uninterrupted high-gain communications is enhanced the farther east the landing site is located. Assuming a vehicle precession angle of 4°, uninterrupted high-gain antenna communications are assured for the translunar phase if the landing site is located between 21 degrees and 39 degrees east selenographic longitude.

D.2.7 PHASE 7.0 LUNAR ORBIT INSERTION

SPS ignition for lunar orbit insertion occurs with the CSM plus X axis north of the orbit plane and 41 degrees above the local horizontal. The plus Z axis is 39 degrees south of the orbit plane away from the moon. At SPS shutdown the CSM plus X axis is about 16 degrees north of the orbit plane and 21 degrees above the negative velocity. The plus Z axis is 45 degrees south of the orbit plane away from the moon, see Fig. D.2.7-1 for illustration. The X axis pointing is defined to satisfy the required lunar orbit injection delta velocity parameters with the roll orientation (Z axis pointing) chosen to satisfy high-gain antenna communications just prior to SPS ignition for lunar orbit insertion. This attitude, which allows the astronauts to observe earthset and the lunar surface through the CSM windows during lunar orbit insertion, is compatible with the first lunar orbit event, an IMU alignment.

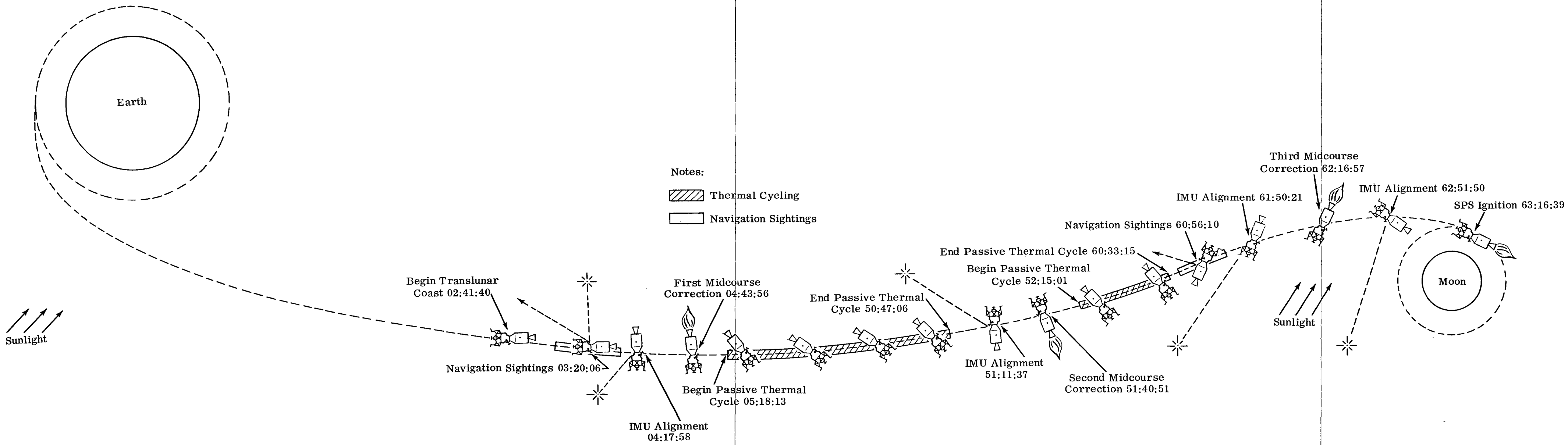


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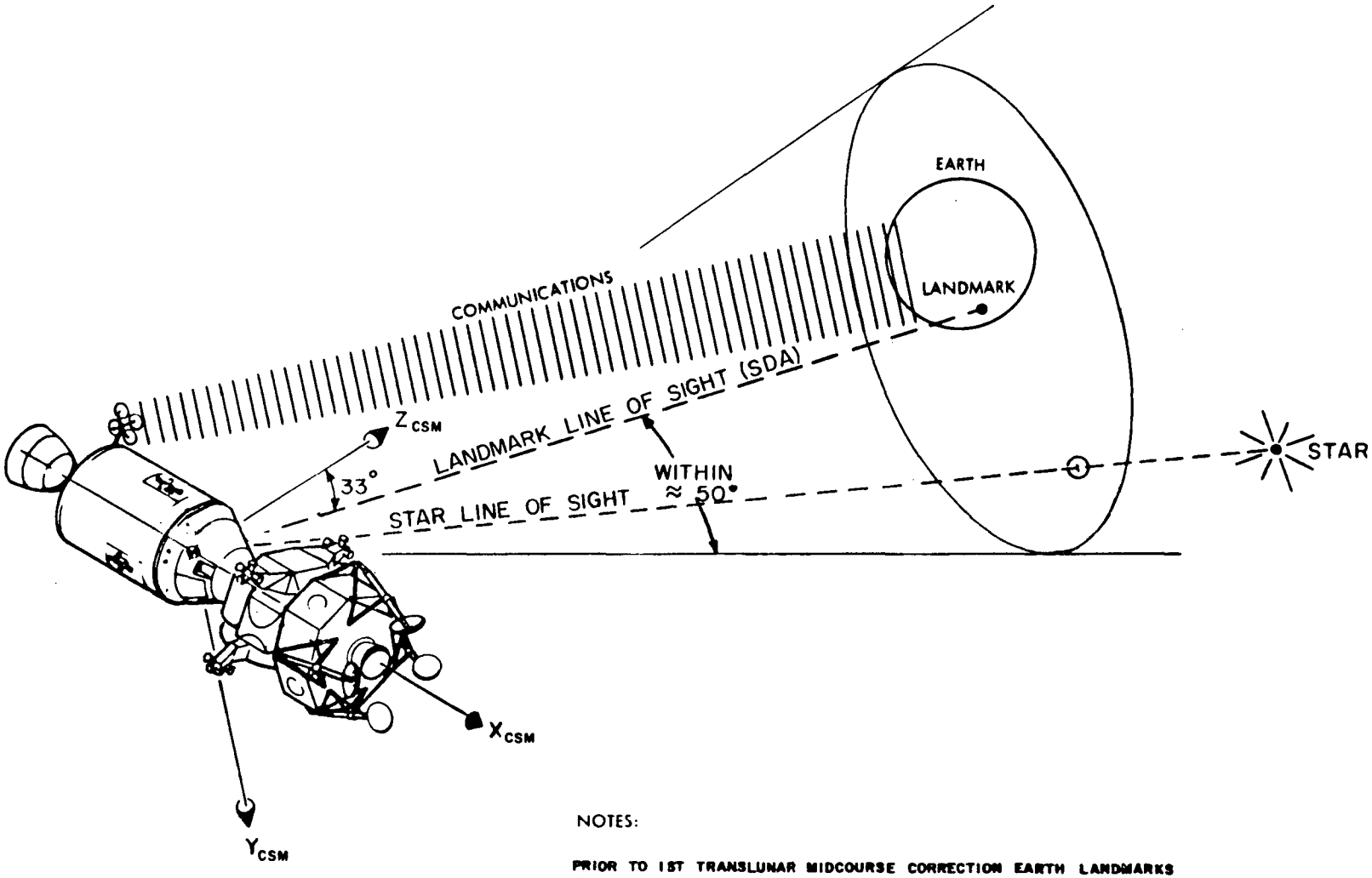
Figure D.2.6-1 Translunar Phase



NOTES:

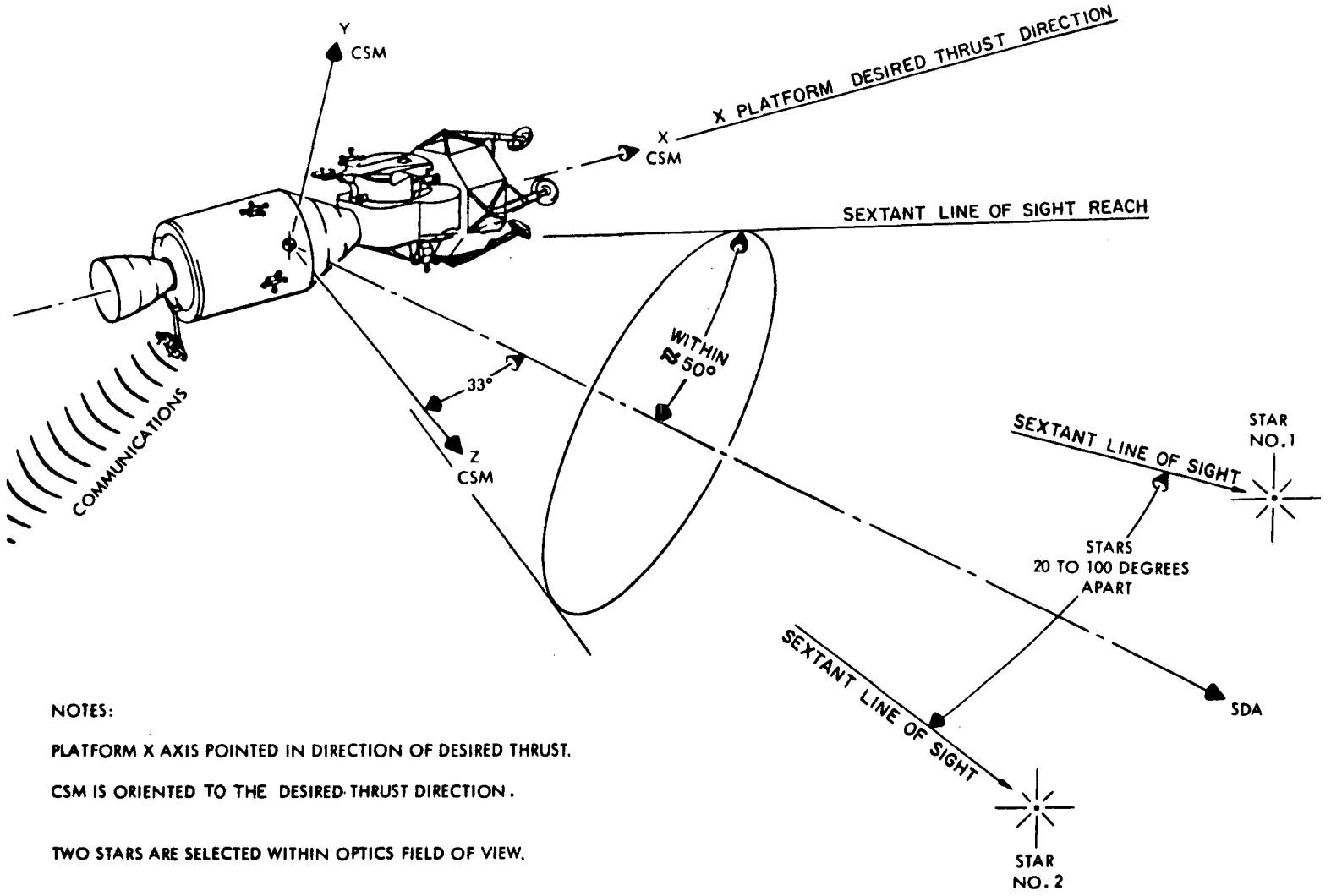
PRIOR TO 1ST TRANSLUNAR MIDCOURSE CORRECTION EARTH LANDMARKS ARE USED

SC ATTITUDE IS HELD SUCH THAT SDA IS POINTED TOWARD AN EARTH LANDMARK

THE SEXTANT IS POINTED TOWARD A STAR WITHIN 50 DEGREES OF THE LANDMARK

THE HIGH-GAIN ANTENNA COVERAGE ENCOMPASES THE SDA POINTING DIRECTION AND THEREFORE, COMMUNICATIONS IMPOSE NO FURTHER RESTRICTIONS ON SPACECRAFT ATTITUDE DURING LANDMARK SIGHTING

Figure D.2.6-2 Optical Navigation Sighting, Translunar Using Earth Landmark



NOTES:

PLATFORM X AXIS POINTED IN DIRECTION OF DESIRED THRUST.

CSM IS ORIENTED TO THE DESIRED THRUST DIRECTION.

TWO STARS ARE SELECTED WITHIN OPTICS FIELD OF VIEW.

Figure D.2.6-3 Midcourse Fine IMU Alignment Prior to Delta V

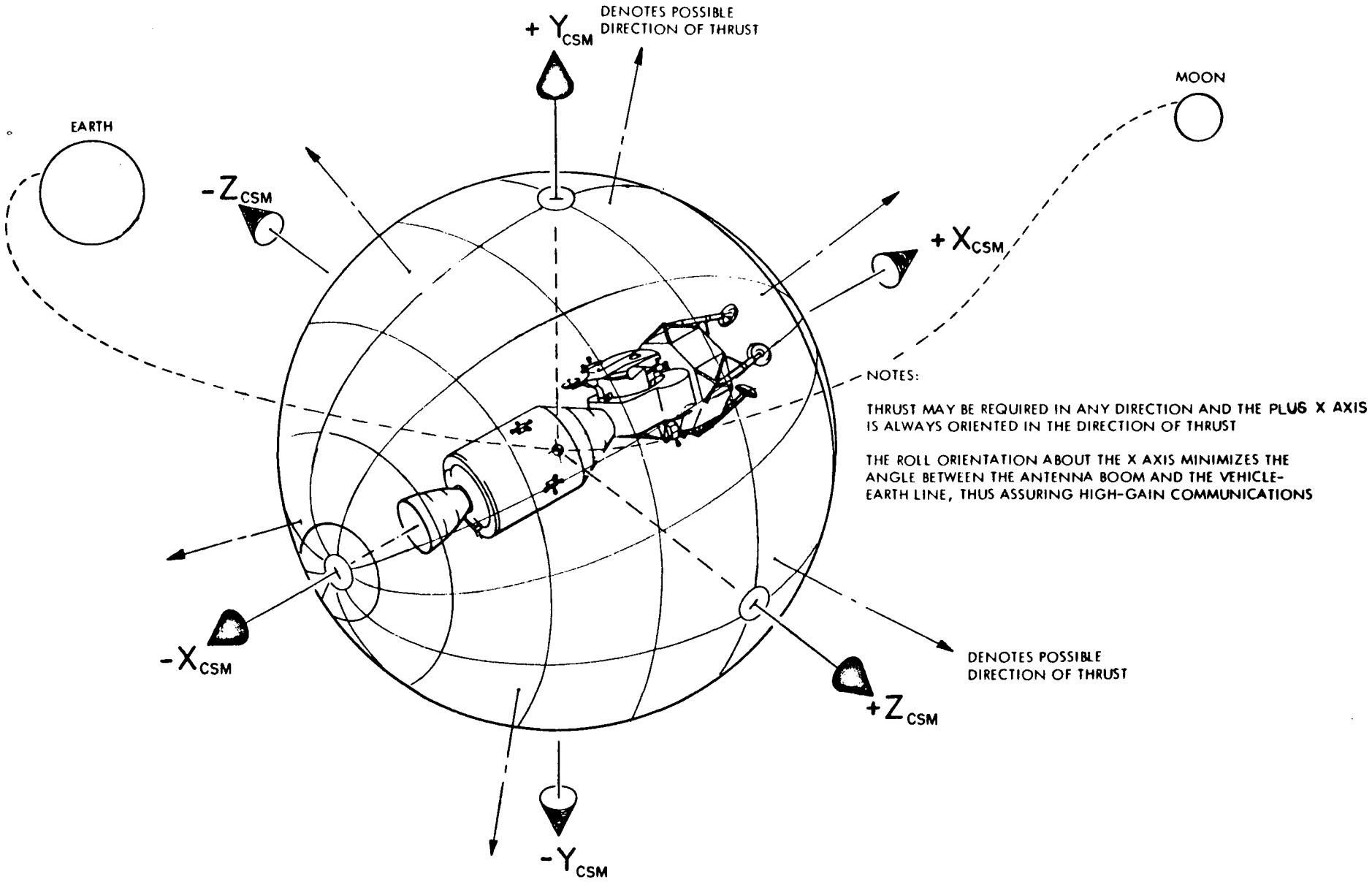


Figure D.2.6-4 Delta Velocity Maneuver, Translunar Midcourse

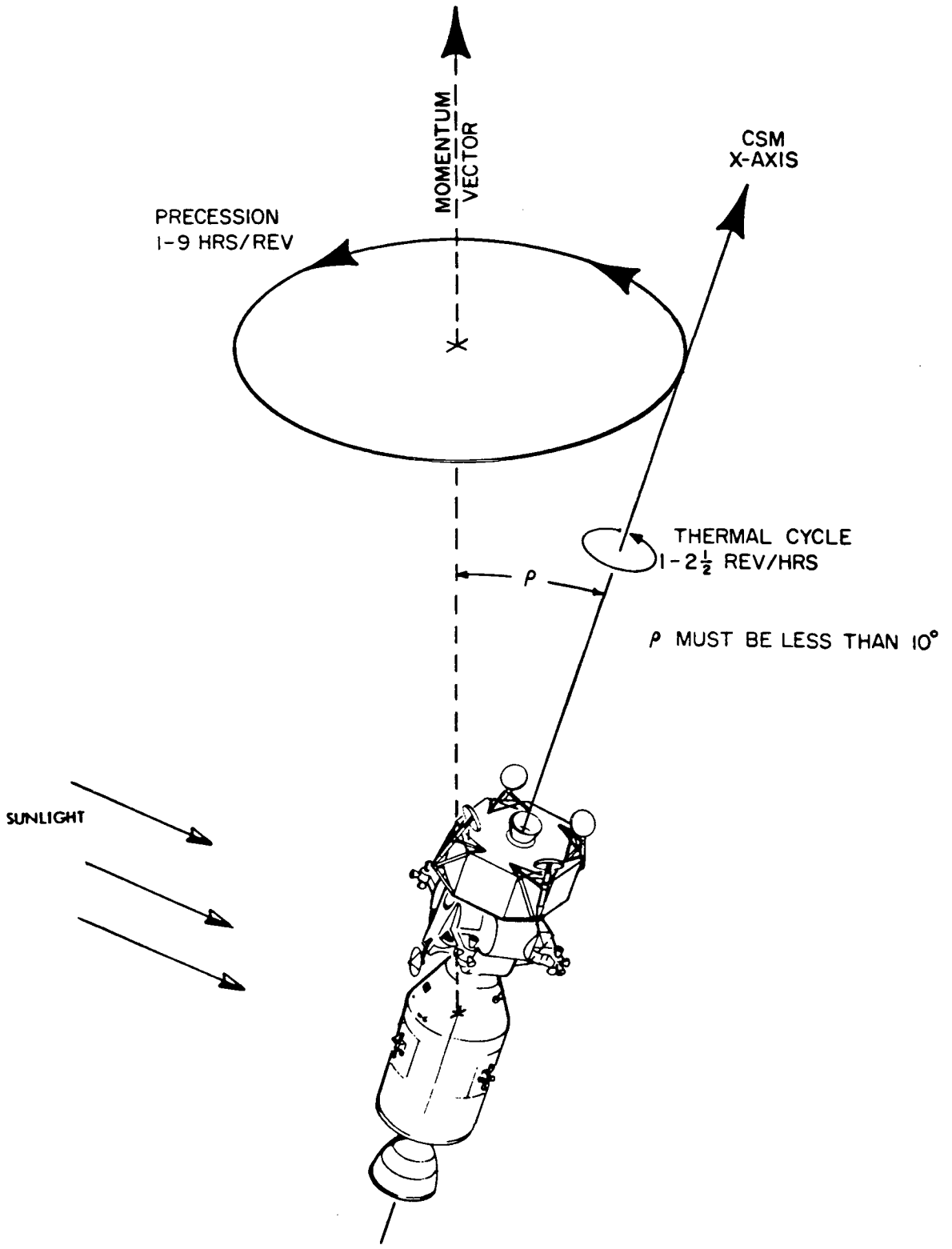


Figure D.2.6-5 Thermal Cycle Body Dynamics

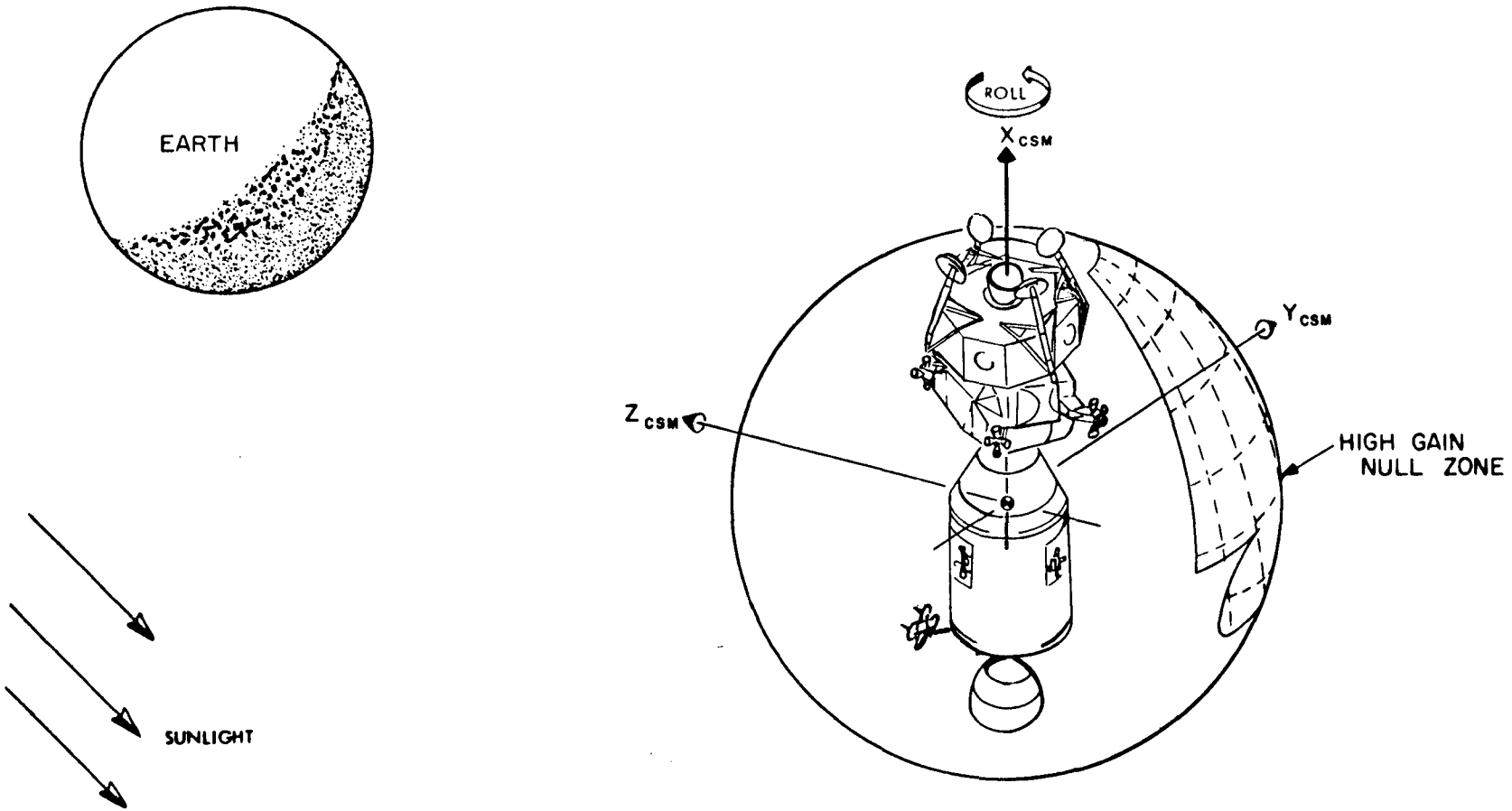
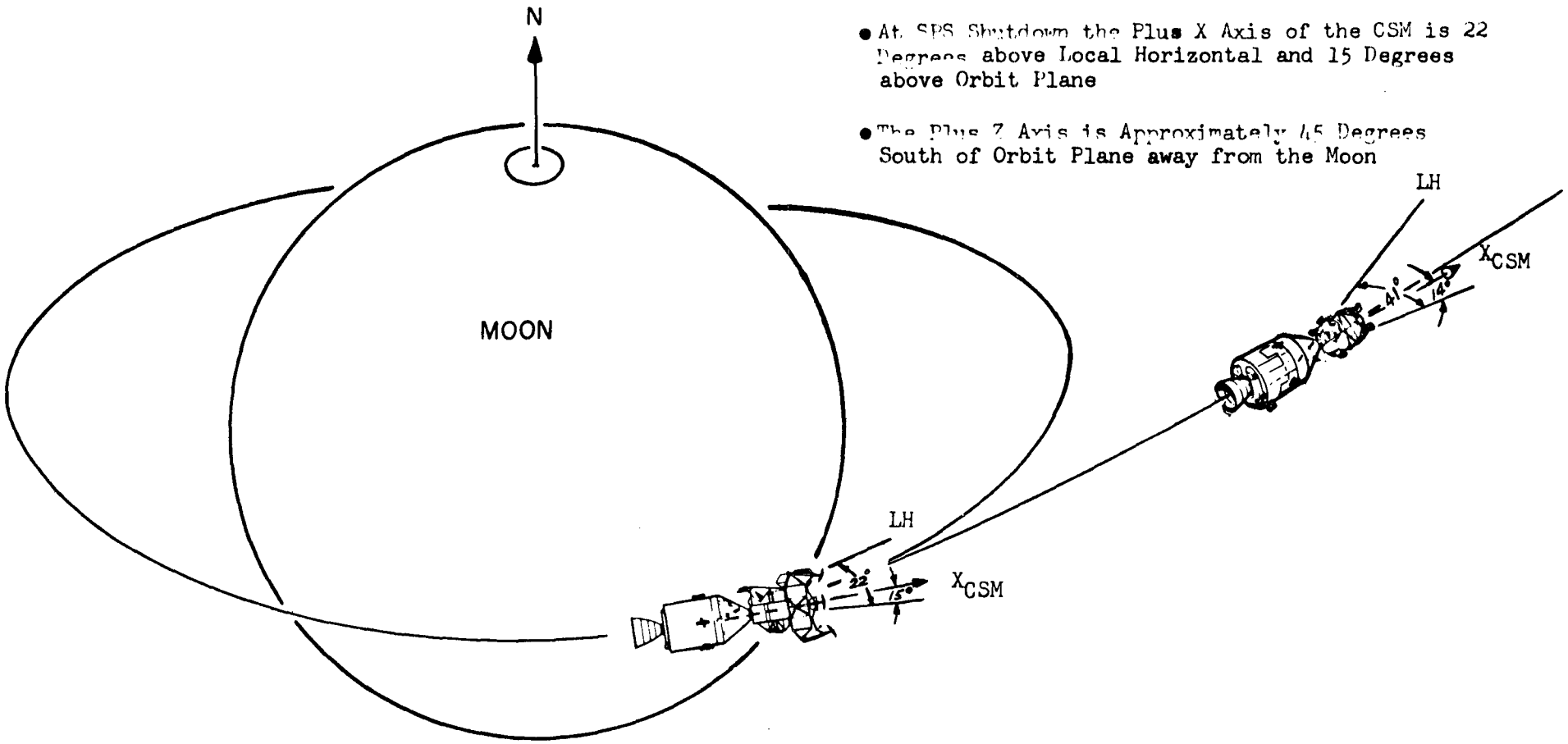


Figure D.2.6-6 High Gain Antenna Null Zone

NOTES:

- At Retro Ignition the CSM Plus X Axis is Pointed in the General Direction of Negative Velocity, 41 Degrees above Local Horizontal
- At SPS Shutdown the Plus X Axis of the CSM is 22 Degrees above Local Horizontal and 15 Degrees above Orbit Plane
- The Plus Z Axis is Approximately 45 Degrees South of Orbit Plane away from the Moon



Note:

LH - Local Horizontal in Orbit Plane

Figure D.2.7-1 Lunar Orbit Insertion

D.2.8 PHASE 8.0 LUNAR ORBIT COAST TO LM SEPARATION

The spacecraft orbit about the moon is a near circular orbit at an altitude of approximately 80 nautical miles. The DRM IIA mission includes three passes of the CSM/LM over the landing site before LM descent. The LM landing site will be located within 45 degrees selonographic longitude of the earth-moon line near the moon's equator. The DRM IIA landing site is located .2 degrees east of the earth-moon line.

Lunar Orbit 1

During the first lunar orbit, an IMU alingment is performed followed by a sequence of four landmark sightings and an observation on the LM landing site. In order to achieve the IMU alignment attitude and the proper X axis orientation for the series of navigation sighting, the following sequence is employed. Following SPS shutdown for lunar orbit injection, the vehicle performs a negative yaw of 21 degrees to bring the X axis into the lunar orbit plane. Following the yaw maneuver the attitude continues to be held inertially fixed in the narrow deadband for 13 minutes after which a local attitude hold begins.
Since the vehicular rate around the moon is 3 degrees per minute, an inertially fixed X axis for 13 minutes results in a local change of the X axis of 39 degrees. The 39-degree local attitude change when coupled with the lunar orbit injection attitude brings the plus X axis about 30 degrees below the local horizontal away from the direction of flight. This attitude satisfies the required X axis pointing for navigation sightings and, by maintaining the Z axis pointing, the optical field of view is pointed away from the moon for an IMU alignment.

The vehicle attitude for the IMU alignment in the first lunar orbit is held locally fixed (narrow deadband) with the X axis 30 degrees below the negative velocity vector in the orbit plane, and the Z axis 45° south of the orbit plane away from the moon.

Following the coarse and fine IMU alignment, the vehicle performs a positive roll of 144 degrees pointing the Z axis toward the moon, 9 degrees north of the orbit plane while maintaining a locally fixed X axis pointing. This attitude is held locally fixed in the narrow deadband throughout the navigation sighting sequence. Upon completing the navigation sighting sequence, the vehicle is placed in an inertial attitude hold and a positive roll of 108 degrees is performed which orients the plus Z axis 63 degrees north of the orbit plane, generally away from the moon. This attitude, which is held for one lunar orbit, assures high gain antenna communications, satisfies the ECS radiator attitude constraint and places the vehicle in a favorable orientation for the next attitude event, an IMU alignment.

Lunar Orbit 2

During lunar orbit 2, the vehicle remains inertially fixed for almost three-fourths of an orbit and then changes to a local attitude hold just prior to the longitude at which the inertial attitude was established in lunar orbit 1.

Toward the end of lunar orbit 2, on the back side of the moon, the CSM disables attitude control allowing the LM to perform RCS hot firing checkout. Upon completing the hot firing checkout the LM returns the vehicle orientation to coincide with the local attitude maintained prior to the RCS checkout period and the CSM re-establishes attitude control.

Lunar Orbit 3

The vehicle continues in a local attitude hold with the plus X axis in the orbit plane about 28 degrees below the negative velocity vector and the plus Z axis 63 degrees north of the orbit plane away from the moon. This attitude satisfies the first event in lunar orbit 3, an IMU alignment. Upon completing the IMU alignment, a negative roll of 108 degrees is performed which points the optical field of view toward the lunar surface. Three landmark sightings and an observation on the LM landing site are performed. The attitude envelope (flexibility) available during the lunar landmark sighting is very limited because of the concurrent requirement for high-gain communication. Consequently, the attitude is not compatible with the LM steerable S-Band antenna attitude constraints.

Between the 5th and 6th navigation sighting the LM performs a coarse IMU alignment which requires that the vehicle hold an inertial attitude for 3 minutes. Upon completing the seventh landmark sighting, attitude control is turned over to the LM for the purpose of performing a LM fine IMU alignment. The LM first executes a negative pitch of 2 degrees and a positive yaw of 19 degrees (CSM positive pitch of 2 degrees and a negative roll of 19 degrees) which points the AOT (Alignment Optical Telescope) away from the moon toward the first star and which satisfies both CSM and LM high gain antenna communications. The LM then performs a positive pitch maneuver of 87 degrees and a positive yaw maneuver of 26 degrees (CSM positive pitch of 87 degrees and a negative roll of 26 degrees) to sight the AOT on second star. After completion of the LM fine IMU alignment the CSM again assumes attitude control in the local mode and executes a roll maneuver which satisfies the LM separation attitude. The local hold is terminated when the vehicle reaches the inertial attitude required to LM separation. Inertial attitude hold is then initiated and maintained up through LM separation.

During the phase from lunar orbit insertion to LM separation, various attitude constraints are imposed on the spacecraft to satisfy the following requirements:

1. IMU Alignments
2. Navigation Sightings
3. Thermal Attitude Control
4. LM Attitude Requirements
5. Maintain High-Gain Communications and Reacquisition

(1) IMU Alignments

During the lunar orbit phase, eleven IMU alignments are performed. An IMU alignment occurs prior to a navigation sighting sequence in the 1st, 3rd, 5th, 9th, 12th, 15th, 19th, 21st, and 24th orbits. During LM ascent an alignment is performed in the 22nd orbit and, just prior to transearth injection, an IMU alignment is performed in the 24th orbit. The technique of performing IMU alignments in lunar orbit is similar to that of earth orbit IMU alignments. As in earth orbit, the spacecraft must be oriented so that the optical shaft drive axis is at least 50 degrees above the local horizon (see Figure D.2.8-1). However, other vehicle attitude restrictions differing from those in earth orbit are imposed in lunar orbit.

(a) During an IMU alignment, whenever the vehicle is in line-of-sight of the earth, uninterrupted earth communication must be maintained using the high-gain antenna.

(b) For lunar orbit IMU alignments, attitude is stabilized within a 0.5 degree deadband (either local or inertially fixed) by the CSM RCS. As all vehicle maneuvers in lunar orbit are planned such that the spacecraft X axis remains within 70 degrees of the orbit plane, the inner gimbal axis of the CSM IMU platform should be aligned normal to the orbit plane. This platform alignment condition allows the CSM to avoid gimbal lock in any attitude provided that the X axis is kept within 70-degrees of the orbit plane. The sequence of maneuvers is immaterial so long as this 70-degree constraint is observed.

NOTES:

- X Axis in the Orbit Plane
- Optical Shaft Drive Axis ≥50 Degrees above the Horizon
- Local or Inertial Attitude Hold in 0.5 Degree Deadband

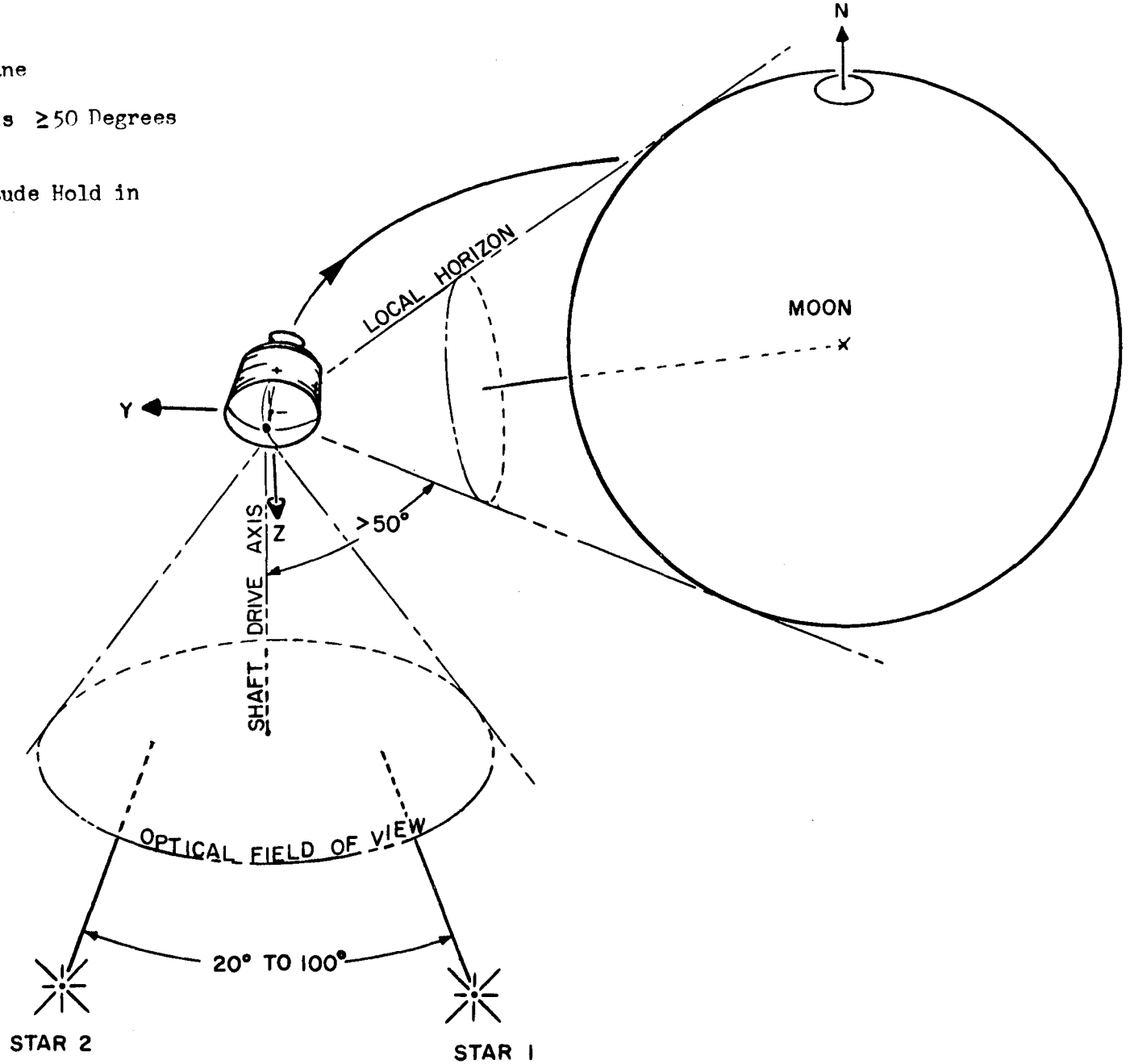


Figure D.2.8-1 CSM IMU Alignment, Lunar Orbit

(2) Navigation Sightings

During lunar orbit, optical navigation is the primary mode of navigation. Landmark sighting periods are 5 minutes each and occur in lunar orbit as follows:

5 in the 1st orbit
4 in the 3rd orbit
1 in the 5th orbit
2 in the 9th orbit
1 in the 12th orbit
2 in the 15th orbit
2 in the 19th orbit
1 in the 21st orbit
4 in the 24th orbit

TOTAL 22 landmark sightings

Pre-selected lunar landmarks are sighted on the lunar surface, using the CSM scanning telescope. (See Figure D. 2. 8-2). Lunar surface landmarks to be utilized will lie within a longitude band 60 degrees from the earth-moon line of centers on the earthward side of the moon and within 65 nautical miles of the orbit plane.

The landmarks must appear in sunlight. The technique for taking navigation sightings during lunar orbit is similar to earth orbit sighting operations; however, different attitude restrictions are noted:

(a) For navigation sightings, spacecraft attitude must be chosen such that the landmark is contained in the SCT field of view for the 5-minute period. To allow adequate time for landmark acquisition, it is desirable to acquire the landmark in the optics field when the landmark is 60 degrees above the local vertical in the direction of flight. Marks are performed when the landmark is within 30 degrees of the local vertical. The landmark is to remain in the optical field until it is 45 degrees from the local vertical behind the flight path.

NOTES:

- PRIMARY MODE OF OPERATION FOR DETERMINING ORBITAL PARAMETERS
- SIGHTINGS ARE RESTRICTED TO KNOWN LANDMARKS WITHIN TYPICAL BOUNDARIES SHOWN
- KNOWN LANDMARKS ARE RESTRICTED TO WITHIN 60 DEGREES OF EARTH-MOON LINE OF CENTERS AND 65 NM OF THE EQUATOR
- HIGH-GAIN COMMUNICATIONS MUST BE MAINTAINED WITH EARTH
- OPTICS ARE DRIVEN ABOUT THE SHAFT DRIVE AXIS (SDA)
- ATTITUDE MAINTAINED LOCALLY FIXED

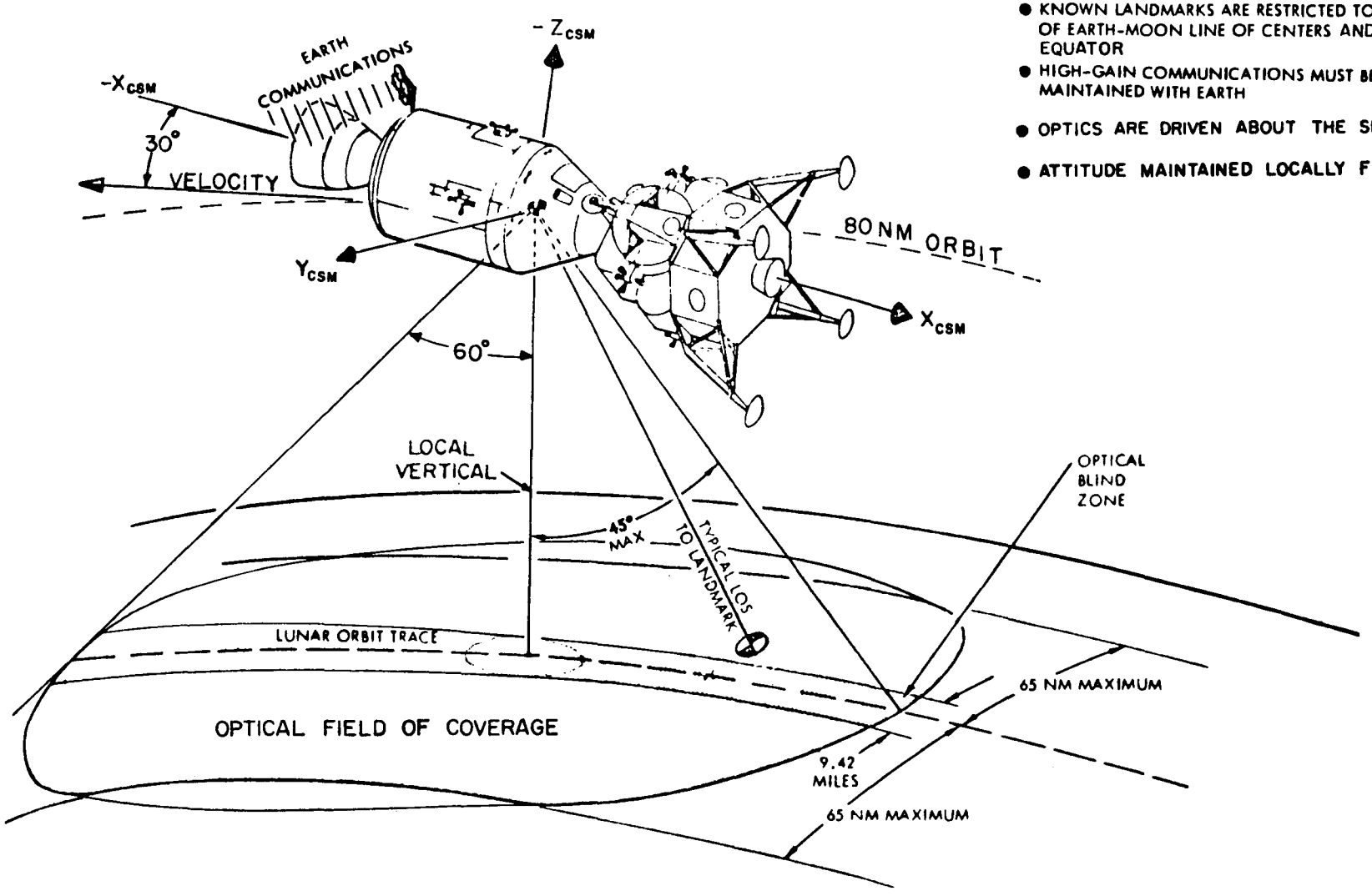


Figure D.2.8-2 Navigational Sighting, Lunar Orbit

Due to excessive tracking rates encountered when the landmark line-of-sight passes through the shaft drive axis, the angle between the shaft line and the vehicle landmark line of sight should not be less than 10 degrees during the sighting.

(b) High gain antenna communication is maintained with earth during navigation sightings periods.

(c) Attitude during navigation sightings which occur within 25 degrees of the subsolar point on the moon must accommodate a thermal constraint requiring the chordal planes of the radiators to remain within 25 degrees of the local vertical.

The attitude selected to satisfy the lunar landmark navigation sights is with the CSM plus X axis in the orbit plane 30 degrees below the negative velocity vector and the Z axis between 9 and 15 degrees north of the orbit plane toward the moon (See Figure D. 2. 8-2). There are three basic reasons for "Flying Backwards" during a navigation sighting period.

1. Since lunar orbit insertion is performed with the spacecraft oriented backwards, no major attitude maneuver is required prior to the first navigation sighting sequence.

2. For the DRM IIA mission, the earth-moon line is about 9 degrees north of the lunar orbit plane. In order to keep the earth from the high-gain antenna null zone, the plus Z, minus Y quadrant (high-gain antenna location) should be north of the orbit plane, requiring that the minus X be in the direction of flight. On the other hand, should the earth-moon line be south of the orbit plane then the plus X axis along the direction of flight would be more desirable for high-gain antenna communications.

3. Of the four lunar landmarks, three are located in the eastern hemisphere. As a result, a "backward flying" vehicle exposes a larger portion of the high-gain antenna coverage region toward the earth.

The vehicle attitude remains locally fixed in the narrow deadband throughout the navigation sighting period. The attitude previously described provides 106 degrees longitude (5 minutes) of optical coverage when the LM is attached and 128 degrees when the LM is not attached.

With the vehicle flying backwards, the astronaut will acquire the landmark at the bottom of the optical field and track from the bottom to the top of the optics. This is unlike earth orbit navigation sightings where the landmark is tracked from the top to the bottom of the optical field.

The Z axis pointing of 9 to 15 degrees north of the orbit plane enhances the high-gain antenna coverage and prevents the landmark from passing through or near the shaft drive axis, requiring excessive tracking rates. Unfortunately the ECS radiator attitude constraint cannot be satisfied when the landmarks are within 25 degrees of the subsolar region without seriously compromising the navigation sighting attitude or eliminating high-gain antenna communications. The ECS radiator attitude, explained in more detail in the next paragraph, may be violated up to 8 times, but in the DRM IIA, since there are nine navigation sighting sequences the violation occurred a total of nine times. Rather than degrade the navigation sighting orientation or sacrifice high-gain antenna communications the ECS radiator attitude constraint is violated one additional time above the allotted 8 times.

(3) ECS Radiators

To avoid excessive water boil-off, CSM attitude is constrained such that the ECS radiators must avoid facing, simultaneously, direct sunlight and highly intense reflected heat from the subsolar region on the lunar surface. One of the two curved ECS radiators lying along the circumference of the SM is located in the CSM positive Y, positive Z quadrant and the other is located in the negative Y, negative Z quadrant. For convenience of expression, the effective surface area of the radiators may be represented by "chordal planes" defined as two planes parallel to the X axis of the CSM, each containing the circumferential extremities of the respective ECS radiators. (See Figure D.2.8-3.) The attitude constraint associated with the ECS radiators may then be described as follows:

The normals to the chordal planes of the radiators must be at least 65 degrees from the local vertical when the vehicle is within 25 degrees of the subsolar point. (The intersection of the moon-sun direction with the lunar surface is referred to as the subsolar point.) However, it is noted that deviation from this constraint is allowed a maximum of 3 consecutive orbits for a total of 8 times per mission in the lunar orbit phase. Since the CSM passes over the subsolar region while in view of the earth, communication with the earth must be maintained while satisfying the ECS radiator constraint.

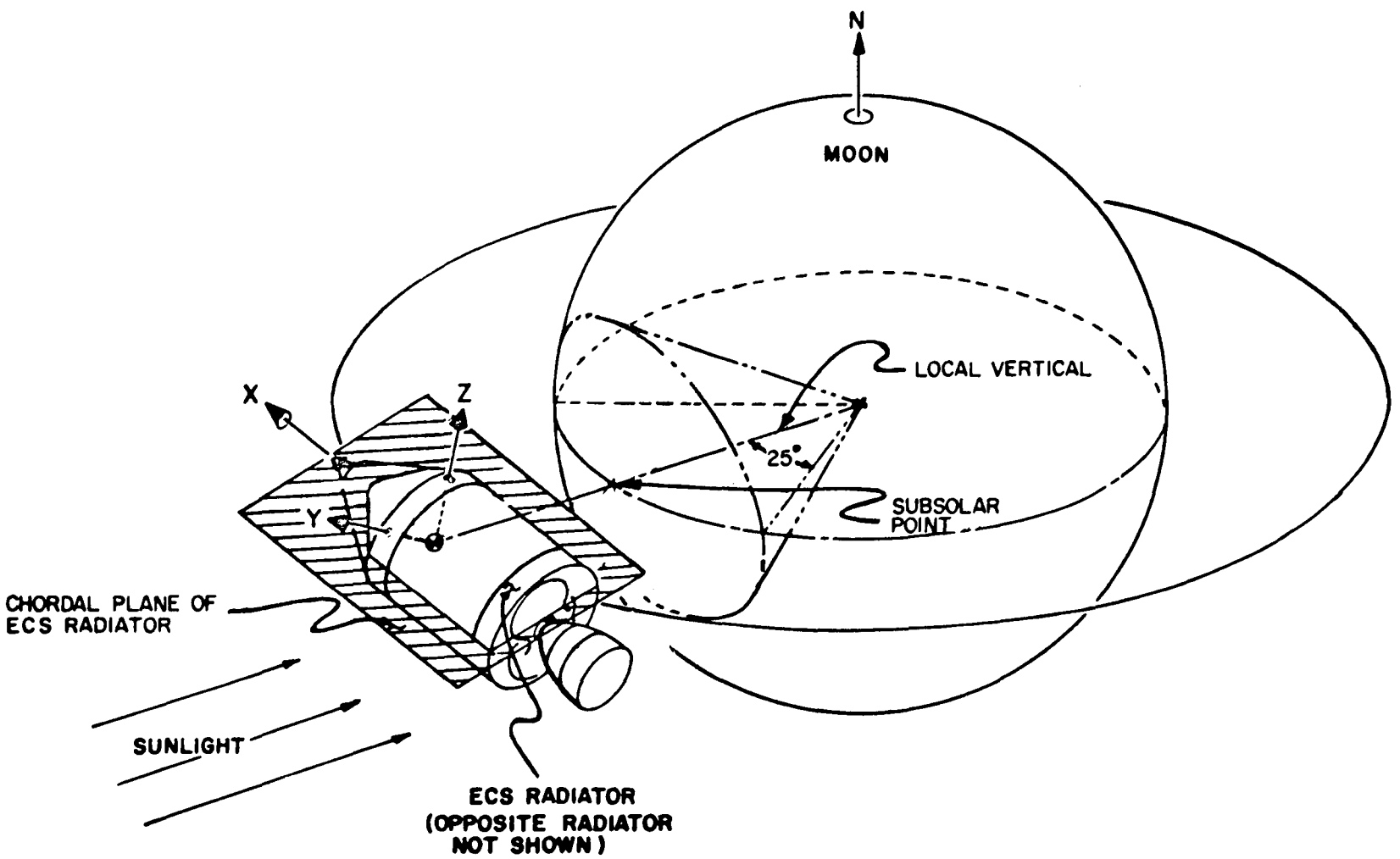


Figure D.2.8-3 Thermal Constraints Upon Attitude, Lunar Orbit

The Electrical Power System (EPS) radiators which are distributed around the periphery of the Service Module provide effective heat dissipation in any attitude.

D.2.9 PHASE 9.0 CSM SOLO LUNAR ORBIT OPERATIONS

The DRM IIA landing site is on the lunar equator, 0.2 degrees east selenographic longitude from the earth-moon line. The LM will land at lunar morning, i.e., the sun will be at an elevation angle of 19 degrees from the east. LM staytime on the moon will be for 17 CSM orbits or 35 hours.

To accomplish LM separation, the RCS of the LM produces a LM translation of 0.5 fps. The LM separation attitude is with the CSM plus X axis down the local vertical toward the moon and the CSM plus Z axis 15 degrees north of the orbit plane toward the negative velocity as shown in Figure D.2.9-1. Following LM separation the CSM continues in an inertial attitude hold and performs a positive pitch so that the LM is contained in the optical field of view. About 8-minutes after LM separation the CSM begins a local attitude hold, performs a positive 164.5-degree roll and a negative yaw of 15 degrees, completing the maneuver about 2 minutes prior to the beginning of LM Transfer Orbit Insertion (TOI) thrusting. The positive roll maneuver keeps the X axis no more than 70 degrees from the orbit plane, precluding gimbal lock, and ensures high-gain antenna communications upon acquisition of earth line-of-sight. At the time of thrusting termination for TOI the LM is contained in both the CSM optical field of view and the transponder coverage pattern. The CSM attitude remains locally fixed maintaining the LM in the optical field and transponder coverage pattern. About 30 minutes from TOI an inertial hold is established for 10 minutes after which the CSM returns to a local attitude hold. This sequence improves optical coverage of the LM and brings the X axis 30 degrees below the orbit plane for the navigation sighting to be performed in the next lunar orbit. Reference Figure D.2.9-2 for an illustration of the LM descent attitude sequence.

Primary requirements which influence the previously described CSM attitude constraints include communication and monitoring which are described as follows:

NOTES:

- CSM POSITIVE X-AXIS IS POINTED DOWN THE LOCAL VERTICAL WITH ITS Z-AXIS 15° NORTH OF THE NEGATIVE VELOCITY DIRECTION TOWARD EARTH.
- INERTIAL ATTITUDE HOLD IN THE 0.5° DEADBAND

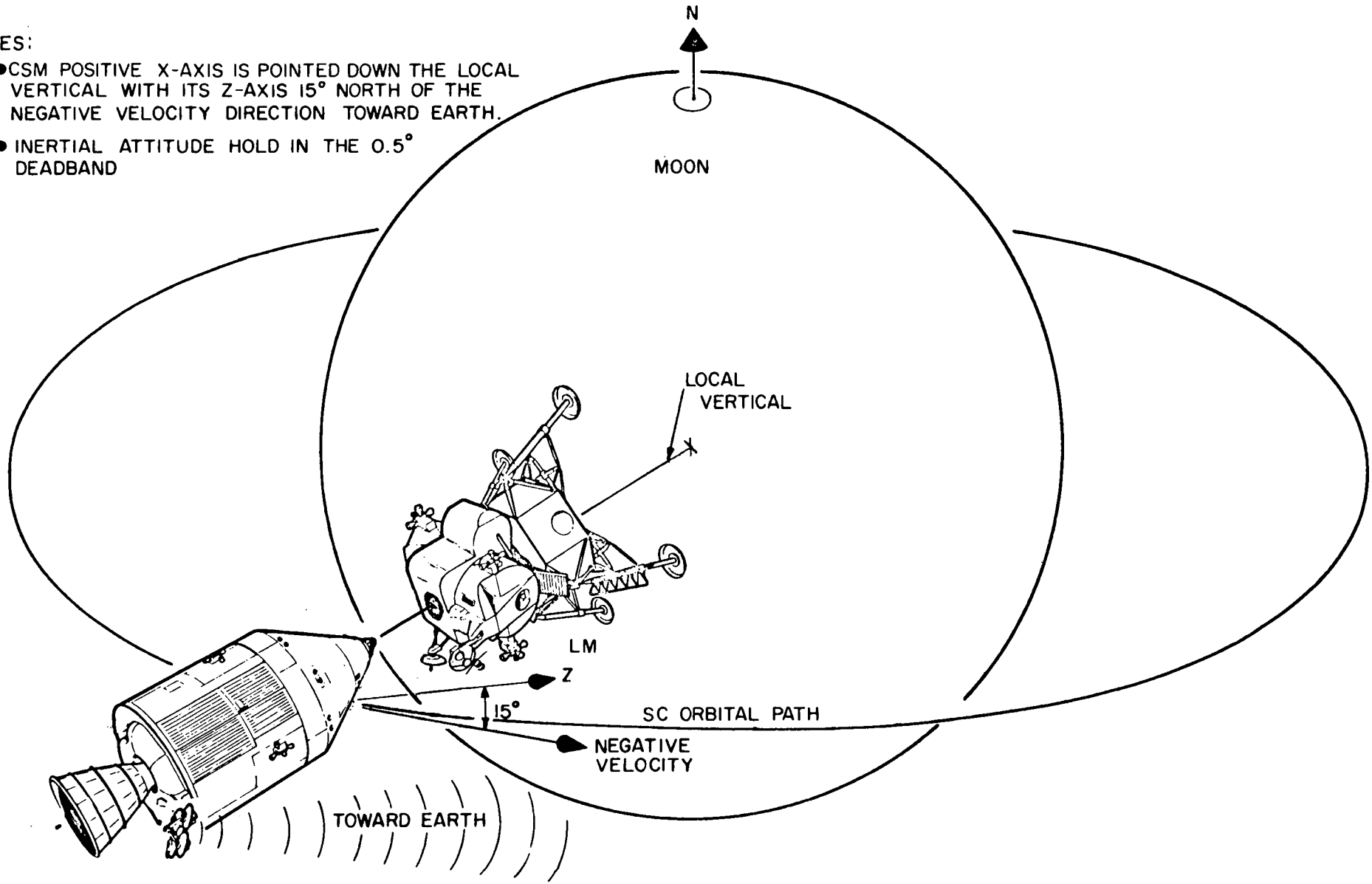
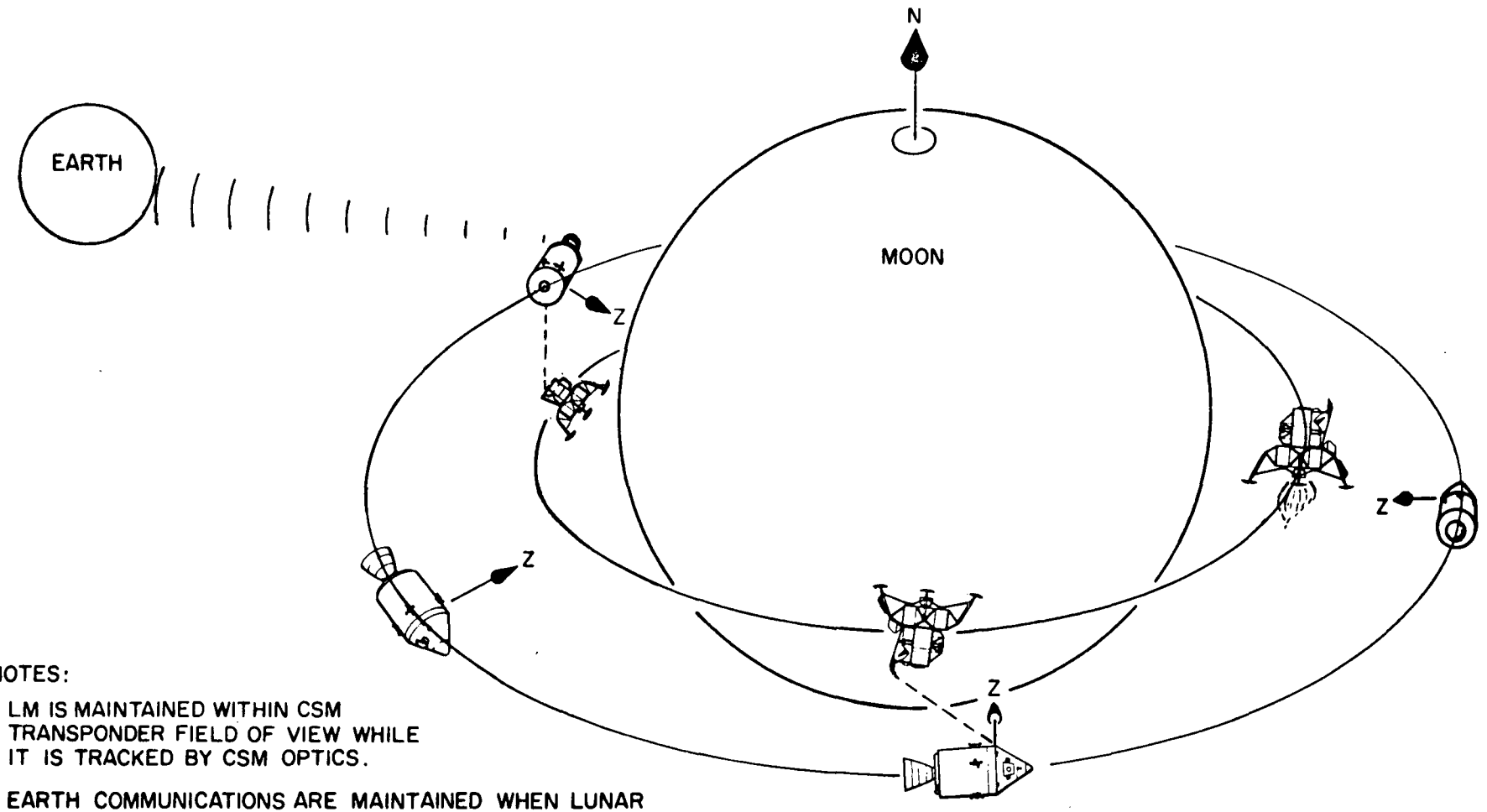


Figure D.2.9-1 LM Separation



NOTES:

- LM IS MAINTAINED WITHIN CSM TRANSPONDER FIELD OF VIEW WHILE IT IS TRACKED BY CSM OPTICS.
- EARTH COMMUNICATIONS ARE MAINTAINED WHEN LUNAR OCCLUSION DOES NOT INTERFERE.

Figure D.2.9-2 LM Monitoring (Descent)

(1) Communications

During LM descent while on the earth side of the moon, CSM attitude is restricted to an envelope which permits the high-gain antenna to point toward a MSFN station. Since much of the CSM plus Y, minus Z quadrant is excluded from the high-gain antenna coverage pattern, this quadrant must face away from the MSFN stations.

(2) Monitoring

Following LM separation and prior to CSM orientation for LM tracking, optical coverage of the LM is required to observe luminescent markings on the LM shutdown probes which indicate whether the probes are extended and locked in place. During this time the LM performs a yaw maneuver of 405 degrees in order to expose all four LM legs to CSM view.

During LM descent, the CSM must have immediate rescue capability in the event of a LM failure which requires CSM rescue of the LM. Consequently, it is required that the CSM optically track the LM during LM Hohmann descent from TOI shutdown through the first 30 minutes of coast. The CSM is in line-of-sight of the LM from initiation of the descent until after touchdown of the LM. A CSM orientation is maintained such that the CSM transponder may be tracked by the LM radar. Since the transponder is located in the plus Y, plus Z quadrant, this quadrant will be kept toward the LM during tracking.

While the LM is on the lunar surface, the CSM with one crew member remains in the 80 nautical mile orbit performing various functions. LM stay on the moon begins with LM touchdown, lasts for about 35 hours and ends with LM ascent engine ignition. This time span occurs from about the middle of the fourth orbit through the 21st CSM orbit.

During LM stay on the moon the CSM attitude sequence is selected to satisfy the following requirements:

1. IMU Alignments
2. Navigation Sightings
3. ECS Radiators
4. CSM LM Communications
5. Earth High-Gain Antenna Communications
6. RR Tracking

Following LM descent and touchdown the CSM remains inertially fixed through orbit 4, continuing into orbit 5.

Lunar Orbit 5

Lunar orbit 5 begins with a 120-degree positive roll and an IMU alignment, performed in an inertial attitude hold. The IMU alignment attitude satisfies the ECS radiator attitude requirements (plus Z axis is 44 degrees north of the orbit plane, away from the moon) and earth high gain antenna communication. Prior to the 8th navigation sighting the CSM performs a 120° negative roll followed by a switch to a local attitude hold immediately preceding the sighting period. By switching to a local attitude hold at this time, the CSM X axis pointing satisfies the landmark sighting attitude requirement.

The navigation sighting is performed and then the CSM rolls 120 degrees positively and establishes an inertial attitude hold in the wide deadband prior to the forthcoming solo astronaut sleep cycle.

Lunar Orbits 6, 7, and 8

During the solo astronaut sleep periods the CSM holds an inertially fixed attitude with the X axis in the orbit plane approximately normal to the earth-moon line. The positive Y axis is 45 degrees from the northward normal to the orbit plane, and the positive Z axis is 45 degrees north of the orbit plane toward the earth. An inertial attitude hold during the lunar orbit sleep period will be required for CSM high-gain antenna reacquisition. The deadband selected must hold the spacecraft attitude within limits which will permit reacquisition and tracking of the MSFN. A wide (approximately 5-degree) deadband will be required throughout the astronaut sleep period. The inertial attitude previously specified enables the CSM to transmit and receive earth communication via the high-gain antenna when in view of the earth and provides favorable S-Band omni coverage for backup of the high-gain antenna. The orientation of plus X generally from the CSM to LM line-of-sight at landing site acquisition places the VHF nulls away from the LM at LM acquisition. The LM-CSM VHF communications link may be used as a relay through the CSM S-Band system, should the LM S-Band system fail. The Y-Z orientation is chosen to satisfy ECS radiator attitude constraints by having the normals to the ECS radiators more than 65 degrees from the local vertical when the CSM is in the subsolar region. Figure D.2.9-3 illustrates the attitude for this phase of the mission.

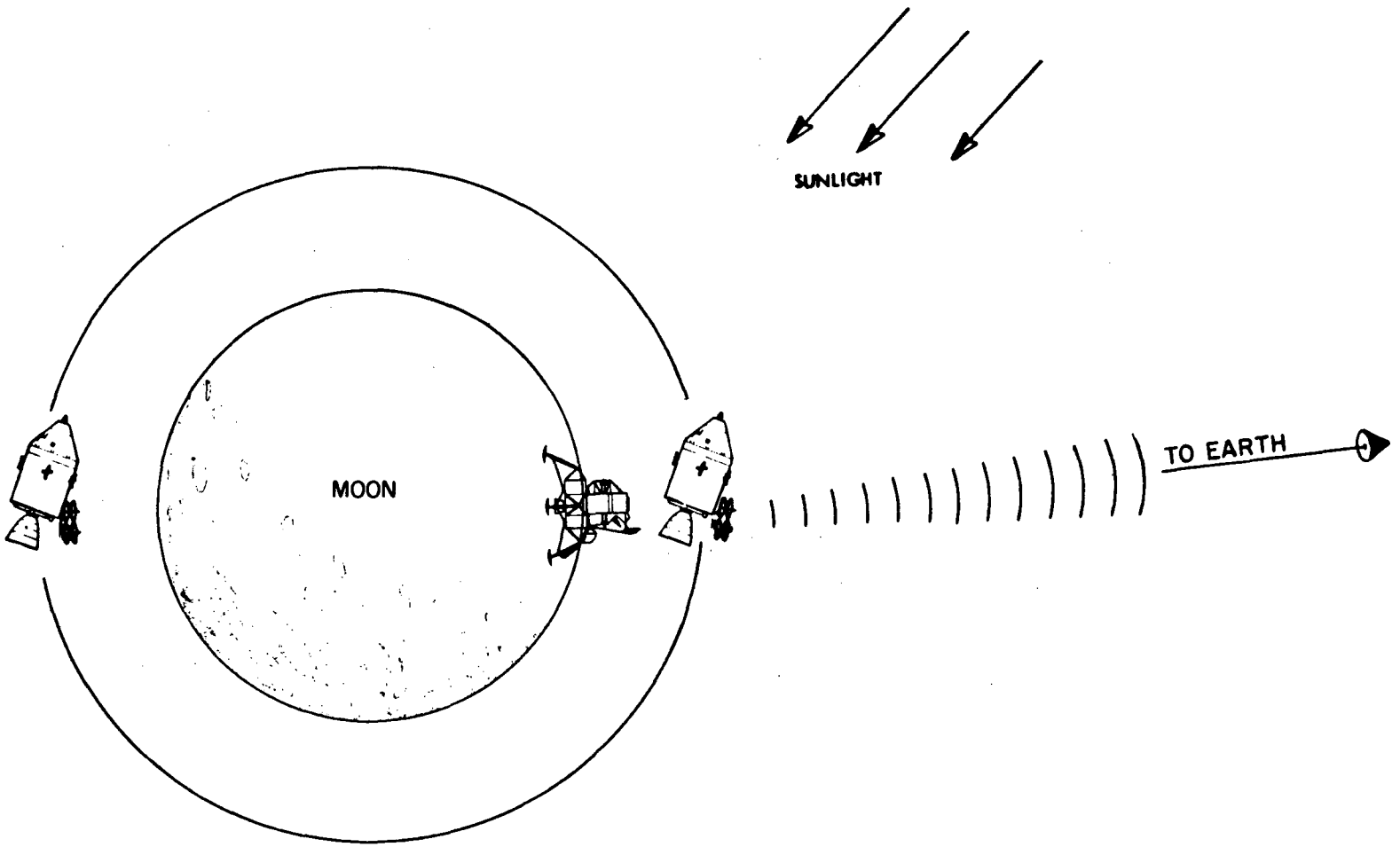


Figure D.2.9-3 Lunar Orbit Solo Sleep

Lunar Orbit 9 through 15

During lunar orbits 9 through 15 the astronaut performs 3 series of navigation sightings, each preceded by an IMU alignment. To avoid pitch maneuvers between sightings the sequence of landmarks used for these orbits have been chosen in order of increasing westerly selenographic longitude. For example, upon completion of navigation sightings 9 and 10 in lunar orbit 9 an inertially fixed CSM attitude satisfies the attitude required for navigation sighting 11 in orbit 12.

Just prior to lunar orbit 9 the CSM performs a negative roll of 135 degrees which points the optics away from the lunar surface (Z axis in the orbit plane) for an IMU alignment. Following the IMU alignment (performed in an inertial hold) a negative pitch maneuver of 144 degrees brings the X axis 25 degrees below the negative velocity vector. This attitude satisfies the required orientation for navigation sighting 9 during which the CSM establishes a local attitude hold. Immediately following the 10th navigation sighting an inertial attitude hold is established and maintained in the wide deadband. A positive roll maneuver of 135 degrees is then performed to satisfy the ECS radiator attitude constraint, high-gain antenna communications and the IMU alignment to be performed in orbit 12. The CSM continues in the wide inertial deadband for the remainder of orbit 9 through the beginning of orbit 12.

During lunar orbit 12 the CSM performs an IMU alignment, rolls 120 degrees and maintains an inertial attitude hold for the navigation sighting. An inertial attitude hold is used in lieu of a local hold for purposes of avoiding a pitch maneuver for the 12th and 13th navigation sightings while preserving the required X axis pointing for the navigation sightings. The penalty involved in the use of an inertial attitude hold is a resultant decrease in available optical average of navigation sighting 11. The decrease is from 5 minutes to 4 minutes 22 seconds. Upon completion of the 11th navigation sighting the vehicle is placed in the wide deadband and a positive roll of 120 degrees is executed. This maneuver places the CSM in an attitude which satisfies ECS radiator attitude constraints, high-gain antenna communications, and the IMU alignment in orbit 15. The inertial attitude hold in the wide deadband is maintained for the remainder of orbit 12 to the 12th navigation sighting in lunar orbit 15.

As in orbit 12, an IMU alignment is performed in the 15th orbit followed by a negative roll of 120 degrees. A local attitude hold is then established and maintained during the navigation sighting sequence. Subsequent to the 12th and 13th navigation sighting the CSM establishes an inertial attitude hold and performs a positive 120-degree roll.

Lunar Orbits 16, 17, and 18

The previous attitude maneuver establishes the solo astronaut sleep cycle attitude which is similar to the attitude employed for the first solo astronaut sleep cycle during orbits 6, 7, and 8. The CSM maintains an inertially fixed attitude hold in the wide deadband.

Lunar Orbits 19 and 20

The attitude sequence employed in lunar orbit 19 is similar to the sequence used in orbit 9. Just prior to the beginning of orbit 19, the CSM performs a 135-degree negative roll which points the optical field of view away from the moon for an IMU alignment and the Z axis in the orbit plane. Upon completion of the fine IMU alignment, a negative pitch maneuver of 156 degrees places the CSM in a favorable attitude for a navigation sighting which satisfies CSM high-gain communications. This attitude is with the X axis 27 degrees below the negative velocity. The CSM maintains a local attitude hold during lunar landmark sightings 14 and 15 after which an inertial attitude hold is established 20 minutes after completion of the navigation sightings and maintained for the remainder of orbit 19 through orbit 20. The 20 minute delay in establishing an inertial attitude hold following the navigation sightings satisfies the required CSM rendezvous radar transponder (XPDR) pointing in lunar orbit 20. Transponder coverage of the LM is required for about 6 minutes during the landing site overpass on the orbit preceding (orbit 20) LM liftoff. In lunar orbit 20, a negative roll of 96 degrees is performed shortly after the vehicle passes the subsolar region to point the XPDR at the landing site. To ensure that the ECS radiator attitude is not violated and to allow time for the XPDR field to contain the LM, the roll begins 8 minutes after passing the subsolar region.

Lunar Orbits 21 through 24

Lunar orbit 21 begins much as lunar orbits 9 and 19 except a negative roll of only 24 degrees for the CSM IMU alignment is required. The IMU alignment is performed followed by a 108° negative pitch and the 16th lunar landmark sighting. Following the navigation sighting the

CSM establishes an inertial attitude hold and orients to an attitude which satisfies the LM ascent attitude requirements. The orientation consists of a 180-degree positive roll with a change to local attitude hold 20 minutes after establishing the inertial hold. This sequence points the CSM plus X near the local vertical toward the moon and places the minus Z axis toward the velocity vector.

During LM ascent the CSM will monitor the LM while maintaining earth high-gain antenna communications. LM liftoff from the lunar surface occurs midway through the 21st CSM orbit. Ascent engine shutdown occurs 6 minutes and 50 seconds after liftoff at a pericynthion altitude of approximately 50,000 feet above the landing site. The CSM attitude sequence during LM ascent is described below for the following stages of LM activity.

The CSM attitude at the time of LM ascent stage shutdown and until the CSM fine IMU alignment is a local vertical mode of operation with the plus X axis near the local vertical toward the moon and minus Z axis along the velocity vector. At 41 minutes after LM ascent engine cutoff the CSM establishes an inertial attitude hold and performs a negative 60-degree pitch in preparation for the IMU alignment. The fine alignment is performed in the inertial hold and a switch to local attitude hold is initiated exactly 20 minutes after initiating the pitch maneuver for the IMU alignment. At this time the plus X axis is down the local vertical toward the moon, the plus Z toward negative velocity in the orbit plane. A small positive roll of 24 degrees is performed following completion of the IMU alignment and prior to establishing local attitude hold in order to ensure high-gain antenna pointing at earthrise.

This attitude is held in a local vertical mode until the LM begins to pass below the CSM at which time the CSM establishes an inertial hold. The inertial attitude hold is maintained for 30 minutes after which a local hold is established. This sequence places the plus X axis along the velocity vector and the plus Z axis 24 degrees south of the orbit plane toward the moon. After establishing the local hold, the CSM is rolled 54 degrees for the final docking maneuvers with the LM. At final docking the LM is in front of and slightly below the CSM. When the LM is within 500 feet of the CSM, the CSM begins an inertial attitude hold for docking.

Since targeting of the LM to the rendezvous position is quite sensitive to LM guidance and navigation errors and CSM navigation errors, the final position of the LM may not be front of the CSM. As a result the CSM attitude at terminal rendezvous may depart from that previously described. The following CSM attitude constraints are observed during the LM ascent phase.

1. High-gain antenna communications maintained with earth.
2. LM monitoring via the CSM transponder, required from 4 minutes after LM ascent engine cutoff until the LM is within 50 feet of the CSM.
3. CSM optical coverage of the LM from LM ascent engine cutoff until rendezvous (500 ft.). This is interrupted periodically for establishing attitude holds and attitude maneuvers.
4. CSM fine IMU alignment.

D.2.10 PHASE 10.0 LM DESCENT

The LM descent covers the period from LM-CSM separation to LM touchdown. The LM attitude constraints, implied by the attitude and subsystem ground rules, are functions of:

- Trajectory profile
- Configuration, subsystem and operational constraints

The nominal DRM IIA trajectory defines the instantaneous state vector at LM/CSM separation, the landing site location and relative motion between the separated LM and CSM. Configuration subsystem and attitude constraints (see ground reles of Sections A.3.2 and A.4.2 of Appendix A) are specified by physical gimbal limits, power requirements and operational capabilities.

The rationale employed to define a particular attitude management schedule is as follows. First, a set of attitude requirements for LM thrusting modes is defined. Second, these attitudes are compared to desired attitudes required to comply with the configuration subsystem and operational constraints. Third, an attitude management schedule, tempered by minimum RCS propellant utilization, is selected from the consideration of these comparisons.

A brief discussion of the configuration, subsystem, and operational constraints follows.

S-Band Steerable

The moon-earth-sun configuration is essentially fixed during the 90-minute interval measured from LM-CSM separation to LM touchdown. For example, in inertial platform coordinates, the earth and sun directions vary by less than 0.5 degree. Thus, the relationship between vehicle attitude and the earth or sun direction cosines for any point in the descent phase correspond to all points in the descent phase.

Figure D.2.10-1 depicts the S-Band steerable shaft and trunnion angles as a function of LM attitude. These data were computed 3 seconds subsequent to LM-CSM separation; however, they apply to the entire LM descent mission whenever a clear line-of-sight exists between LM and earth. Three families of data, corresponding to roll angles of -20 degrees, 0 degrees and +20 degrees, are presented. For each family, the solid lines represent a constant LM yaw angle orientation and the dashed lines denote varying pitch angle orientations.

The allowable S-Band steerable shaft and trunnion angle boundary is superimposed on each family. Vehicle orientations that lie within the boundary satisfy the gimbal angle constraints. In addition to the S-Band boundary, the front window and upper window visibility regions are overlaid on each family. Thus, the earth center is visible in the windows for vehicle orientations that fall within the window boundaries.

Sun Incidence Angles

Presented in Figure D.2.10-2 are the body-related shaft and trunnion angles that define the sun's direction as a function of LM stable member orientation (see Figures C-10 and C-11 of Appendix C for azimuth elevation vs. shaft-trunnion coordinate system differences), although these data are based on a LM-moon-sun configuration specified at 39 minutes after LM-CSM separation, they also apply throughout the entire sunlit portion of the LM descent mission. Figure D.2.10-2 can be used to define the included angle between the sun's direction and the:

(1) S-Band steerable boresight axis
(2) Rendezvous radar boresight axis
(3) Body axis of the LM vehicle

Also shown in the figure are the boundaries for the AOT field of view with a 15-degree margin. IMU alignments by means of AOT sightings on stars are assumed possible if at least one field-of-view is available.

Rendezvous Radar

Rendezvous radar shaft and trunnion gimbal angle limits depend on the instantaneous position of the LM and CSM vehicles. Mode I and II rendezvous radar gimbal boundaries, as a function of LM pitch attitude, were computed and are presented in the descent summary chart of Figure D.2.10-3. Rendezvous radar tracking of the CSM is possible whenever the LM attitude lies within the boundary lines shown.

Inertial Measurement Unit Alignments

It must be noted that the studies performed to determine the LM attitude for star sightings was restricted to a two-degree-of freedom rotation (pitch and yaw). As a result of this study particular stars were chosen for the LM IMU alignment and are presented in this section. It is suggested that future studies of the IMU alignment attitude should not be restricted to two degrees of freedom (pitch and yaw) but should also utilize the rotation about the Z-body axis (i.e., roll). IMU alignments can be conducted by viewing stars through at least one AOT field of view with a sun vector at least 15 degrees from the perimeter of the sighting field. Figure D.2.10-3 shows the regions for which AOT sightings are not possible. It should be noted that this holds true for zero roll and yaw only. Future mission studies should define these regions for all angles: i.e., pitch, roll and yaw.

LM Attitude Profile

Table D-1 contains the tabular summary of the LM descent phase attitude time history, including vehicle position; inertial and local attitude angles; and line-of-sight angles to earth, sun, CSM and landing site (when applicable). Figure D.2.10-3 presents a summary plot of LM orientation during the descent phase. Also included on the figure are:

- The attitude-time locus required for the LM body axis to point at the CSM (i.e., line-of-sight to CSM) and the orientation boundary to satisfy LM tracking light requirements.
- The approximate boundary required to switch from rendezvous radar tracking Mode I to tracking Mode II and vice versa.
- Attitudes for which earth communications are not possible (S-Band antenna allowable gimbal angles exceeded or earth occulted by moon).
- Attitudes for which AOT fields of view are within 15 degrees of line-of-sight to sun and times when the sun is occulted by the moon.
- Timelines of operations and equipment associated with orientation requirements (S-Band to MSFN, VHF data and voice to CSM, rendezvous and landing radar, tracking light, and IMU alignment).

The following sections summarize the LM attitude time history for each phase of LM descent.

D.2.10.1 PHASE 10.1 LM SEPARATION

At mission time 69:05:32 hours the LM/CSM separation occurs. At separation the LM attitude is such that the LM X-body axis is pointing toward the center of the moon and the plus Z-body axis is 45 degrees above the orbital plane. The LM corresponding inertial angles are -96 degrees pitch, 0 degree roll and -45 degrees yaw. Immediately following LM separation the CSM performs a positive pitch maneuver at a rate of 11 deg/min. so that the LM is contained in the optical field of view, for the visual inspection of LM landing gear probes. Upon attaining a range of 58 feet from the CSM the LM performs a 120-degree pitch maneuver 45 degrees to the orbital plane. It must be noted that during this maneuver the LM X-body axis passes thru a maximum angle of 45 degrees to the orbital plane and at the termination of the pitch maneuver the angle between the X-body axis and the orbital plane is approximately 30 degrees. If the angle between the X-body axis and the orbital plane had exceeded 60 degrees, the LM would have been required to perform an additional maneuver in order to avoid gimbal lock. Stable platform gimbal lock is approached when the inner gimbal axis - which is coincident with the X-body axis - approaches within 30 degrees of the outer gimbal axis - which is aligned to the orbital plane. It is therefore suggested that for future mission planning the LM yaw angle at separation should not exceed 60 degrees to the orbital plane. This requirement was satisfied in the DRM IIA attitude timeline. During the visual inspection, while holding a constant pitch angle, the LM will yaw 405 degrees. This maneuver aids in the inspection of the LM probes and also places the LM in an attitude such that when the subsequent pitch to TOI attitude is complete, the LM Z-body axis will be in the orbital plane.

Five minutes from LM separation the CSM initiates an inertial attitude hold which is held for two minutes. At the end of this period the CSM initiates a local attitude hold, performs a positive 164.5-degree roll and 15-degree negative yaw. The maneuver is completed 2 minutes prior to the LM TOI maneuver. The CSM attitude is such that at the completion of the LM TOI maneuver the LM will be contained in the CSM optics field of view and in the transponder coverage pattern.

At mission time 069:14:04 the Inertial Measurement Unit (IMU) is realigned. The first orientation from an inertial attitude of 24 degrees pitch, 0 degree roll, and 30 degrees yaw brings the star β Ceti to the center field of view of the AOT for marking. The LM is then oriented to an attitude of 5 degrees pitch, 0 degree roll, and 43 degrees yaw to place the star β Orionis (Rigel) in the center field of view of the AOT. A fine alighment check is then executed by orienting again to the star β Ceti. At the completion of this marking, the LM is then oriented to the Transfer Orbit Insertion (TOI) attitude of -75 degrees pitch, 0 degree roll, and 0 degree yaw.

D.2.10.2 PHASE 10.2 TRANSFER ORBIT INSERTION

At mission time of 69:28:31 hours the LM initiates the Transfer Orbit Insertion (TOI). During this phase the LM moves from in front of and below the CSM to the rear of and below the CSM. Due to the thrust vector requirements the LM begins the maneuver at an inertial attitude of -75 degrees pitch, 0 degree roll and 0 degree yaw and terminates the maneuver at an inertial attitude of -76 degrees pitch, 0 degree roll, and 0 degree yaw.

D.2.10.3 PHASE 10.3 COAST TO POWERED DESCENT

At mission time 69:29:03, the LM orients from the terminal inertial attitude of the TOI maneuver to an inertial attitude of -150 degrees pitch, 0 degree roll, and 0 degree yaw. This inertial attitude insures tracking light capability for approximately the first 30 minutes of the descent coast. During this time the CSM is in local attitude hold. Subsequently, the LM performs a positive pitch maneuver (a positive pitch maneuver is performed in order to avoid interruption in S-Band communications due to body interference) to place the star α Canis Majoris (Sirius) to the center field of view of the AOT for the start of an IMU alignment. The inertial attitude required for the sighting is 16 degrees pitch, 0 degree roll, and 0 degree yaw. After marking, the LM then orients to an inertial attitude of 9 degrees pitch, 0 degree roll, and 21 degrees yaw to sight on the star α Aurigae in the right field of view of the AOT. The LM then orients back to the first star (α Canis Majoris) for an alignment check. These stars were chosen since other combinations of stars would have brought the sun into the view of the AOT and, hence, would have obviated the operation. Upon completion of the IMU alignment maneuver, the LM then orients to the attitude required for the beginning of the braking maneuver of Powered Descent.

D.2.10.4 PHASE 10.4 BRAKING

At mission time 70:27:17, the LM is at the required attitude for the commencement of the braking maneuvers: 109 degrees pitch, 0 degree roll, and 0 degree yaw. For the remainder of the descent phase, the XZ plane of the CSM; that is, the inertial angles of roll and yaw, are held at 0 degree. For the 7-minute duration of the braking maneuver, the LM pitches in a continuous manner, terminating the maneuver at hi-gate at an inertial pitch attitude of 71 degrees.

D.2.10.5 PHASE 10.5 FINAL APPROACH

At mission time 70:34:17, the LM final approach maneuver is initiated at hi-gate. The LM then performs a rapid pitchover to 42 degrees in order to assess the landing area and the trajectory as it approaches the lunar surface. The spacecraft gradually pitches up to 52 degrees at lo-gate, while satisfying the thrusting vector requirements during the final approach.

D.2.10.6 PHASE 10.6 LANDING

At mission time 70:36:02 the LM landing maneuver is initiated at the lo-gate. The subsequent maneuvers are performed manually by the Commander. This phase begins with the LM at an inertial pitch angle of 52 degrees. A pitchover to zero degrees pitch angle is performed. This attitude is maintained until such time that a manual pitch up maneuver to 25 degrees and subsequent pitchover to 0 degree is performed to null out the relative forward velocity. During the subsequent vertical descent to the lunar surface the vehicle attitude is zero degrees pitch, roll and yaw.

D.2.11 LUNAR STAY

General Approach to Define Recommended Attitudes

LM attitude freedom is constrained at touchdown. Prior to touchdown, however, the astronaut can select any arbitrary heading angle by yawing about the LM's thrust axis. Heading is defined as the included angle, measured eastward, from lunar north to the LM Z-body axis. Aside from local terrain and surface reflectivity uncertainties, the selection of a desired heading angle at touchdown should be tempered by:

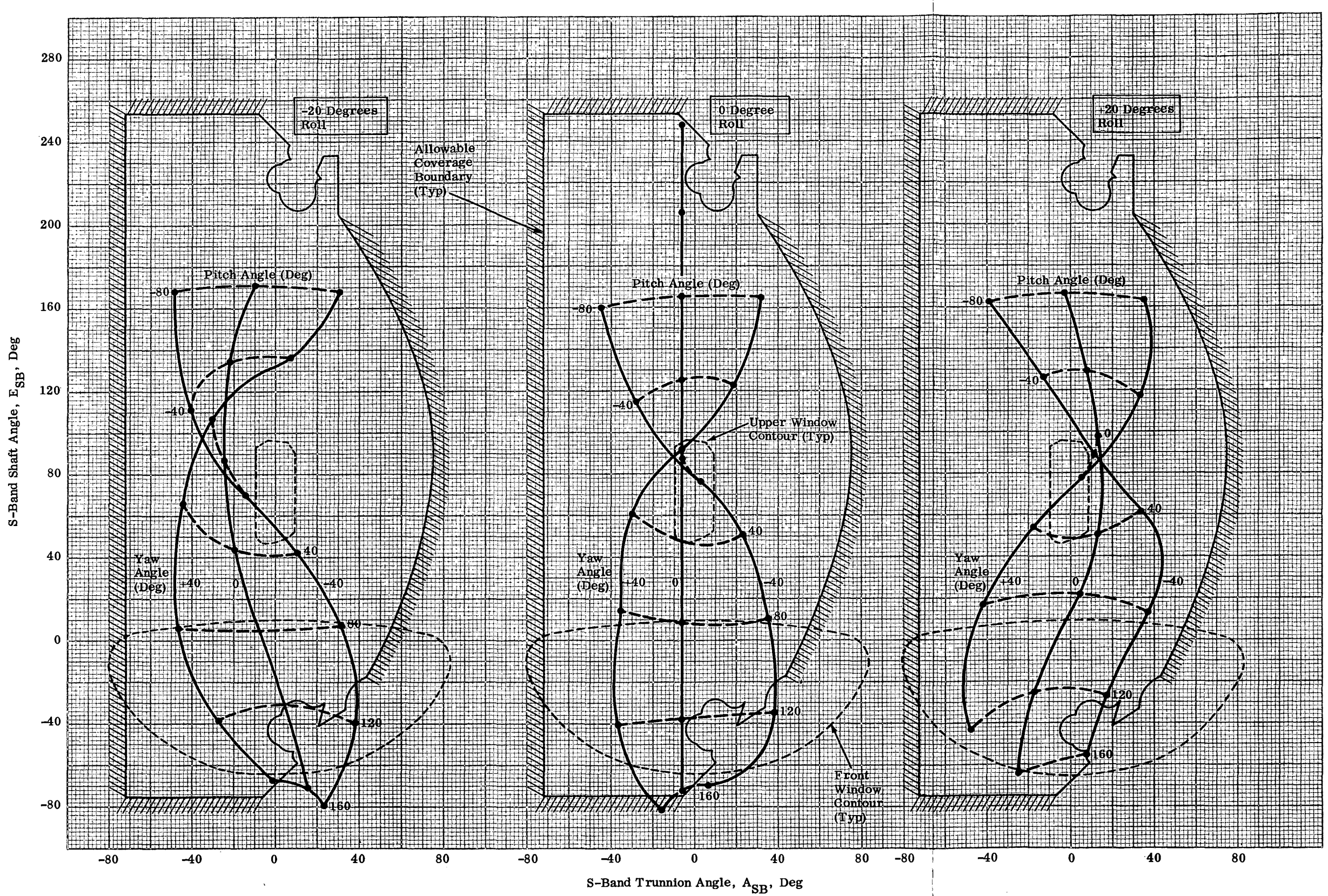


Figure D.2.10-1 S-Band Attitude Constraints DRM IIA: 3 Seconds Subsequent to Separation

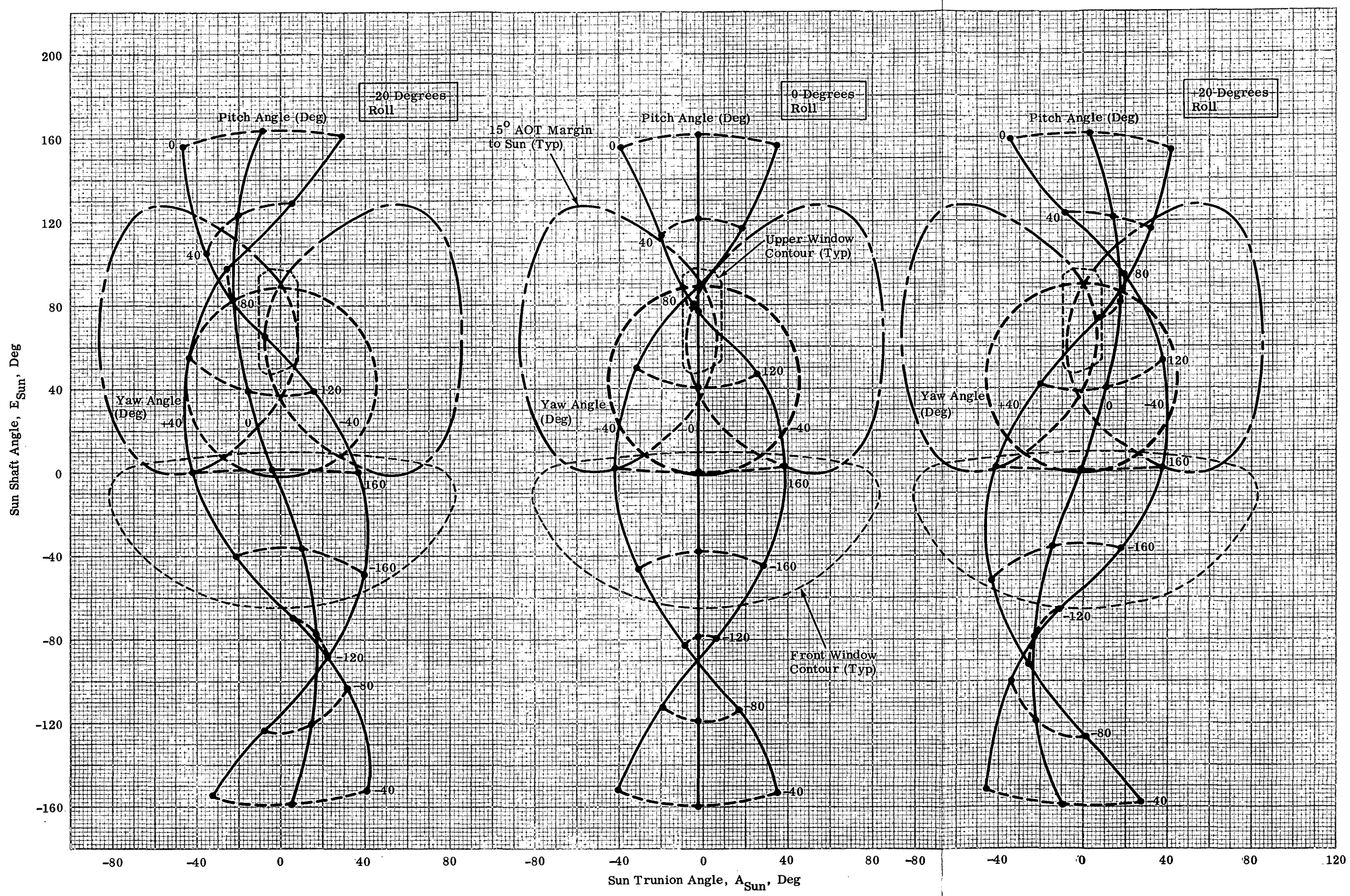


Figure D.2.10-2 Sun Attitude Constraints DRM IIA: 39 Min Subsequent to Separation

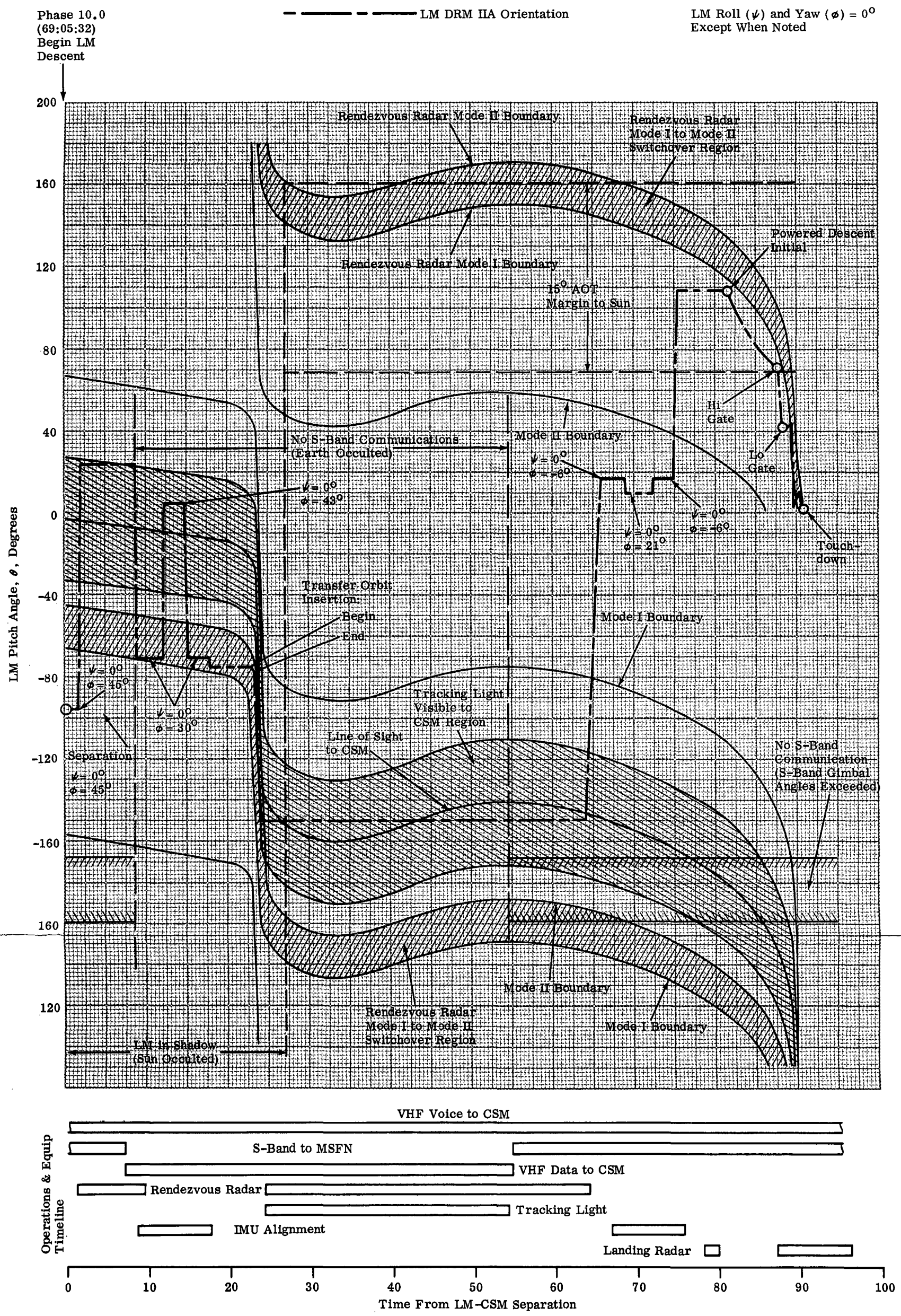


Figure D.2.10-3 LM Descent Phase Orientation Timeline and Constraint Boundaries

- The ability to track the CSM
- The ability to track the earth
- The ability to sight stars, without solar glare, using the Alignment Optical Telescope.

Rendezvous Radar

Horizon-to-horizon tracking of the CSM is not possible if the LM heading angle at touchdown is approximately within ± 15 degrees of either due north or south. This restriction is caused by the rendezvous radar trunnion limit based on an inertial touchdown attitude of zero pitch and roll.

S-Band Steerable

S-Band steerable gimbal angle constraints are not violated regardless of the heading angle at touchdown. For all heading angles between zero and 360 degrees, during the lunar stay, the S-Band shaft and trunnion angles vary between 80 degrees and 100 degrees, and between -10 degrees and 10 degrees, respectively. These variations are well within the gimbal boundaries.

Alignment Optical Telescope

The alignment optical telescope (AOT) has three fixed viewing positions relative to the LM body axes. By means of a pinion knob, the astronaut can detent the telescope in position left, right or center. The AOT field of view, for any fixed position, is 60 degrees (30-degree semi-cone angle). Star sightings are prohibited whenever the included angle between the AOT boresight axis and the star's direction is less than 45 degrees.

An extensive study was conducted to define the probability of utilizing at least one, two or three AOT positions to sight stars during any lunar stay, as a function of vehicle heading angle (see reference D.3). Due to the uncertainty of the lunar terrain, this study assumed a 3σ tilt angle of 30 degrees. Tilt is the angle between the X-body axis and the landing site vertical. Results of this study, applicable to the DRM IIA mission, are presented in reference D.3. These results assume star sightings are made approximately one hour prior to liftoff. As expected, the maximum probability occurs for a zero yaw angle or west heading angle. This orientation causes the AOT optical axes to point away from the sun.

In general, a range of inertial yaw angles between -70 degrees and +70 degrees at touchdown will ensure:

- Horizon-to-horizon LM rendezvous radar tracking of the CSM,
- That two AOT positions will always be available to sight stars.

D. 2. 12 LM ASCENT

The LM ascent covers the period from LM liftoff to LM-CSM docking. The approach employed to define LM ascent phase attitude is consistent with the discussion of Section D. 2. 10. Figure D. 2. 12-1 presents the resulting LM inertial attitude time history as well as configuration and operational constraints boundaries. Table D-1 summarizes the LM ascent orientation parameters time history.

The following paragraphs briefly cover the constraints during LM ascent and present a description of LM orientation for each mission phase.

S-Band Steerable

The shaft and trunnion angles used to relate the earth's position to LM orientation during the descent mission (Figure D. 2. 10-1) approximately apply to the ascent mission. The reason for this is that the inertial reference frame, fixed during the descent phase, is re-initialized for the ascent phase. Re-initialization corresponds to selecting the reference direction which coincides with the launch site local vertical at the nominal time of liftoff. As before, the Z reference axis is formed by the cross product of the CSM specific angular momentum vector with the X reference axis. Thus, if physical and optical lunar librations, together with the small out-of-plane excursion between the launch site and CSM plane, are neglected, then the ascent stable member system has the same angular relation to the earth as the descent stable member system.

S-Band gimbal limits that prohibit earth communication are shown on the ascent summary sheet of Figure D. 2. 12-1.

Sun Incidence Angles

Body-related shaft and trunnion angles that define the sun's direction as a function of LM stable member orientation (Figure D. 2. 10-2) are not directly applicable to the ascent mission. This results because of the moon's orbital and rotational motion. For example, during the 35-hour lunar stay the sun rises by approximately 18 degrees. Accordingly, the data presented in Figure 2. 10-2 will apply to the ascent mission provided these descent mission attitude data are diminished by 18 degrees.

Thermal constraints are non-existent during the ascent phase. However, it is necessary for CSM tracking capability that the sun not lie along the LM-CSM line-of-sight during the terminal coast and rendezvous phases. Figures D. 2. 10-2 and D. 2. 12-1 are used to define

whether this requirement is satisfied. Note that the sun will not be visible in the front windows during LM ascent except for the time interval just prior to the CDH maneuver until just after the second rendezvous gate.

Rendezvous Radar and Tracking Light

Rendezvous radar shaft and trunnion gimbal angle limits were computed from the ascent trajectory timeline. These limits are presented in the ascent summary chart of Figure D.2.12-1. Also included is the attitude-time history required to point the LM Z-body axis (line-of-sight) toward the CSM, the region of attitudes for which the LM tracking light is visible to the CSM.

IMU Alignment

IMU alignments can be conducted by viewing stars through at least one AOT field of view with a sun vector at least 15° from the perimeter of the sighting field. Figure D.2.12-1 shows the regions for which AOT sightings are not possible. It should be noted that this holds true for zero roll and yaw only. Future mission studies should define these regions for all angles: i.e., pitch, roll and yaw.

D.2.12.1 PHASE 12.1 POWERED ASCENT

At mission time 105:19:04 LM liftoff occurs. From a liftoff altitude of 0° pitch, 0° roll, and 0° yaw, the LM rises vertically for twelve seconds and begins a rapid pitchover and roll steering maneuver. The roll maneuver is necessary since the LM (due to the rotation of the moon during lunar stay) is out-of-plane with the CSM by 0.44°. Approximately midway through this phase a maximum roll angle of -12° is attained. At the completion of this phase, the LM is at an inertial attitude of -104° pitch, -6° roll, and 0° yaw.

D.2.12.2 PHASE 12.2 COAST TO CSI

At the termination of the powered ascent the LM begins an elliptical orbit coast to the CSI maneuver. During the coast the LM will orient to an inertial attitude of -40° pitch, 0° roll and 0° yaw. The LM will maintain this inertial attitude which insures visibility of the LM tracking light by the CSM. The LM will maintain this constant inertial attitude until it attains the outer limit of the tracking light visibility cone. At this time the LM orients to an inertial attitude of -100° pitch, 0° roll, and 0° yaw which is the inertial attitude required for the CSI maneuver and tracking light visibility.

D.2.12.3 PHASE 12.3 CSI MANEUVER

At mission time of 105:53:29 the LM initiates the CSI maneuver. This maneuver utilizes the LM Z-axis RCS jets. These jets were chosen since they allow simultaneous rendezvous radar/tracking light operations to take place during the burn. The maneuver is performed with the LM Z-axis essentially pointing along the local horizontal and in the direction of the velocity vector. At the initiation of the maneuver the LM inertial attitude is -100° and terminates at an inertial attitude of -102°. The inertial yaw and roll angles are zero throughout the phase since the LM X and Z-body axes are maintained in the orbital plane.

D.2.12.4 PHASE 12.4 COAST TO CDH

At the termination of the CSI maneuver the LM maintains the inertial attitude of -102° until such time that it attains the outer limits of the tracking light visibility cone. At this time the LM orients to a new inertial attitude such that the tracking light visibility is maintained. This inertial attitude of -152° is held until mission time of 106:21:51 hours at which time the LM orients to the first star to perform the IMU alignment.

This first orientation of the spacecraft brings the star α Leonis (Regulus) to the center field of view of the AOT for marking. The inertial attitude of the LM at this time is 86° pitch, 0° roll, and -5° yaw. On the completion of the marking, the spacecraft is then oriented to an inertial attitude of 0° pitch, 0° roll, and 3° yaw to bring the star α Persei into the center field of view of the AOT. The fine alignment is then checked by orienting the spacecraft to the inertial attitude -19° pitch, 0° roll, and 10° yaw to bring the star α Tauri (Aldebaran) into the right field of view of the AOT. Upon completing the fine alignment, the LM orients to an inertial attitude of 132° which again satisfies tracking light visibility requirements. The LM will maintain this attitude until it performs a pitchover to an inertial attitude of 109° which is required for the CDH maneuver.

D.2.12.5 PHASE 12.5 CDH MANEUVER

At mission time of 106:43:21 hours the LM performs the CDH maneuver. The LM initiates this maneuver at an inertial pitch attitude of 109° and terminates at an inertial attitude of 108°. This maneuver utilizes the LM Z-axis RCS jets. As in the case of the CSI burn, the

Z-axis jets were chosen to enable simultaneous rendezvous radar/tracking light operations during the maneuver. The inertial yaw and roll angles are zero throughout the phase since the LM X and Z body axes are maintained in the orbital plane.

D.2.12.6 PHASE 12.6 COAST TO TPI

At the termination of the CDH maneuver the LM maintains the inertial attitude of 108° until a pitchover is required to the TPI inertial attitude of 101°.

D.2.12.7 PHASE 12.7 TPI MANEUVER

At mission time of 107:01:31 hours the LM performs the TPI maneuver which takes 23 seconds. The LM Z-axis jets are utilized for the burn and the local pitch angle is such that the thrust vector points essentially along the line-of-sight to the CSM. It is to be noted, however, that the elevation angle to the CSM at TPI (see Table D-1) is not equal to zero, as the concentric flight plan guidance philosophy intended (see ref. 8 of Vol. I). Future reference trajectories should, therefore, satisfy the requirement that the nominal TPI thrust vector be directed along the line-of-sight to the CSM.

D.2.12.8 PHASE 12.8 COAST TO TERMINAL RENDEZVOUS

Upon completing the TPI maneuver the LM orients to the first rendezvous gate pitch attitude of 82° to provide CSM optical tracking of the LM tracking light during this phase. The LM orients from this inertial attitude for the performance of two midcourse corrections (which have no specified nominal orientation) and regains this attitude upon completion of these burns.

D.2.12.9 PHASE 12.9 TERMINAL RENDEZVOUS

At a range to the CSM of 5 n. mi. the terminal rendezvous phase is initiated. At this time, the LM is at an inertial pitch attitude of 82° roll and 9° yaw. It must be noted that at this time the LM is behind and below the CSM. Since the first rendezvous gate does not require thrusting, the LM maintains the terminal coasting pitch attitude of 82°.

Prior to the first rendezvous burn (2nd gate), the LM orients to an inertial pitch attitude of 81°. This attitude is maintained during burn.

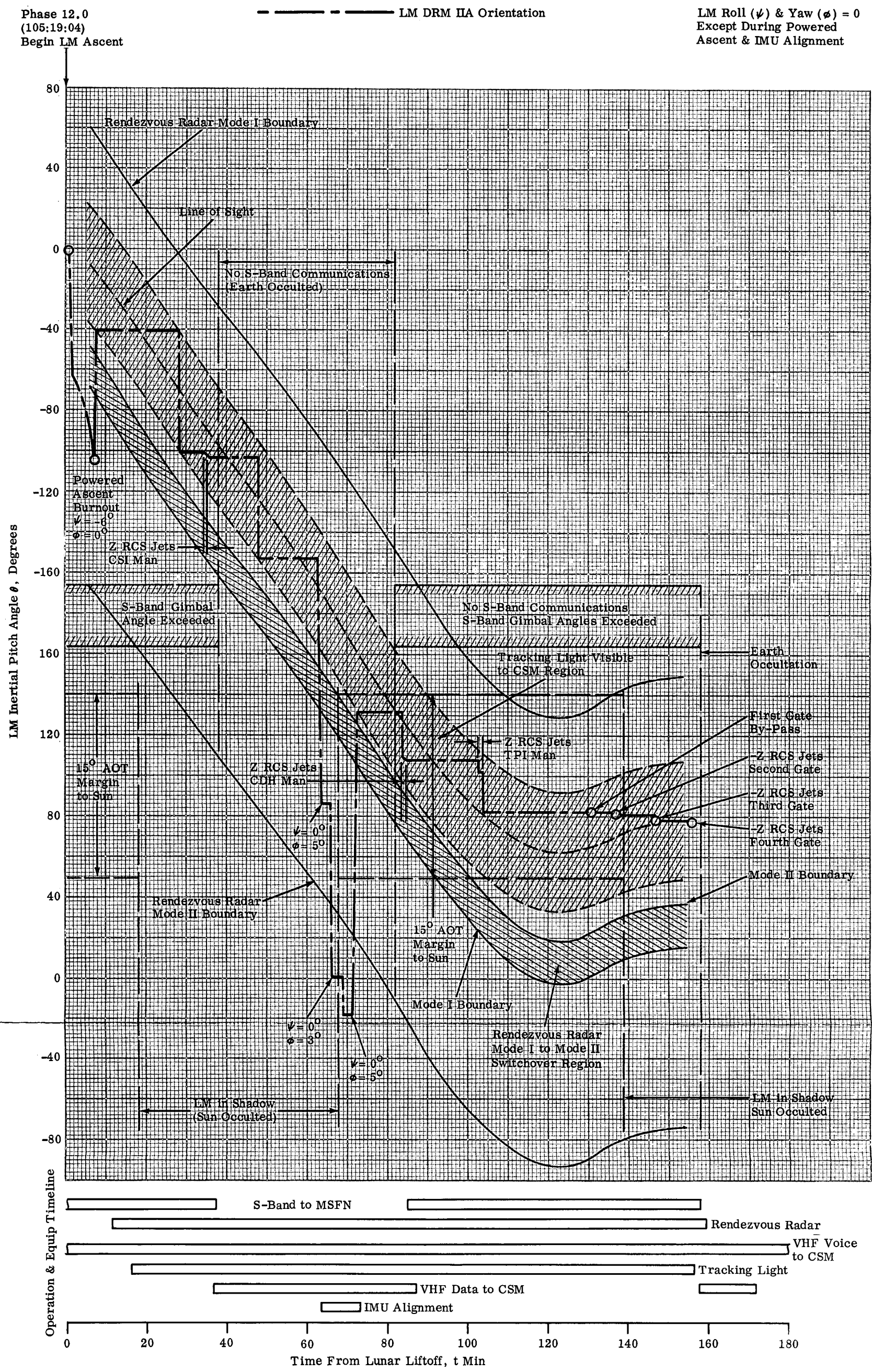


Figure D.2.12-1 LM Ascent Phase Orientation Timeline and Constraint Boundaries

During the LM coast to the second rendezvous burn (3rd gate), the CSM will establish a local attitude hold. Prior to the second rendezvous burn (3rd gate), the LM orients to an inertial pitch attitude of 78°. This attitude is held for the duration of this burn. Prior to the third and final rendezvous burn (4th gate), the LM orients to an inertial pitch attitude of 77°. It must be noted that the Z-body axis generally points along the line-of-sight direction to the CSM during the coast periods between burns. At the completion of the third rendezvous burn (3rd gate), the LM is spatially located below and in front of the CSM.

D.2.12.10 PHASE 12.10 DOCKING MANEUVER

At a range of 500 feet to the CSM, the docking maneuver is initiated. At this time, the LM is at an inertial attitude of 77° pitch, 0° roll, and 0° yaw. During the translation to 50 feet in front of the CSM docking target, the LM will gradually orient such that the inertial attitude is 82° pitch, 9° roll, and 19° yaw. It must be noted that during the docking maneuver the CSM is in an inertial attitude hold of 172° pitch, -41° roll, and 9° yaw. At the 50-foot range to the CSM, the LM will pitch over to an inertial attitude of -8° pitch, 9° roll, and 19° yaw in order to regain the docking target in the overhead window. Utilizing the X-axis thruster in the pulse (discrete) mode, the Commander then translates at this attitude toward the CSM to achieve docking.

D.2.13 PHASE 13.0 LUNAR ORBIT COAST TO TRANSEARTH INJECTION

After LM completion of terminal rendezvous, preparation for docking begins. Axial alignment (roll index) between the CSM and LM for docking is the same as that occurring during the transposition and docking portion of the translunar phase (Figure D.2.5-1). During the docking phase the LM is nominally the active vehicle. The CSM attitude during docking is with the negative Z axis 30 degrees north of the orbit plane toward the moon and the positive X axis in the orbit plane toward the LM (see Fig. D.2.13-1). This attitude is maintained inertially fixed throughout the docking phase.

Since the earth will probably be occulted by the moon during docking and docking is likely to occur away from the subsolar region, no earth communication or ECS radiator attitude

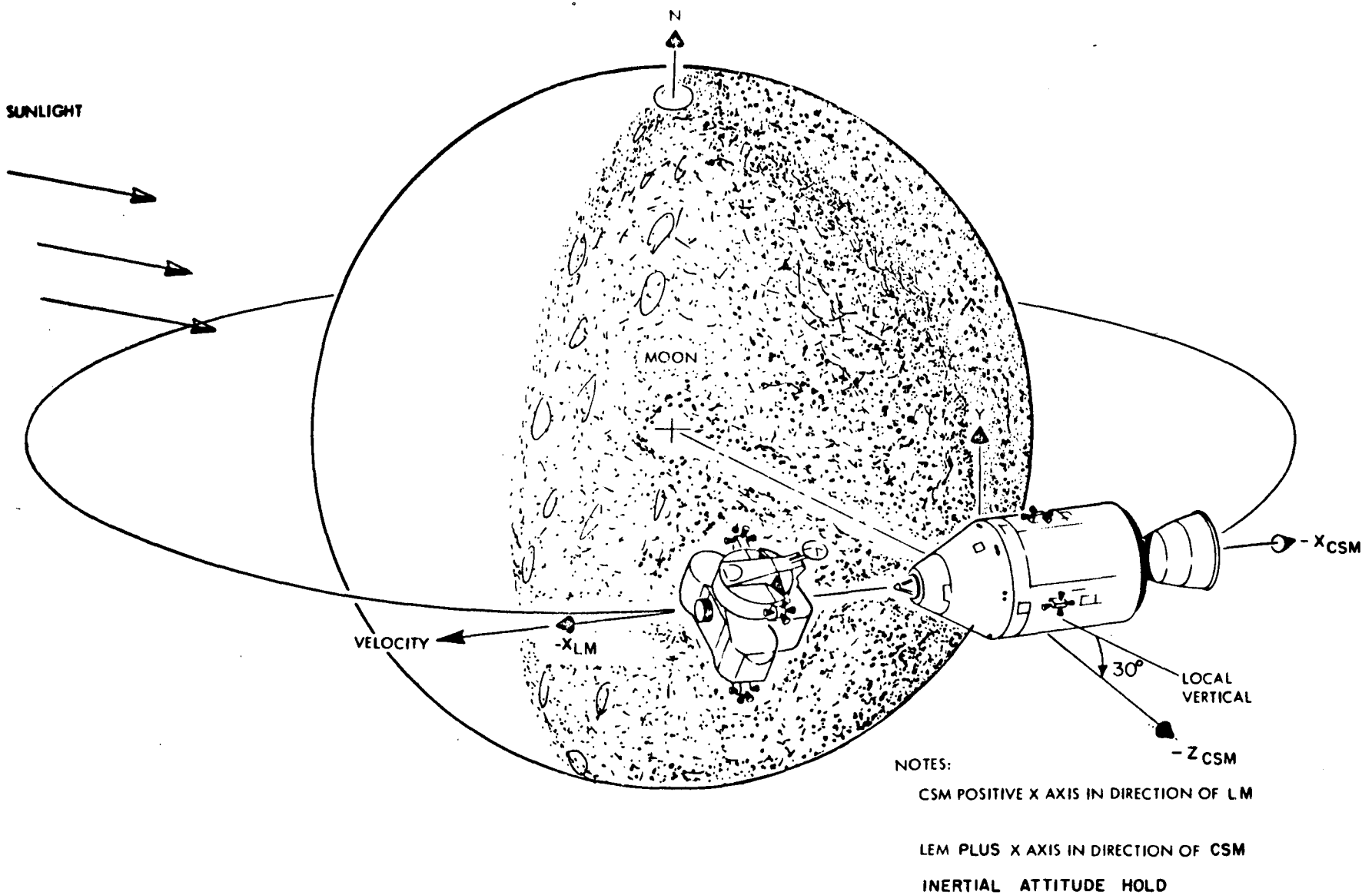


Figure D.2.13-1 CSM-LM Docking

NOTES:

- CSM Minus X Axis (RCS Thrust) away from LM
- Maintain Earth Communications

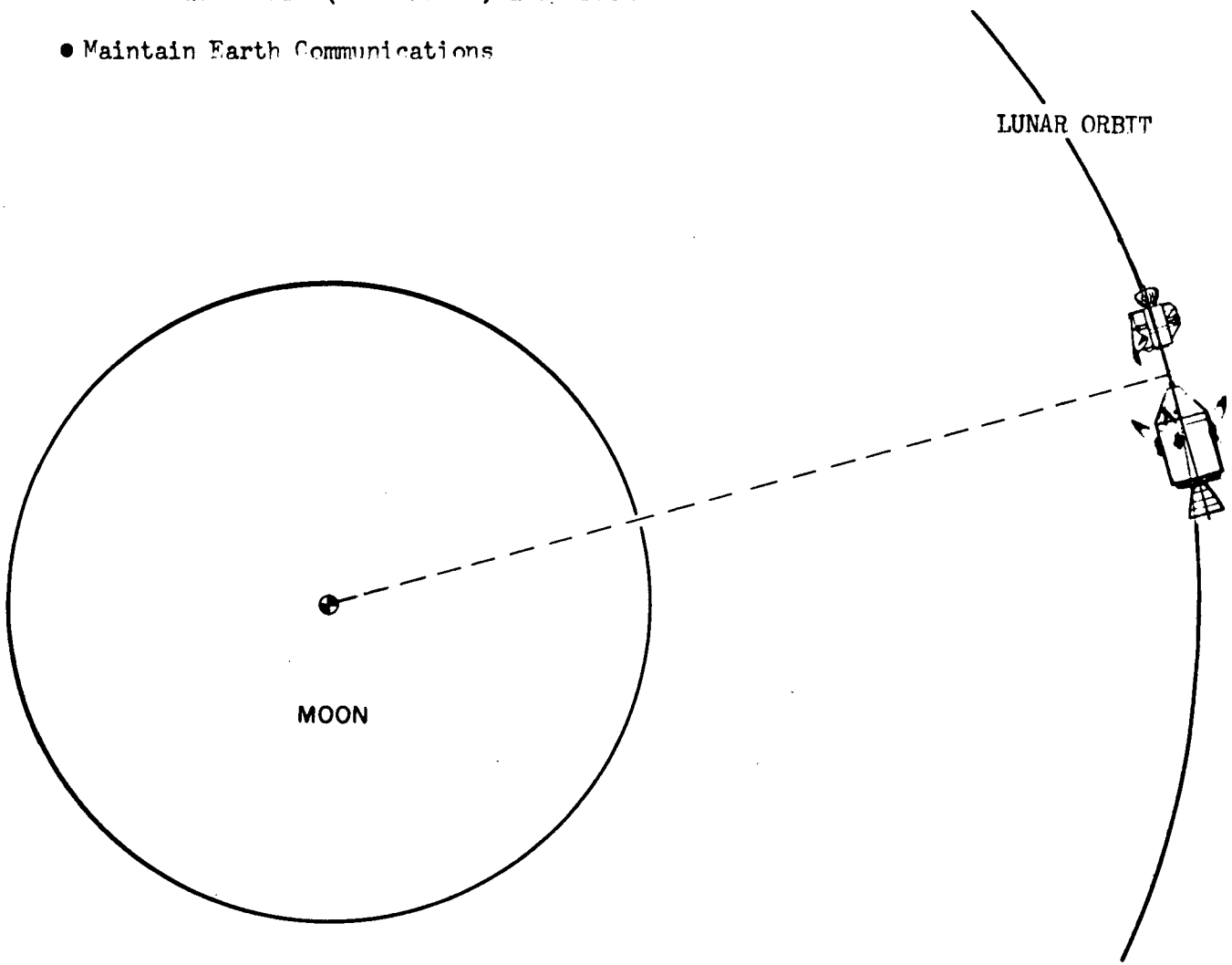


Figure D.2.13-2 LM Jettison

constraints are in effect. However, two requirements are in effect during this period:

(1) CSM positive X axis will mate to the LM positive X axis.

(2) Should docking occur in sunlight the requirement is to orient the CSM (passive vehicle) such that the sun's incident rays are 45 to 75 degrees from the CSM plus X axis. This orientation will allow the sun to appear from behind the LM astronaut during the docking maneuver.

The CSM/LM remains inertially fixed during the docking procedures. The attitude sequence employed subsequent to docking satisfies CSM high-gain antenna pointing, ECS radiator attitude constraint, and LM jettison attitude. The CSM attitude for LM jettison is with the CSM plus X axis approximately along the negative velocity vector and with plus Z axis 30 degrees north of the orbit plane toward the earth (Fig. D.2.13-2). The jettison attitude is primarily selected for crew safety purposes. The LM must be left behind in such a manner as to avoid the possibility of collision with the CSM. Therefore, the CSM positive X axis shall be within 90 degrees of the negative direction of flight just prior to separation. The LM is jettisoned by a CSM negative X axis translation. No special attitude other than that previously mentioned is assumed for purposes of biasing the CSM trajectory with the translation delta velocity. The previously described attitude also satisfies LM S-Band omni coverage from the LM minus Z axis antenna. The LM systems are to be left active upon jettisoning and the S-Band omni will serve to monitor their status.

Following LM jettison the CSM remains inertially fixed until the plus X axis is 30 degrees below the negative velocity vector, which satisfies the attitude for the series of navigation sightings in orbit 24. This X axis pointing is achieved 71 minutes from the time of establishing the inertial hold for LM docking. At this time a local attitude hold is established and maintained for the remainder of lunar orbit 23.

Lunar orbit 24 begins with a fine IMU alignment. The LM jettison attitude followed by the aforementioned sequence satisfies the required IMU alignment attitude. The IMU alignment is followed by a 138 °negative roll placing the plus Z axis 12 degrees north of the orbit plane toward the moon which is favorable for the following navigation sighting sequence.

After completing the navigation sighting sequence, the CSM performs a positive roll of 90 degrees to point the optics away from the moon. The fine IMU alignment is performed in

local attitude hold. After the fine IMU alignment has been completed the CSM begins inertial attitude hold and performs a 3-axis maneuver to the transearth injection attitude.

Illustrated in Figures D. 2. 13-3 through D. 2. 13-10 are the attitude events, orientations, and attitude hold sequences for the lunar orbit phase of DRM IIA.

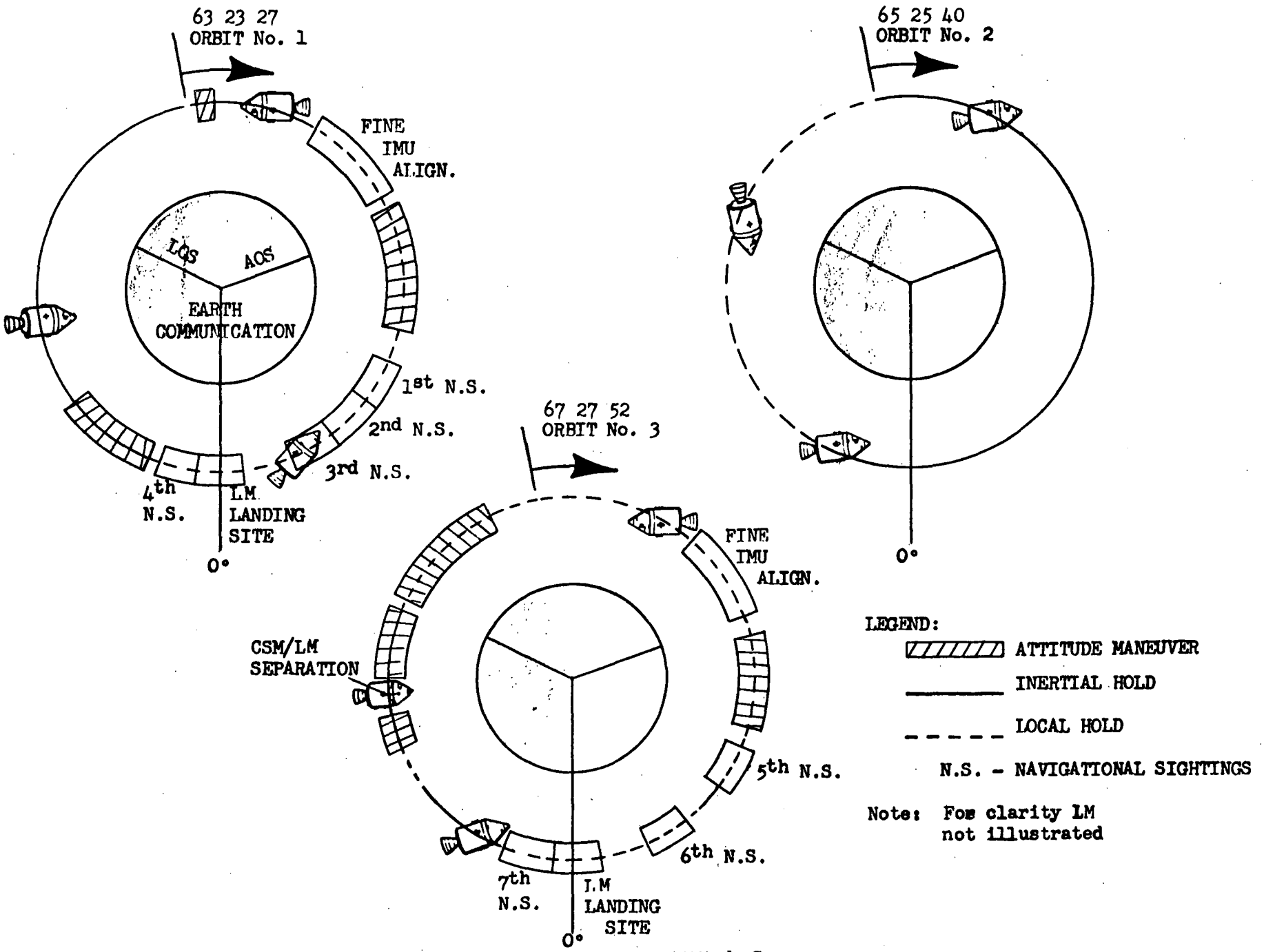


Figure D.2.13-3 Lunar Orbit 1-3 Attitude Sequence

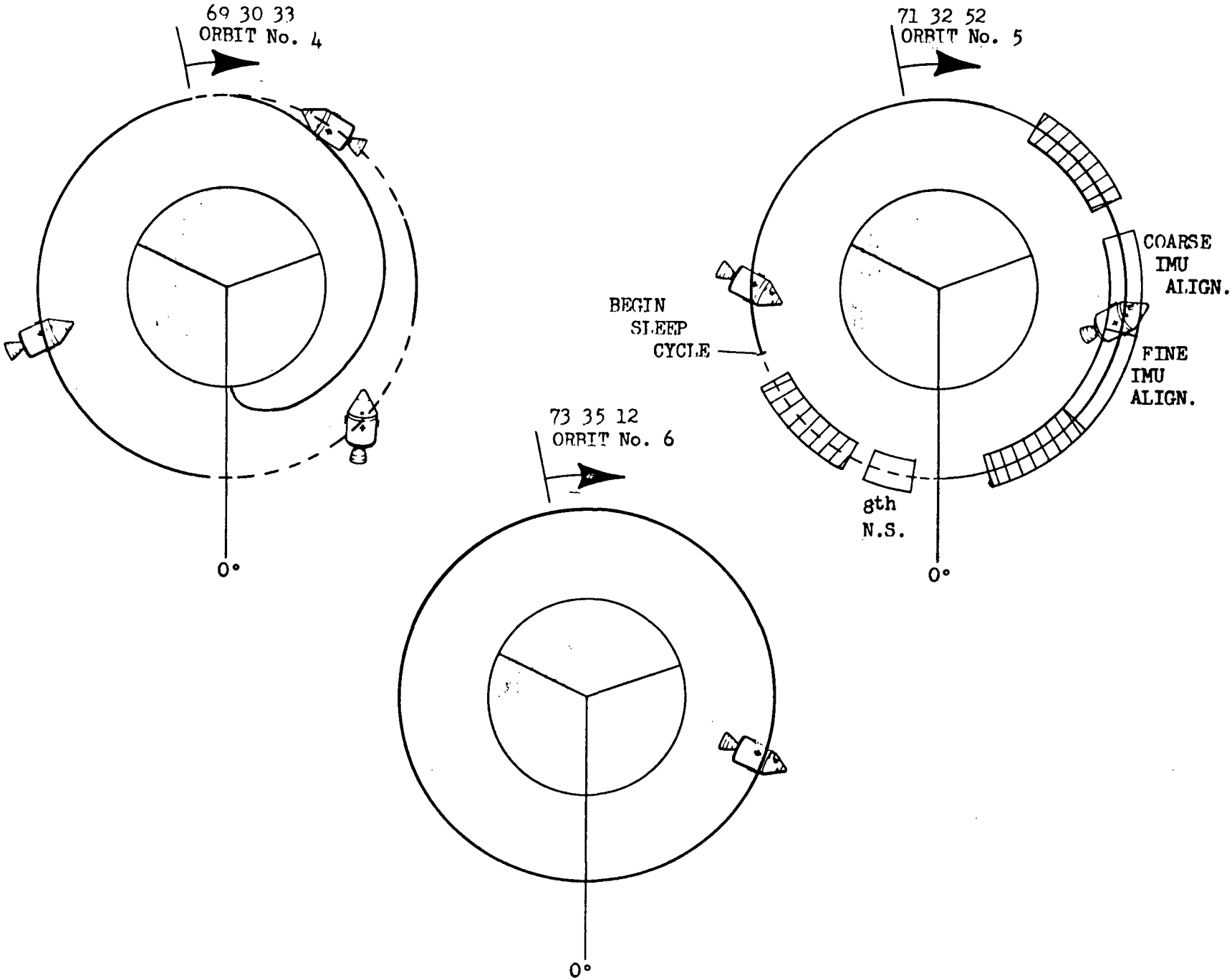


Figure D.2.13-4 Lunar Orbit 4-6 Attitude Sequence

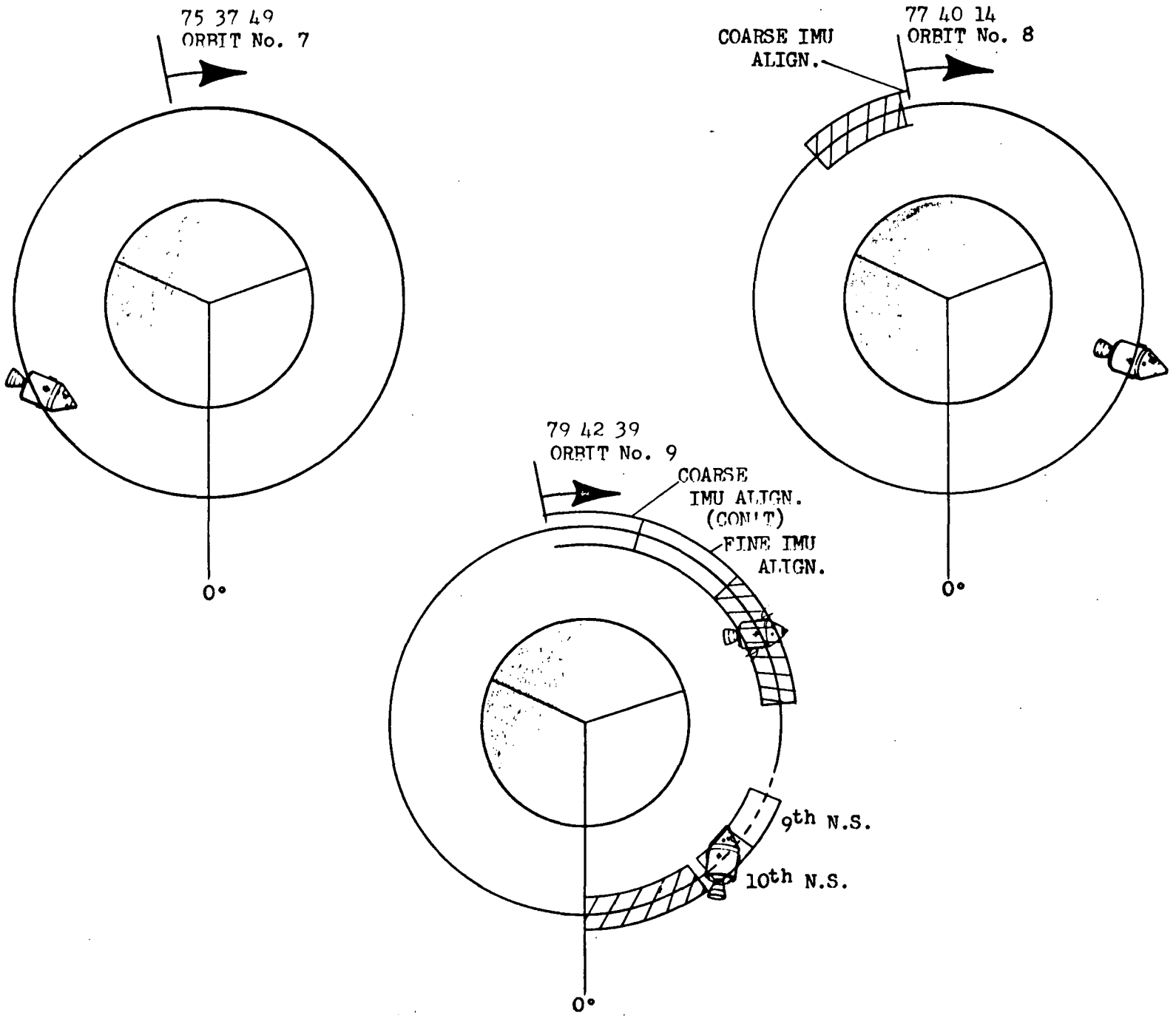


Figure D.2.13-5 Lunar Orbit 7-9 Attitude Sequence

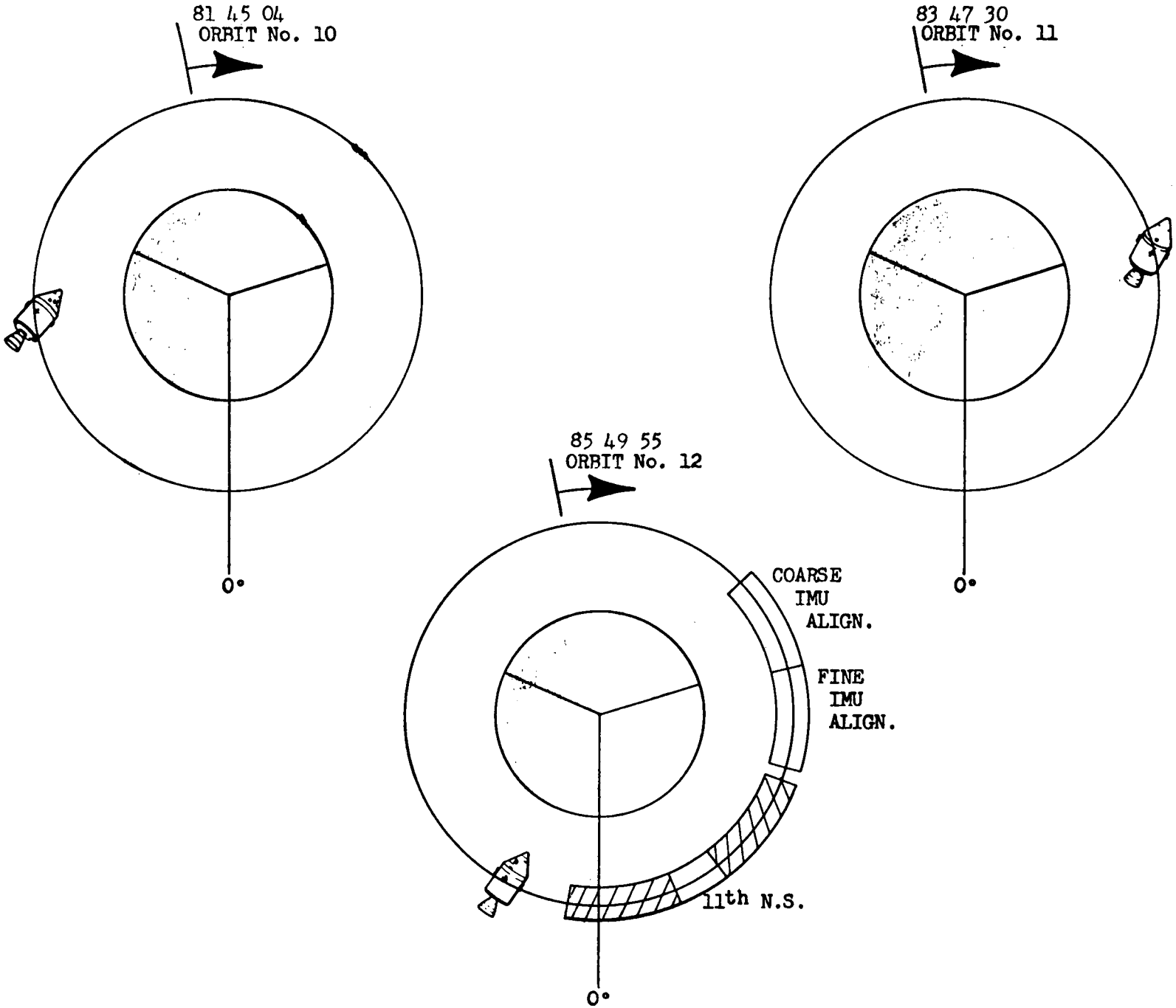


Figure D.2.13-6 Lunar Orbit 10-12 Attitude Sequence

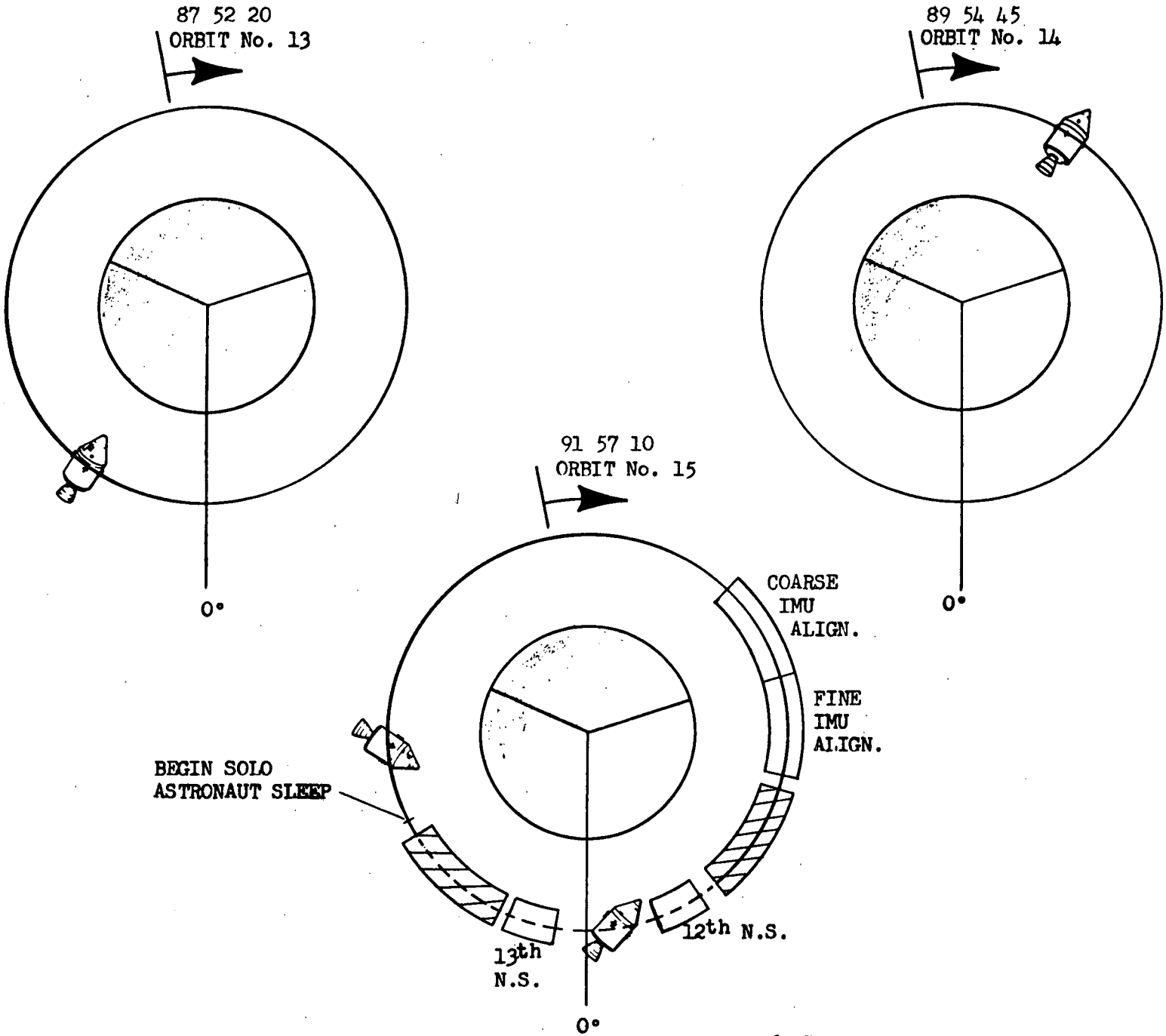


Figure D.2.13-7 Lunar Orbit 13-15 Attitude Sequence

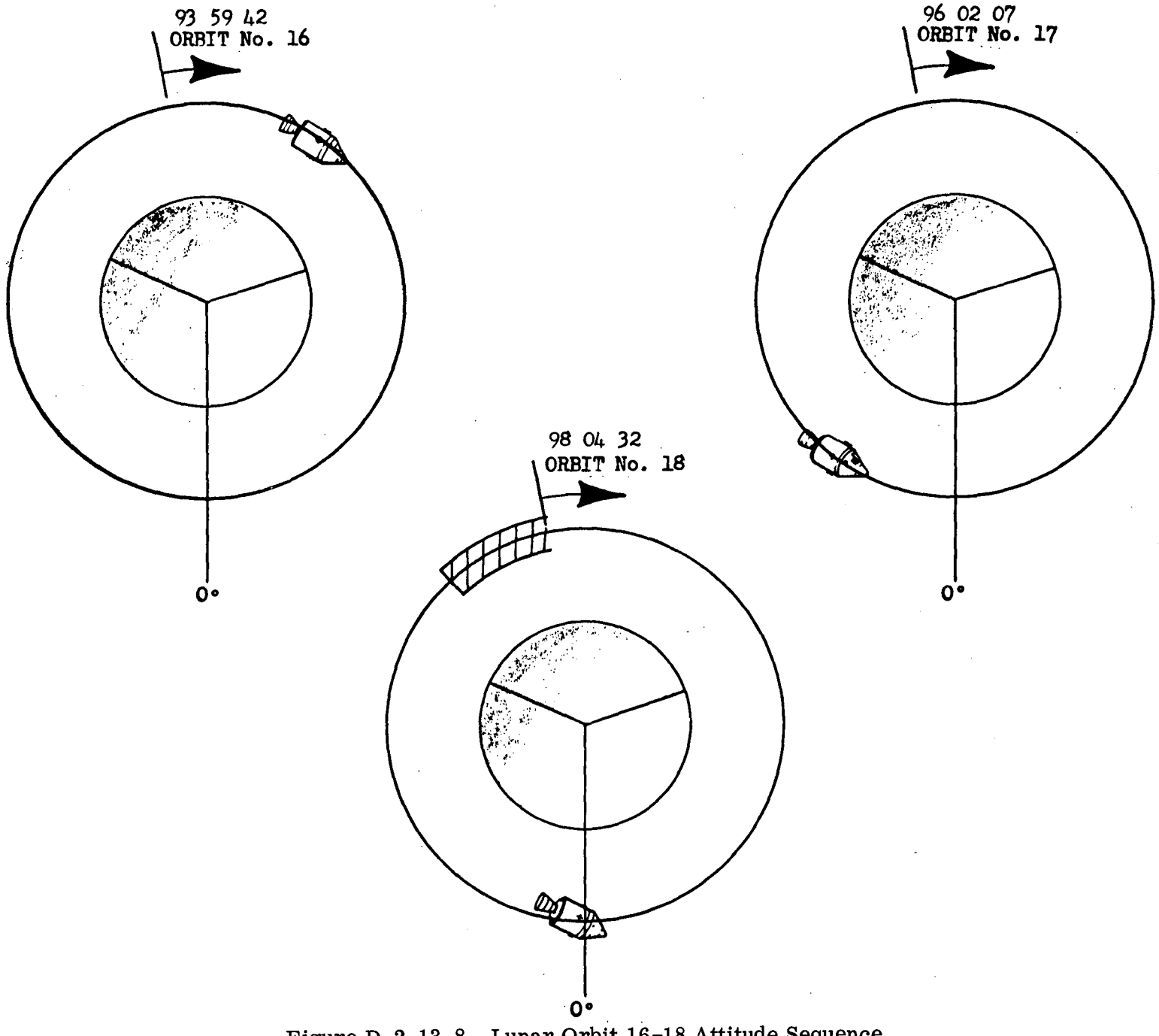


Figure D.2.13-8 Lunar Orbit 16-18 Attitude Sequence

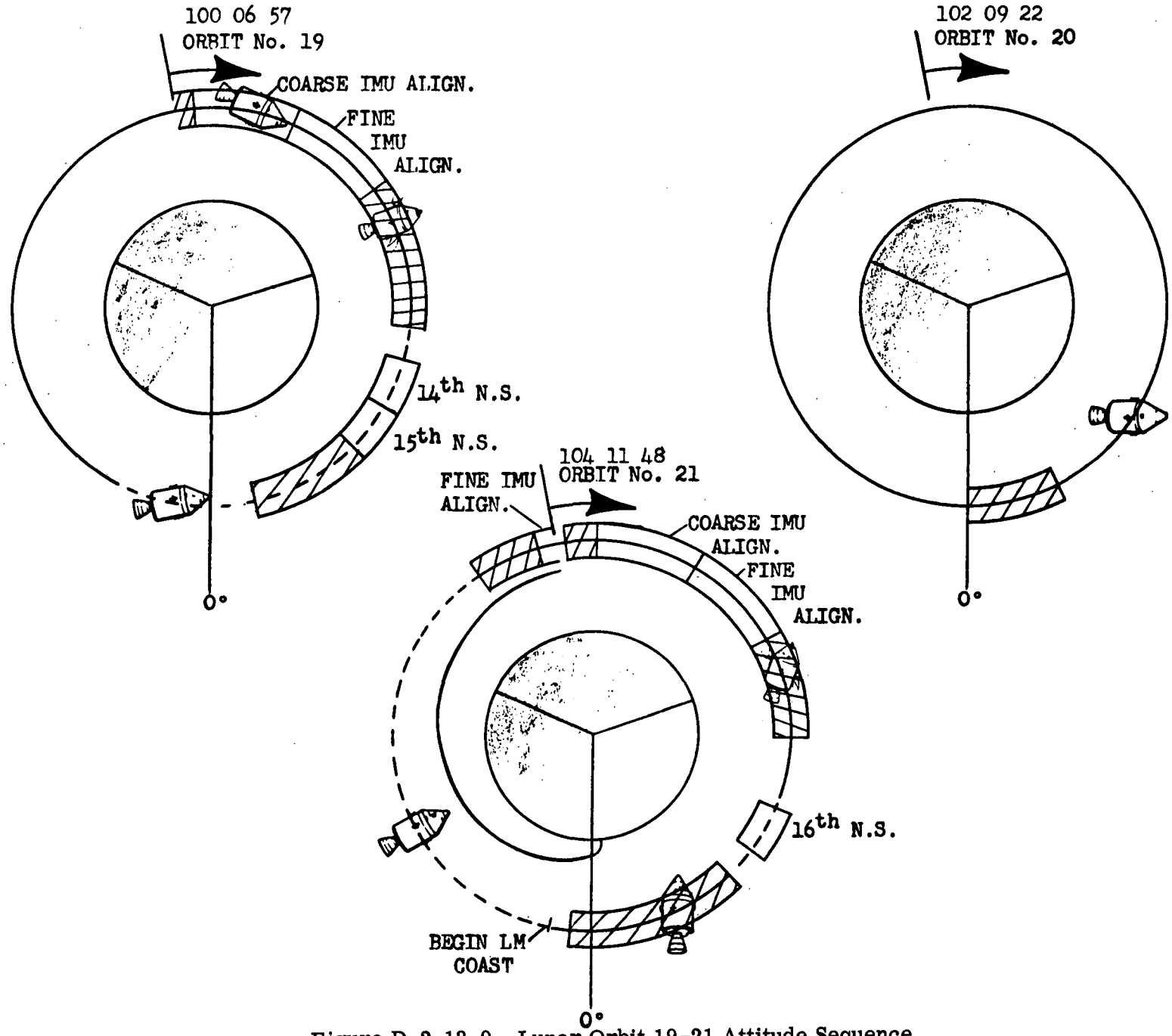


Figure D.2.13-9 Lunar Orbit 19-21 Attitude Sequence

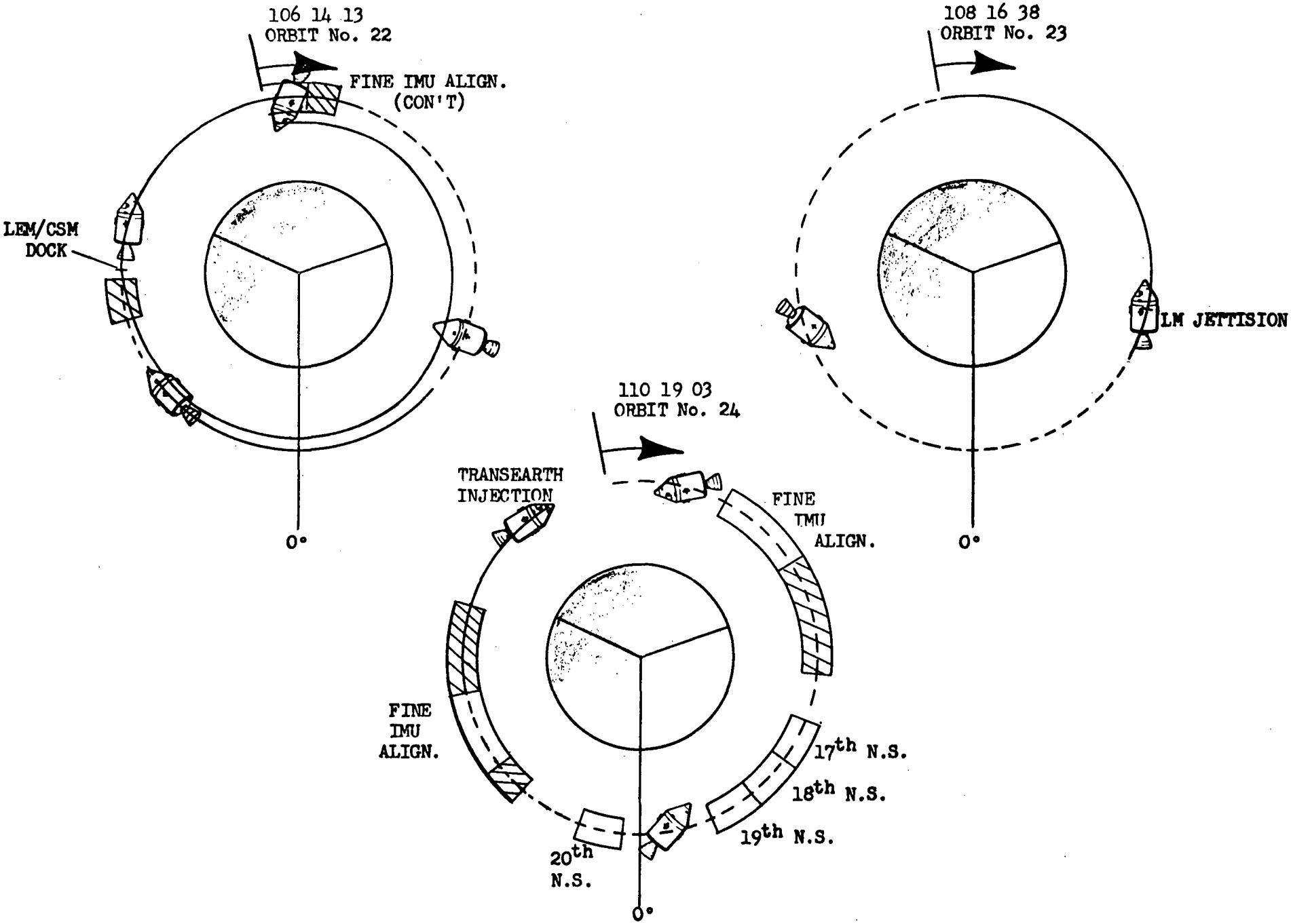


Figure D.2.13-10 Lunar Orbit 22-24 Attitude Sequence

D.2.14 PHASE 14.0 TRANSEARTH INJECTION

Transearth injection is initiated at a selenographic longitude of 141 degrees west near the lunar equator. The SPS is ignited and burns for 1 minute and 56 seconds. The CSM attitude remains inertially fixed through transearth injection. See Figure D.2.14-1.

At SPS ignition and during transearth thrusting, the earth is occulted by the moon. Since the X axis roll attitude is unconstrained for an SPS delta velocity maneuver, the roll orientation is chosen to be compatible with earth high-gain antenna communications during the final IMU alignment attitude prior to SPS transearth injection. The roll orientation during the IMU alignment is with the plus Z axis 15 degrees above the orbit plane away from earth.

An ullage maneuver is required prior to SPS ignition for transearth injection since much of the SPS propellant has been depleted. The purpose of an ullage maneuver is to force propellant to be compacted in the outlet end of the SPS tanks; hence, propellant gases will not be released into the combustion chamber causing failure. The attitude of the spacecraft for an ullage maneuver must be constrained such that the plus X axis is in the direction of required thrust. Using the Service Module Reaction Control System thrust, an ullage maneuver (RCS translation) is performed just prior to Service Propulsion System ignition.

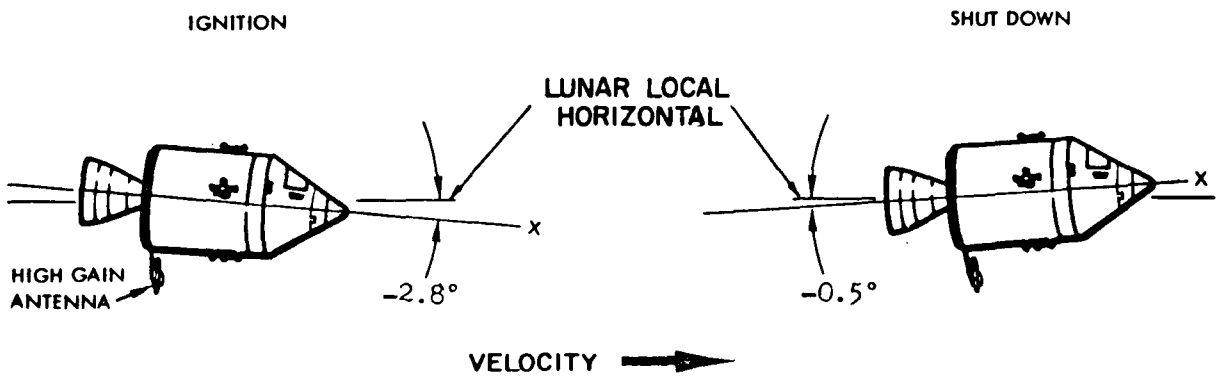
D.2.15 PHASE 15.0 TRANSEARTH COAST

For the events specified, attitude constraints imposed on the CSM for the transearth phase are similar to those occurring during the translunar phase. CSM requirements for the transearth phase of the mission include the following:

- Midcourse Corrections
- IMU Alignments
- Earth Communications
- Passive Thermal Control
- CM-SM Separation

Navigation sightings will not be taken during the transearth phase except as a contingency backup.

The transearth coast phase begins with a CSM orientation for passive thermal cycling while on the back side of the moon. The orientation consists of a maneuver which places the vehicle X axis normal to the vehicle sun line. Following the orientation the vehicle is allowed to stabilize in the narrow deadband and then a .25 degree per second (2.5



NOTES:

- At SPS Ignition the X Axis is in the General Direction of Velocity Minus 2.8 Degrees from Local Horizontal
- Spacecraft Attitude Remains Almost Inertially Fixed through Transearth Injection (TEI)
- Roll Attitude Selected to Permit High-Gain Communications with Earth at TEI IMU Alignment

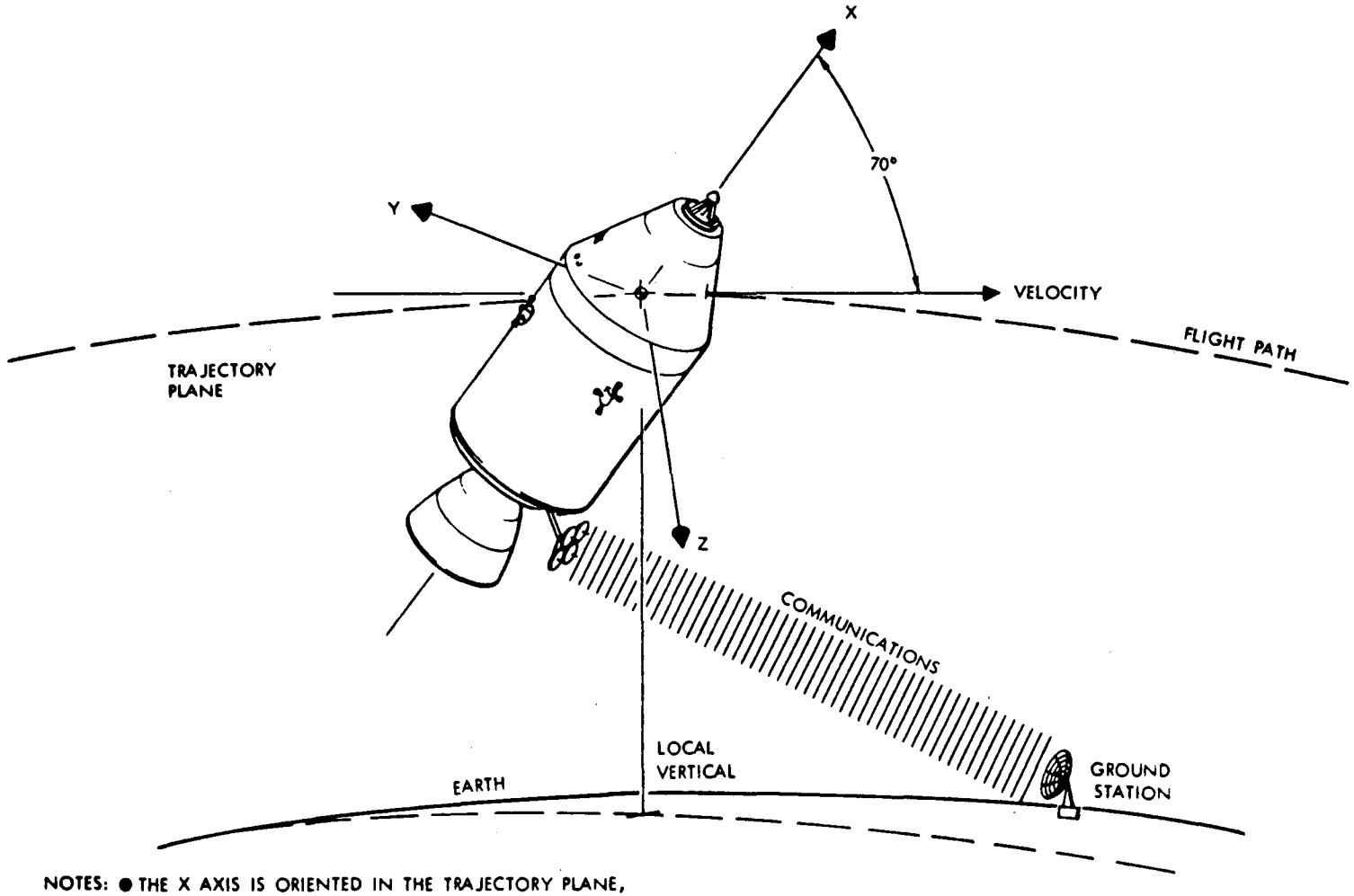
Figure D.2.14-1 Transearth Injection

revolutions per hour) roll is initiated. Thermal roll continues for 9 hours after which the CSM roll is stopped and a coarse IMU alignment is performed. The coarse IMU alignment attitude is compatible with high-gain communications and does not have the sun in the optics field. The CSM is then oriented to the midcourse correction (MC) attitude, a fine IMU alignment performed followed by a small adjustment in attitude for the midcourse correction. A roll orientation is chosen for the fine IMU alignment and midcourse correction attitude that satisfies high-gain antenna communications. The first transearth midcourse correction occurs 10 hours after transearth injection (lunar sphere of influence). Specific attitude requirements for the transearth IMU alignments and midcourse corrections are the same as for the translunar phase.

During the transearth phase there are three periods of passive thermal control. Due to the lighter vehicle, the PTC roll rate must be greater than the translunar roll rate in order to meet the ± 20-degree thermal deadband requirements. Studies are currently in process which indicate that roll rates may be as high as 6 revolutions per hour. However, due to the preliminary nature of the results, roll rate for transearth is currently specified at 2.5 revolutions per hour for DRM IIA. Since the sun-vehicle-earth geometry has changed from that of the translunar phase, high-gain antenna communications are interrupted for about 4 minutes duration during each of the 250 vehicle rotations.

As in the translunar phase, the high-gain antenna interruption conditions may be related in terms of the landing site location. Assuming the maximum vehicle precession angle of 10 degrees, uninterrupted high-gain antenna communications cannot be assured if the landing site is located west of 17 degrees lunar selenographic longitude. At the time of LM landing the sun incident angle at the landing site is required to be between 7 and 20 degrees. The likelihood of uninterrupted high-gain antenna communications is enhanced by locating the landing site farther east of 17 degrees selenographic longitude.

Following the first midcourse correction, the vehicle is oriented normal to the vehicle-sun line for passive thermal control, stabilized in the narrow deadband and the 2.5 revolution per hour thermal cycling is initiated. The second thermal cycling period lasts 30 hours. At about 40 hours from transearth injection, the roll rate is stopped and a coarse IMU alignment is performed. The CSM is maneuvered to approximately the MC attitude and a fine IMU alignment is performed. A small attitude change is made to the MC attitude.



NOTES: ● THE X AXIS IS ORIENTED IN THE TRAJECTORY PLANE, 70-DEGREES ABOVE THE VELOCITY VECTOR

● ROLL ATTITUDE SELECTED TO ASSURE HIGH-GAIN COMMUNICATIONS CAPABILITY PRIOR TO SEPARATION

Figure D.2.15-1 CM-SM Separation

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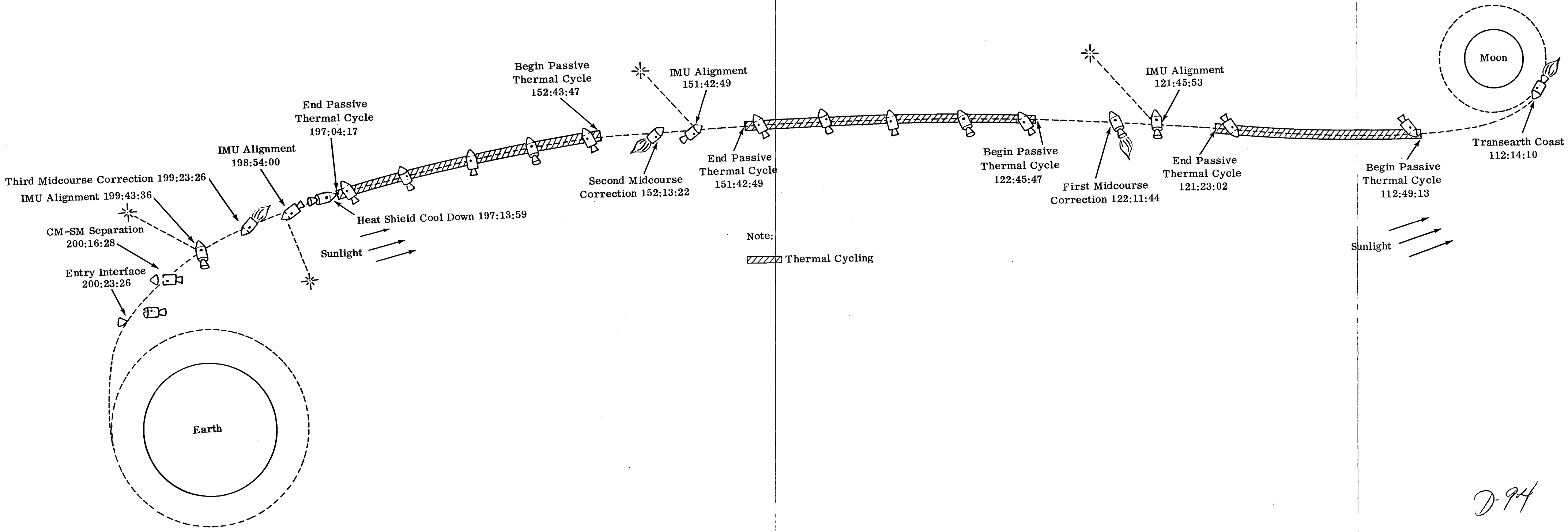

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Figure D.2.15-2 Transearth Phase

The second midcourse correction is executed followed by orientation and establishment of passive thermal cycling.

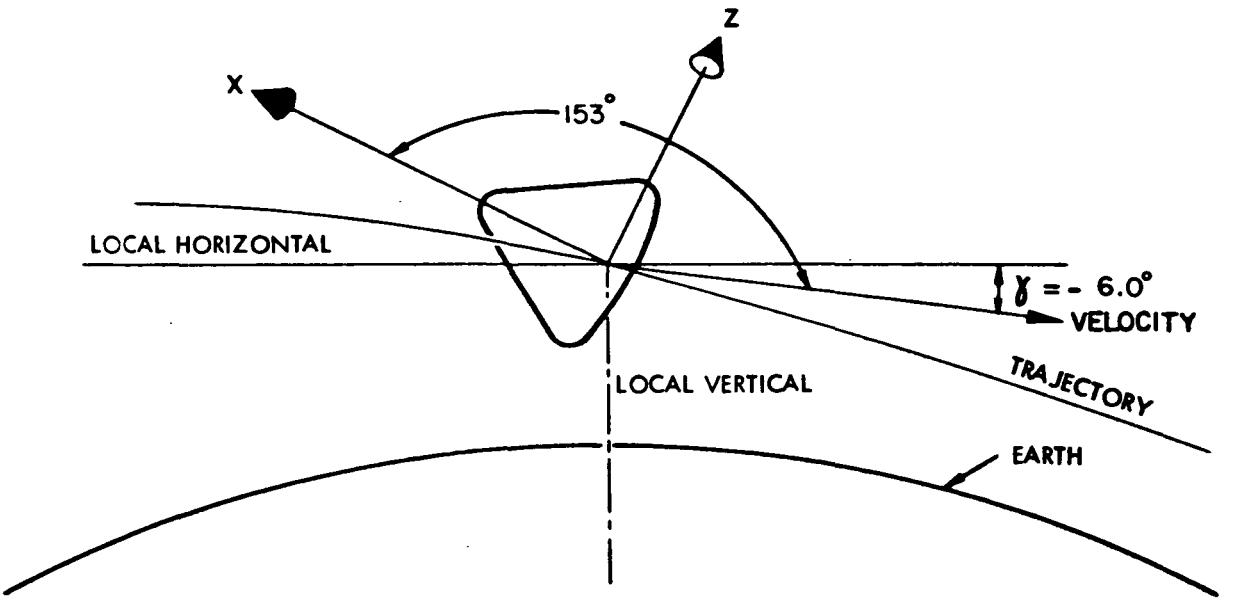
Three hours prior to entry the CSM ends passive thermal control and orients for heat shield cool-down. The attitude, maintained in the wide inertial deadband, requires that the CSM minus X axis be pointed toward the sun. This attitude maintains the conical surface of the forward heat shield in the shadow during the pre-entry phase. Following 75 minutes of heat shield cool-down, the CSM is oriented to approximately the MC attitude for a fine IMU alignment. Following the alignment a small maneuver is made to the MC attitude. After the final MC the CSM enters the earth's shadow for about one hour which provides a total heat shield cool-down period of over two hours. During the time the CSM is in the shadow, an orientation is made for a fine IMU alignment. The Service Module is jettisoned 7 minutes before entry. An acceptable attitude at CM-SM separation is obtained by having the spacecraft positive X axis 70 degrees above the positive velocity direction and in the trajectory plane. See Figure D. 2. 15-1. Roll orientation is selected so that the high-gain antenna coverage pattern contains an MSFN station. Separation is accomplished by use of the SM RCS jets which provide minus X axis translation. Since the high-gain antenna is left with the SM, earth communication is maintained with the omni link after separation. Figure D. 2. 15-2 illustrates the transearth attitude sequence for the DRM IIA mission.

D. 2. 16 PHASE 16. 0 ENTRY

Earth entry phase begins about 88 hours from transearth injection at an altitude of 416, 662 feet.

At entry the flight path angle is minus 6. 56 degrees (angle between velocity vector and local horizontal) and the plus X axis is in the trajectory plane about 27 degrees above the negative velocity vector with the plus Z axis pointed away from earth. See Figure D. 2. 16-1. During entry, attitude operations consist of damping of pitch and yaw rates (about CM body axes) and controlling of roll about the velocity vector which in turn controls the lift vector (affording some measure of range control).

The CSM orientation during the entry phase shown in table D-1 differs somewhat from the profile shown in the mission description (Vol. I). This is the result of the fact that the attitude table was based on an earlier entry trajectory. Before publication, the entry trajectory was updated based on more recent CM aerodynamic data and that version is the one which



NOTES:

- ENTRY INTERFACE 416,662 FEET.
- THE CM XZ PLANE IS IN THE TRAJECTORY PLANE WITH THE +X AXIS 153 DEGREES FROM THE VELOCITY VECTOR: THE Z AXIS IS UP; THE ENTRY FLIGHT PATH ANGLE γ IS MINUS 6.0 DEGREES
- POST ENTRY INTERFACE ATTITUDE IS A FUNCTION OF THE STEERING PROGRAM

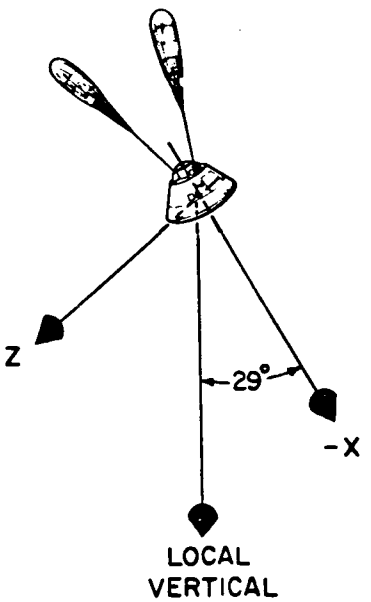
Figure D.2.16-1 Earth Entry of Command Module

appears in the mission description. Because of the small differences it was not considered necessary to recalculate the attitude data (look angle, etc.) in table D-1 for the new entry.

D.2.17 PHASE 17.0 PARACHUTE DESCENT TO TOUCHDOWN

The parachute descent phase begins at an altitude of about 24,000 feet. After the forward heat shield is jettisoned, the two drogue chutes are mortar-deployed in a reefed condition. This occurs at an altitude of about 23,500 feet. The drogue parachutes are fully opened in approximately nine seconds. This will orient the CM apex upward during the descent to 10,000 feet. At 10,000 feet the three pilot parachutes are mortar deployed and the drogue parachutes disconnected. The pilot parachutes in turn deploy the three main parachutes in a reefed condition. A few seconds later the main parachutes are fully opened. The CM is then lowered to touchdown by the main parachutes.

During the parachute descent phase, the CM attitude is determined by the relative velocity, prevailing winds and the CM center-of-gravity. For this study no prevailing winds were assumed. The major contributor to determining the CM attitude is the relative position of the CM center-of-gravity with respect to the parachute tie point. This results in an angle between the minus X axis and the local vertical of 29 degrees. Figure D.2.17-1 illustrates the CM attitude during this phase.



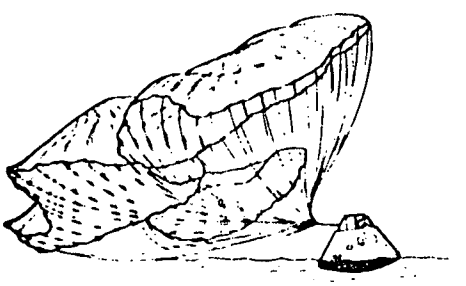


Figure D.2.17-1 Parachute Descent to Touchdown

TABLE D.2-1 - SUMMARY OF ROTATIONAL ATTITUDE MANEUVERS (SM RCS) AND ATTITUDE HOLDS

MISSION PHASE	ATTITUDE EVENT	MANEUVER					ATTITUDE HOLDS (HRS)			
		3 Axis	Roll	Pitch	Yaw	Min. Imp.	.2	.5	4.2	5.0
Translunar	Transposition & Docking		1	1		Several		0.25		
	Navigation Sightings	2				10		1.0		
	IMU Alignments	4						1.0	1.0	
	Midcourse Correction					6		0.12		
	Orient Passive Thermal Control	2								
	Begin Passive Thermal Control		2					0.5		
Translunar	Lunar Orbit Insertion					2		0.1		
Lunar Orbit (with LM)	IMU Alignments		1		1					
	Navigation Sightings		2							
	LM Separation		1							
	Attitude Holds							5.5		
Lunar Orbit (with LM)										
	NOTE: All maneuvers performed at .2°/sec. except where noted (.XX)									

TABLE D.2-1 - CONTINUED

MISSION PHASE	ATTITUDE EVENT	MANEUVER					ATTITUDE HOLDS (HRS)			
		3 Axis	Roll	Pitch	Yaw	Min. Imp	.2	.5	4.2	5.0
Lunar Orbit (Without LM)	LM Observation			1 (.25)						
	LM Tracking		2 1 (.25)		1					
	IMU Alignments		6 1 (.5)	1						
	Navigation Sightings		4	3						
	Sleep Cycle		2						13.5	
	Rendezvous		1							
	Transearth Injection	1								
Lunar Orbit (Without LM)	Attitude Holds							10.25	18.25	
Transearth	Orient Passive Thermal Control	3						.75		
	Begin Passive Thermal Control		3							
	IMU Alignment	4						.5	1.5	
	Midcourse Correction					6		.12		
	Orient Heat Shield Cooldown	1								
	Cool Down								1.5	
Transearth	SM Separation	1								

D. 3 ATTITUDE TIMELINE

D.3.1 CSM

The attitude timeline is a tabulated history of vehicle attitude. The basic format of the timeline contains: (1) mission and phase time, (2) inertial and local attitude, (3) supplemental line-of-sight directions of interest, and (4) remarks. The exact format of the supplemental data changes with mission phase because the requirements are not constant For example, LM line-of-sight is needed only when separated and near-earth line-of-sight is required only in earth orbit. The first column of the timeline, which is the same for all mission phases, lists mission time. Mission time is given in hours, minutes, seconds, and is measured from lift-off.

The second column, which is the same for all mission phases, lists phase time. Phase time begins at zero for each phase. The third column presents the vehicle position. For all phases except the translunar and transearth coast phases, the position is given in longitude of the planet being orbited. For the translunar and transearth phases the position column was omitted.

The fourth column describes vehicle attitude in inertial space. A number of different inertial references are used in the timeline, which are described in detail in Appendix C. The first inertial reference, origin at the launch site, is used from lift-off to TLI. The inertial reference for the translunar and transearth phases through entry is the mean equinox and equatorial plane. For the translunar injection firing, it was assumed that the thrust was along the vehicle X axis. For the other two firings, the gimbal off-set angles resulting from calculated center-of-gravity movement were accounted for in the determination of vehicle attitude. In lunar orbit the inertial reference origin is the LM landing site.

The fifth column presents vehicle attitude in a local coordinate system. Two different local coordinate systems are used throughout the mission: one within the earth region of influence and a second within the lunar sphere of influence. Within each sphere of influence, the local vertical and local horizontal in the orbital plane are used as the reference. Refer to Appendix C for further detail.

The next three or four columns (depending on mission phase) present key line-of-sight direction to points of special interest. The directions are measured in degrees in an azimuth-elevation coordinate system, which is described in detail in Appendix C. The

earth orbit, line-of-sight directions are given to two tracking stations. During both translunar and transearth coast, line of sight direction to the moon is provided. Line of sight directions to LM landing site and from one vehicle (CMS or LM) to the other are provided while the spacecraft is in lunar orbit. Line-of-sight directions to one tracking station and to the landing site are tabulated during entry to splashdown. The final column is the remarks column, which contains a brief statement of the event, operation, or function taking place.

Figures containing continuous plots of vehicle attitude are provided in Vol I for translunar injection, lunar orbit insertion, and transearth injection in the appropriate phase discription of Vol I. The vehicle attitude is presented in the same local coordinate system as used in the attitude timeline. For the translunar injection firing, it was assumed that the thrust was along the vehicle X axis. For the other two firings the gimbal off-set angles resulting from calculated center-of-gravity movement were accounted for in the determination of vehicle attitude. In lunar orbit the inertial reference origin is the LM landing site.

D.3.1 LM

Figure D.2.10-3 presents the LM pitch attitude profile during descent. Also included in the figure are:

- The attitude-time locus required for the LM Z-body axes to point at the CSM (i.e. Line-of-sight to CSM). This attitude corresponds to zero shaft and trunnion angles.
- The approximate boundary required to switch from rendezvous radar tracking Mode I to tracking Mode II or vice versa.
- Illumination and S-band steerable constraint.
- Operation times of equipment requiring orientation (rendezvous and landing radar, tracking light, and IMU alignment).

Table D-1 tabulates the resulting inertial and local attitudes, as well as body azimuth and elevation angles to earth, sun, CSM and landing site. (See pages D-125/126).

Figure D.2.12-1 presents the LM pitch attitude profile during ascent.

Also included on the figure are:

- The attitude-time locus required for the LM Z-body axes to point at the CSM (i.e., Line-of-sight to CSM). This attitude corresponds to zero shaft and trunnion angles.
- The approximate boundary required to switch from rendezvous radar tracking Mode I to tracking Mode II or vice versa.
- Illumination and S-band steerable constraint.
- Operation times of equipment requiring orientation (rendezvous radar, tracking light, and IMU alignment).

Table D-1 tabulates the resulting inertial and local attitudes, as well as body azimuth and elevation angles to earth, sun, and CSM. (See pages D-127/128.)

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Table D-1 Spacecraft Attitude Time History

Phase 2

Earth Ascent

MISSION TIME			PHASE TIME	VEHICLE POSITION		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		STATION ONE DIRECTION		STATION TWO DIRECTION		REMARKS	
HR	MIN	SEC	MIN	LONG	LAT	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV	AZI	ELV		
0	0	0	0	279	28	-0	360	180	90	360	180	180	-0	357	85	270	17	0	-0	PHASE 2.0 EARTH ASCENT	CNV
0	0	0	0	279	28	-0	360	180	90	360	180	180	-0	357	85	270	17	0	-0	LIFTOFF	CNV
0	0	12	0	279	28	0	360	180	90	360	180	180	-0	357	85	270	18	0	-0	BEGIN PROGRAMMED PITCH	CNV
0	0	52	1	279	28	346	360	180	76	0	180	180	14	359	71	262	18	0	-0	PITCH PROGRAM CONTINUED	CNV
0	1	40	2	279	28	313	360	180	43	0	180	180	47	360	37	225	23	0	-0	PITCH PROGRAM CONTINUED	CNV
0	2	35	3	280	28	292	360	180	24	0	180	180	66	360	17	192	16	0	-0	S-IC INBOARD ENGINE CUTOFF	CNV
0	2	39	3	280	28	291	360	180	23	0	180	180	67	360	16	190	15	0	-0	S-IC OUTBOARD ENGINE CUTOFF	CNV
0	2	39	3	280	28	291	360	180	23	0	180	180	67	360	16	190	15	0	-0	S-IC JETTISON ROCKETS IGNITION	CNV
0	2	40	3	280	28	291	360	180	23	0	180	180	67	360	16	190	15	0	-0	S-II ULLAGE ENGINE IGNITION	CNV
0	2	42	3	280	28	291	360	180	22	0	180	180	68	360	15	190	15	0	-0	S-II IGNITION	CNV
0	2	45	3	280	28	301	360	180	33	0	180	180	57	360	26	189	3	0	-0	S-II MIXTURE RATIO CHANGE	CNV
0	3	9	3	281	28	299	360	180	31	0	180	180	59	360	24	185	-0	0	-0	S-IC/S-II FWD INTERSTAGE JETTISON	CNV
0	3	14	3	281	28	299	360	180	31	0	180	180	59	360	24	185	-1	0	-0	LAUNCH ESCAPE TOWER JETTISON	CNV
0	4	10	4	282	28	294	360	180	28	0	180	180	62	360	19	182	-4	0	-0	OPTIMUM STEERING PROGRAM	CNV
0	5	46	6	286	28	285	360	180	22	0	180	180	68	360	10	178	-4	0	-0	OPTIMUM STEERING PROGRAM	CNV
0	7	23	7	290	28	274	360	180	15	0	180	180	75	360	-1	175	-1	46	28	S-II MIXTURE RATIO CHANGE	CNV BDA
0	8	56	9	295	27	264	360	180	9	0	180	180	81	360	-12	89	22	0	-0	S-II ENGINE CUTOFF	BDA
0	8	56	9	295	27	264	360	180	9	0	180	180	81	360	-12	89	22	0	-0	S-IVB ULLAGE ENGINE IGNITON	BDA
0	8	56	9	295	27	264	360	180	9	0	180	180	81	360	-12	89	22	0	-0	S-II/S-IVB SEPARATION	BDA
0	8	56	9	295	27	264	360	180	9	0	180	180	81	360	-12	89	22	0	-0	S-IVB ENGINE IGNITION	BDA
0	8	56	9	295	27	264	360	180	9	0	180	180	81	360	-12	89	22	0	-0	START OPTIMUM TILT PROGRAM	BDA
0	11	23	11	305	26	245	360	180	0	360	180	182	90	360	-30	5	16	0	-0	S-IVB ENGINE CUTOFF	ASH

☐ Indicates Line of Sight Occluded By Earth or Moon

Table D-1 (Continued)

Phases 3 & 4

Earth Parking & Translunar Injection

MISSION TIME			PHASE TIME	VEHICLE POSITION		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		STATION ONE DIRECTION		STATION TWO DIRECTION		REMARKS	
HR	MIN	SEC	MIN	LONG	LAT	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV	AZI	ELV		
0	11	23	0	305	26	245	0	180	0	0	180	0	90	0	-30	17	16	-0	-0	PHASE 3.0 EARTH PARKING ORBIT	ASH,
0	11	23	0	305	26	245	0	180	0	0	180	0	90	0	-30	17	16	-0	-0	START EARTH ORBIT COAST	ASH,
0	17	44	6	330	17	219	0	180	0	0	180	0	90	0	-56	-0	-0	-0	-0	ORIENT FOR FINE IMU ALIGNMENT	,
0	20	10	9	338	13	209	0	160	0	0	160	90	70	322	-59	-0	-0	-0	-0	ORIENTATION CONTINUED	,
0	21	59	11	345	10	202	0	145	0	0	145	90	55	297	-52	-0	-0	-0	-0	ORIENTATION CONTINUED	,
0	23	48	12	351	7	194	0	130	0	0	130	90	40	282	-39	-0	-0	-0	-0	ORIENTATION CONTINUED	,
0	26	14	15	359	2	184	0	110	0	0	110	90	20	269	-20	-0	-0	-0	-0	ALIGNMENT ATTITUDE REACHED	,
0	29	15	18	9	-4	172	0	110	0	0	110	90	20	256	-19	-0	-0	-0	-0	BEGIN IMU FINE ALIGNMENT	,
0	40	33	29	50	-23	126	0	110	0	0	110	90	20	209	-10	21	25	-0	-0	END IMU FINE ALIGNMENT	ISH,
0	42	03	31	58	-25	117	0	110	0	0	110	90	20	201	-7	163	18	-0	-0	ORIENT TO NOMINAL ATTITUDE	ISH,
0	45	1	34	68	-27	108	0	130	0	0	130	90	40	190	-8	-0	-0	-0	-0	ORIENTATION CONTINUED	,
0	46	41	35	76	-28	101	0	145	0	0	145	90	55	183	-5	-0	-0	-0	-0	ORIENTATION CONTINUED	,
0	48	39	37	84	-28	93	0	160	0	0	160	90	70	179	2	-0	-0	-0	-0	ORIENTATION CONTINUED	,
0	51	5	40	95	-28	83	0	180	0	0	180	0	90	180	12	-0	-0	-0	-0	NOMINAL ATTITUDE REACHED	,
0	51	22	40	96	-28	82	0	180	0	-0	180	0	90	180	14	-0	-0	-0	-0	LEAVE SUNLIGHT	,
1	0	23	49	133	-20	45	0	180	0	-0	180	0	90	180	50	-0	-0	-0	-0	BEGIN IMU FINE ALIGNMENT	,
1	11	41	60	173	1	359	0	180	0	-0	180	0	90	359	84	-0	-0	-0	-0	END IMU FINE ALIGNMENT	,
1	28	10	77	233	26	291	0	160	0	-0	180	0	90	0	16	47	15	-0	-0	ORIENT FOR TLI	CAL,
1	28	48	77	236	27	270	0	180	341	0	180	0	71	0	-5	57	6	-0	-0	ENTER SUNLIGHT	CAL,
1	29	8	78	238	27	259	0	180	332	0	180	0	62	0	-16	64	5	-0	-0	TLI ATTITUDE REACHED	CAL,
1	35	8	84	264	28	259	0	180	356	0	180	0	86	0	-16	223	57	20	12	SIV-B IGNITION	TEX,EGL
1	35	8	0	264	28	259	0	180	356	0	180	0	86	0	-16	223	57	20	12	PHASE 4.0 TRANSLUNAR INJECTION	TEX,EGL
1	35	8	0	264	28	259	0	180	356	0	180	0	86	0	-16	223	57	20	12	SIV-B IGNITION	TEX,EGL
1	40	50	6	292	23	240	0	180	4	0	180	180	86	0	-35	332	25	91	20	SIV-B ENGINE SHUTDOWN	ANT,BDA

☐ Indicates Line of Sight Occluded By Earth or Moon

Table D-1 (Continued)

Phases 5 & 6

Initial Translunar Coast Through S-IVB Jettison & S-IVB Jettison to LOI

MISSION TIME			PHASE TIME	VEHICLE ALTITUDE		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		MOON DIRECTION		REMARKS	
HR	MIN	SEC	MIN	EARTH	MOON	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV		
1	40	50	0	0.2	203.5	153	14	155	4	0	180	180	86	0	-35	0	35	PHASE 5.0 TRANSLUNAR COAST / SIV+B JETTISON	
1	40	50	0	0.2	203.5	153	14	155	4	0	180	180	86	0	-35	0	35	BEGIN TRANSLUNAR COAST	
1	43	16	2	0.3	202.8	153	14	155	17	0	180	350	46	0	-35	0	36	BEGIN PITCH MANEUVER	ASCENSION
1	44	46	4	0.4	202.4	174	4	152	47	0	180	331	75	0	-13	359	58	PITCH MANEUVER CONTINUED	ASCENSION
1	46	16	5	0.6	201.9	194	353	152	76	0	180	204	70	0	10	358	81	PITCH MANEUVER CONTINUED	ASCENSION
1	47	56	7	0.8	201.4	217	342	157	109	0	180	191	34	0	35	181	74	END PITCH MANEUVER	ASCENSION
1	49	1	8	0.9	201.1	217	342	157	113	0	180	190	25	0	35	181	74	END INERTIAL ATTITUDE HOLD BEGIN ROLL MANUEVER	ASCENSION
1	50	1	9	1.1	200.8	217	342	217	116	0	240	199	-0	329	17	252	28	ROLL MANEUVER CONTINUED	ASCENSION
1	51	1	10	1.2	200.5	217	342	277	120	0	300	181	-11	329	-16	252	-29	ROLL MANEUVER CONTINUED	ASCENSION
1	51	46	11	1.3	200.3	217	342	322	122	0	345	171	-1	350	-33	222	-68	END ROLL MANUEVER	ASCENSION
1	57	5	16	2.2	198.8	217	342	322	137	0	345	222	56	350	-33	221	-68	CSM SEPARATION AND PULLOUT	MADRID
1	57	43	17	2.3	198.6	217	342	322	138	0	345	222	58	350	-33	221	-68	END INERTIAL ATTITUDE HOLD BEGIN ROLL MANUEVER	MADRID
1	57	49	17	2.3	198.6	217	342	352	138	0	15	241	34	10	-33	138	-68	ROLL MANEUVER CONTINUED	MADRID
1	57	55	17	2.3	198.5	217	342	22	138	0	45	246	7	26	-24	112	-43	END ROLL MANUEVER	MADRID
1	58	34	18	2.5	198.3	217	342	22	140	0	45	247	8	26	-24	112	-43	INERTIAL HOLD - END PULLOUT	MADRID
1	58	42	18	2.5	198.3	217	342	22	140	0	45	248	9	26	-24	112	-43	BEGIN TURNAROUND - PITCH	MADRID
1	58	54	18	2.5	198.3	271	9	27	191	38	27	267	24	81	-66	137	-6	PITCH MANEUVER CONTINUED	MADRID
1	59	6	18	2.5	198.2	332	28	5	270	38	333	290	13	152	-31	123	35	PITCH MANEUVER CONTINUED	MADRID
1	59	18	18	2.6	198.1	37	18	338	321	0	315	291	-10	154	24	68	43	END PITCH MANEUVER	MADRID
2	3	8	22	3.2	197.1	37	18	338	328	0	315	286	-16	154	24	68	42	INITIAL DOCKING	MADRID
2	5	48	25	3.7	196.5	37	18	338	332	0	315	283	-19	154	24	68	42	FINAL DOCKING	MADRID
2	41	40	0	9.7	189.1	37	18	338	0	0	315	271	-45	154	24	68	42	PHASE 6.0 SIV-B JETTISON / L.O.I.	
2	41	40	0	9.7	189.1	37	18	338	0	0	315	271	-45	154	24	68	42	CSM - LEM PULLOUT	
3	1	33	20	12.6	185.8	37	18	338	6	0	315	261	-45	154	24	68	43	BEGIN ORIENTATION FOR NAV. SIGHTINGS	
3	7	33	26	13.5	184.9	31	338	343	344	326	313	291	-50	196	32	100	47	ORIENTATION CONTINUED	
3	13	33	32	14.3	184.0	18	298	340	296	303	282	330	-56	240	31	140	53	ORIENTATION CONTINUED	
3	17	33	36	14.8	183.4	303	278	270	248	306	245	1	-57	268	28	171	55	END ORIENTATION FOR NAV. SIGHTINGS	
3	20	6	38	15.2	183.0	303	278	270	249	306	245	0	-57	268	28	171	55	BEGIN FIRST NAV. SIGHTING	
3	24	5	42	15.7	182.5	302	278	270	249	306	245	0	-57	268	27	173	55	BEGIN SECOND NAV. SIGHTING	
3	28	5	46	16.3	181.9	301	278	270	250	305	246	0	-57	269	26	174	56	BEGIN THIRD NAV. SIGHTING	
3	32	4	50	16.8	181.4	300	278	270	250	305	246	0	-57	269	25	175	56	BEGIN FOURTH NAV. SIGHTING	
3	36	4	54	17.3	180.8	299	277	270	251	305	247	0	-57	269	25	176	56	BEGIN FIFTH NAV. SIGHTING	
3	40	4	58	17.8	180.3	299	277	270	251	305	247	359	-57	269	25	176	56	END NAV. SIGHTING PERIOD	
4	1	54	80	20.5	177.6	299	277	270	255	305	247	353	-56	269	25	177	56	BEGIN ORIENTATION FOR IMU FINE ALIGNMENT	
4	6	54	85	21.1	177.0	31	296	107	307	297	40	69	-0	206	-66	248	-2	ORIENTATION CONTINUED	
4	11	54	90	21.7	176.4	40	323	222	353	309	186	291	78	129	-4	116	-75	ORIENTATION CONTINUED	
4	16	54	95	22.3	175.8	44	350	331	15	331	308	255	-29	169	40	78	31	ORIENTATION CONTINUED	
4	17	54	96	22.4	175.7	45	355	353	18	336	330	243	-50	182	41	68	52	END ORIENTATION FOR IMU FINE ALIGNMENT	
4	17	58	96	22.4	175.7	45	355	353	18	336	330	243	-50	182	41	68	52	BEGIN FINE ALIGNMENT	
4	28	54	107	23.7	174.5	45	355	353	20	336	330	242	-49	182	41	68	52	END FINE ALIGNMENT	
4	29	4	107	23.7	174.4	45	355	353	20	336	330	242	-49	182	41	68	52	BEGIN ORIENTATION FOR MCC NO 1.	
4	30	4	108	23.8	174.3	47	357	353	23	337	332	238	-48	180	42	64	52	END ORIENTATION	
4	43	56	122	25.4	172.8	47	357	353	24	337	332	237	-47	180	42	64	52	FIRST MCC	
4	47	13	126	25.7	172.5	47	357	353	24	337	332	237	-47	180	42	64	52	BEGIN ORIENTATION FOR FTC	
4	52	13	131	26.3	172.0	61	8	54	42	343	39	154	-44	229	31	325	48	ORIENTATION CONTINUED	
4	57	13	136	26.8	171.4	76	18	112	59	350	105	148	-1	250	-17	320	-1	ORIENTATION CONTINUED	
5	2	13	141	27.4	170.9	93	27	167	76	358	168	175	14	255	-77	353	-22	ORIENTATION CONTINUED	
5	3	13	142	27.5	170.8	96	28	178	79	0	180	180	11	0	-90	0	-19	END ORIENTATION	
5	3	13	142	27.5	170.8	96	28	178	79	0	180	180	11	0	-90	0	-19	BEGIN ESTABLISHMENT OF FTC ATTITUDE	

☐ Indicates Line of Sight Occluded By Earth or Moon

Table D-1 (Continued)

Phases 6 & 7

S-IVB Jettison to LOI & Lunar Orbit Insertion

MISSION TIME			PHASE TIME	VEHICLE ALTITUDE		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		MOON DIRECTION		REMARKS
HR	MIN	SEC	MIN	EARTH	MOON	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV	
5	18	13	157	29.1	169.3	96	28	178	80	0	180	180	10	0	-90	0	-20	END ESTABLISHMENT OF FTC ATTITUDE
50	47	7	2885	171.4	32.8	96	28	256	105	0	258	165	-3	88	-12	30	-7	END FTC
50	55	37	2894	171.7	32.5	96	28	178	105	0	180	180	-15	5	-88	359	-31	BEGIN ORIENTATION FOR IMU FINE ALIGNMENT
51	0	37	2899	171.9	32.3	86	27	233	96	358	230	174	-3	100	-39	32	-26	ORIENTATION CONTINUED
51	5	37	2904	172.1	32.1	76	25	288	87	357	280	184	2	107	11	49	5	ORIENTATION CONTINUED
51	10	37	2909	172.2	31.9	66	22	342	78	356	330	190	-9	137	53	42	45	ORIENTATION CONTINUED
51	11	37	2910	172.3	31.8	64	21	353	76	355	340	189	-12	151	58	35	53	END ORIENTATION FOR IMU FINE ALIGNMENT
51	11	37	2910	172.3	31.8	64	21	353	76	355	340	189	-12	151	58	35	53	BEGIN FINE ALIGNMENT
51	22	28	2921	172.6	31.4	64	21	353	76	355	340	189	-12	151	58	35	53	END FINE ALIGNMENT
51	22	28	2921	172.6	31.4	64	21	353	76	355	340	189	-12	151	58	35	53	BEGIN ORIENTATION FOR MC NO 2.
51	23	28	2922	172.7	31.3	66	23	348	78	357	337	188	-10	143	57	36	50	END ORIENTATION
51	40	51	2939	173.3	30.6	66	23	348	78	357	337	188	-10	143	57	36	50	SECOND MC
51	44	1	2942	173.4	30.5	66	23	348	328	357	152	188	-10	143	57	36	50	BEGIN ORIENTATION FOR FTC
51	49	1	2947	173.5	30.3	74	25	48	320	357	215	179	-4	244	46	324	38	ORIENTATION CONTINUED
51	54	1	2952	173.7	30.1	83	27	108	312	356	277	184	-2	260	-14	318	-7	ORIENTATION CONTINUED
51	59	1	2957	173.9	29.9	92	28	167	304	356	340	182	-12	263	-77	350	-33	ORIENTATION CONTINUED
52	0	1	2958	173.9	29.8	94	28	178	303	356	352	180	-14	0	-90	359	-33	END ORIENTATION
52	0	1	2958	173.9	29.8	94	28	178	303	356	352	180	-14	0	-90	359	-33	BEGIN ESTABLISHMENT OF FTC ATTITUDE
52	15	1	2973	174.4	29.2	94	28	178	303	356	352	180	-14	0	-90	359	-33	END ESTABLISHMENT
60	33	13	3472	190.9	7.9	94	28	43	312	356	217	190	10	270	45	329	30	END FTC
60	37	35	3476	191.0	7.7	94	28	43	312	356	217	190	10	270	45	329	30	BEGIN ORIENTATION FOR NAV. SIGHTINGS
60	42	35	3481	191.2	7.5	95	350	64	316	34	236	214	-25	273	25	327	46	ORIENTATION CONTINUED
60	47	35	3486	191.3	7.3	97	311	85	329	72	246	241	-65	273	7	285	53	ORIENTATION CONTINUED
60	52	35	3491	191.5	7.1	124	273	132	121	68	116	354	-64	273	-11	249	29	ORIENTATION CONTINUED
60	53	35	3492	191.5	7.0	258	275	270	125	60	117	0	-57	273	-15	244	22	END ORIENTATION
60	56	10	3495	191.6	6.9	258	275	270	125	60	117	0	-57	273	-15	244	22	BEGIN FIRST NAV. SIGHTING
61	0	10	3499	191.8	6.7	258	275	270	125	60	117	0	-57	273	-15	244	21	BEGIN SECOND NAV. SIGHTING
61	4	10	3503	191.9	6.5	258	275	270	126	60	117	0	-57	273	-15	244	21	BEGIN THIRD NAV. SIGHTING
61	8	10	3507	192.0	6.3	258	275	270	126	60	117	0	-57	273	-15	245	21	BEGIN FOURTH NAV. SIGHTING
61	12	10	3511	192.2	6.2	258	275	270	126	60	117	0	-57	273	-15	245	21	BEGIN FIFTH NAV. SIGHTING
61	16	10	3515	192.3	6.0	258	275	270	216	338	195	0	-57	273	-15	245	20	END NAV. SIGHTINGS
61	34	21	3533	192.9	5.1	258	275	270	129	60	117	0	-57	273	-15	246	18	BEGIN ORIENTATION FOR IMU FINE ALIGNMENT
61	39	21	3538	193.1	4.9	133	307	257	248	73	113	85	30	58	-41	1	-75	ORIENTATION CONTINUED
61	44	21	3543	193.3	4.6	129	347	5	282	37	195	236	39	3	55	33	20	ORIENTATION CONTINUED
61	49	21	3548	193.5	4.4	126	27	116	291	357	303	215	-25	307	-38	343	-14	ORIENTATION CONTINUED
61	50	21	3549	193.5	4.3	125	35	139	293	349	325	208	-31	323	-58	355	-25	END ORIENTATION FOR IMU FINE ALIGNMENT
61	50	21	3549	193.5	4.3	125	35	139	49	356	327	208	-31	323	-58	355	-25	BEGIN FINE ALIGNMENT
62	1	17	3560	193.9	3.8	125	35	139	295	349	325	208	-31	323	-58	353	-26	END ALIGNMENT
62	1	27	3560	193.9	3.8	125	35	139	295	349	325	208	-31	323	-58	353	-26	BEGIN ORIENTATION FOR MC NO. 3.
62	2	27	3561	193.9	3.8	127	37	140	294	347	327	209	-32	329	-60	357	-27	END ORIENTATION
62	16	57	3575	194.5	3.0	127	37	140	298	347	327	209	-32	329	-60	354	-30	THIRD MC
62	35	50	3594	195.2	2.1	127	37	140	305	347	327	209	-32	329	-60	349	-36	BEGIN ORIENTATION FOR IMU FINE ALIGNMENT
62	45	10	3603	195.5	1.6	6	39	294	48	320	82	239	-10	159	-32	133	-34	ORIENTATION CONTINUED -- SUNSET
62	51	50	3610	195.8	1.3	328	348	348	113	352	152	305	-47	201	-31	184	-24	END ORIENTATION FOR IMU FINE ALIGNMENT
62	51	50	3610	195.8	1.3	328	348	348	113	352	152	305	-47	201	-31	184	-24	BEGIN FINE ALIGNMENT
63	2	46	3621	196.2	0.7	328	348	348	127	352	152	305	-47	201	-31	193	-36	END FINE ALIGNMENT
63	2	56	3621	196.2	0.7	328	348	348	128	352	152	305	-47	201	-31	193	-36	BEGIN ORIENTATION FOR LOI
63	3	56	3622	196.2	0.7	2	336	251	103	14	47	270	50	173	24	180	19	END ORIENTATION FOR LOI
63	13	17	3632	196.6	0.3	2	336	251	180	14	41	270	49	173	24	201	33	EARTHSET
63	16	39	3635	196.6	0.2	2	336	251	139	14	47	270	49	173	24	215	39	PHASE 7.0 LUNAR ORBIT INSERTION

☐ Indicates Line of Sight Occluded By Earth or Moon

Table D-1 (Continued)

Phase 8

Lunar Orbit Coast to LM Separation

MISSION TIME			PHASE TIME	VEHICLE POSITION		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		LEM DIRECTION		LANDING SITE DIRECTION		REMARKS
HR	MIN	SEC	MIN	LONG	LAT	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV	AZI	ELV	
63	23	27	0	192	3	257	15	47	158	15	47	261	53	172	16	0	0	248	45	PHASE 8.0 LUNAR ORBIT COAST / LEM SEPARATION
63	23	27	0	192	3	257	15	47	158	15	47	261	53	172	16	0	-0	248	45	SPS CUTOFF--INERTIAL ATTITUDE HOLD CONTINUED
63	25	27	2	186	3	257	15	47	164	15	47	261	53	172	16	0	0	252	45	BEGIN YAW MANEUVER AT -24/MIN--ENTER SUNLIGHT
63	26	27	3	183	3	272	0	45	182	0	45	282	53	193	16	0	0	275	45	END YAW MANEUVER AT -24 DEG /MIN.
63	33	31	13	153	2	272	0	45	212	0	45	282	53	193	16	0	0	296	41	BEGIN IMU ALIGNMENT AND LOCAL ATTITUDE HOLD
63	47	27	24	121	-0	240	0	45	212	0	45	232	48	170	-6	0	0	275	43	END IMU ALIGNMENT
63	48	27	25	118	-0	237	0	45	212	0	45	228	47	168	-8	0	0	273	43	BEGIN ROLL MANEUVER AT +12 DEG./MIN.
63	50	27	27	112	-1	231	0	69	212	0	69	232	26	160	-5	0	0	269	19	ROLL MANEUVER CONTINUED—ACQUIRE EARTH
64	0	27	37	83	-2	202	0	189	212	0	189	186	-28	194	48	0	0	143	-72	END ROLL MANEUVER AT +12 DEG./MIN.
64	4	38	41	71	-3	190	0	189	212	0	189	187	-16	201	59	0	0	152	-68	BEGIN NAVIGATION SIGHTING NO. 1
64	9	27	46	56	-3	175	0	189	212	0	189	189	-2	219	72	0	0	160	-62	BEGIN NAVIGATION SIGHTING NO. 2
64	14	27	51	42	-3	161	0	189	212	0	189	192	12	273	78	0	0	165	-57	BEGIN NAVIGATION SIGHTING NO. 3
64	19	27	56	27	-3	146	0	189	212	0	189	195	27	324	71	0	0	168	-54	LOCAL ATTITUDE HOLD CONTINUED
64	24	27	61	12	-3	131	360	189	212	0	189	200	41	340	58	0	0	167	-59	OBSERVE LEM LANDING SITE
64	29	27	66	357	-3	117	360	189	212	0	189	209	54	348	44	0	0	6	-27	BEGIN NAVIGATION SIGHTING NO. 4
64	34	27	71	343	-2	102	360	189	212	0	189	227	66	352	30	0	0	1	8	END NAV. PERIOD--BEGIN INERTIAL ATTITUDE HOLD
64	35	27	72	340	-2	102	360	189	215	0	189	227	66	352	30	0	0	1	12	BEGIN ROLL MANEUVER AT +12 DEG./MIN.
64	38	27	75	331	-1	102	360	225	224	0	225	250	34	336	19	0	0	348	16	ROLL MANEUVER CONTINUED
64	41	27	78	322	-1	102	360	261	232	0	261	254	-0	329	2	0	0	334	7	ROLL MANEUVER CONTINUED--LEAVE SUNLIGHT
64	44	27	81	313	-0	102	360	297	241	0	297	250	-35	333	-16	0	0	330	-11	END ROLL MANEUVER AT +12 DEG./MIN.
65	7	27	104	246	3	102	360	297	309	0	297	251	-35	333	-16	0	0	292	-24	INERTIAL ATTITUDE HOLD CONTINUED--LOSE EARTH
65	27	27	124	187	3	102	360	297	7	0	297	251	-35	333	-16	0	0	258	-27	INERTIAL ATTITUDE HOLD CONT.—ENTER SUNLIGHT
65	53	27	150	110	-1	102	360	297	83	0	297	251	-35	333	-16	0	0	217	-15	INERTIAL ATTITUDE HOLD CONT.—ACQUIRE EARTH
66	36	27	193	344	-2	102	360	297	210	0	297	251	-35	333	-16	0	0	354	-0	BEGIN LOCAL ATTITUDE HOLD
66	43	27	200	323	-1	81	360	297	210	0	297	277	-36	352	-7	0	0	355	1	LOCAL ATTITUDE HOLD CONTINUED--LEAVE SUNLIGHT
67	10	27	227	244	3	2	360	297	210	0	297	360	-10	67	23	0	0	27	14	LOCAL ATTITUDE HOLD CONTINUED —LOSE EARTH
67	30	27	247	185	3	304	0	297	210	0	297	53	13	130	19	0	0	55	23	LOCAL ATTITUDE HOLD CONTINUED —ENTER SUNLIGHT
67	46	27	263	138	1	257	0	297	210	0	297	101	18	174	0	0	0	79	28	BEGIN IMU ALIGNMENT
67	52	27	269	120	-0	239	0	297	210	0	297	119	15	190	-8	0	0	89	29	END IMU ALIGNMENT
67	55	27	272	111	-1	230	0	297	210	0	297	127	13	198	-12	0	0	94	29	ACQUIRE EARTH
67	57	30	274	106	-1	224	0	297	210	0	297	133	11	203	-14	0	0	97	29	BEGIN ROLL MANEUVER AT -12 DEG./MIN.
68	1	27	278	94	-2	213	0	249	210	0	249	149	-21	218	10	0	0	102	-19	ROLL MANEUVER CONTINUED
68	6	27	283	79	-2	198	0	189	210	0	189	186	-22	196	52	0	0	150	-69	END ROLL MANEUVER AT -12 DEG./MIN.
68	9	27	286	70	-3	189	0	189	210	0	189	187	-13	201	60	0	0	155	-66	BEGIN NAVIGATION SIGHTING NO. 5
68	14	27	295	56	-3	175	0	189	210	0	189	189	1	221	73	0	0	162	-60	BEGIN INERTIAL ATTITUDE HOLD--LEM COARSE IMU
68	18	27	295	44	-3	175	0	189	221	0	189	189	1	221	73	0	0	157	-67	BEGIN LOCAL ATTITUDE HOLD--END LEM COARSE IMU
68	19	27	296	41	-3	172	0	189	221	0	189	190	4	228	75	0	0	158	-66	BEGIN NAVIGATION SIGHTING NO. 6
68	29	27	306	11	-3	142	360	189	221	0	189	197	33	330	68	0	0	160	-69	OBSERVE LEM LANDING SITE
68	34	27	311	357	-3	128	360	189	221	0	189	204	46	343	54	0	0	3	-12	BEGIN NAVIGATION SIGHTING NO. 7
68	38	38	315	345	-2	116	360	189	221	0	189	212	57	348	43	0	0	360	17	END NAVIGATION SIGHTING PERIOD
68	40	27	317	339	-2	110	360	189	221	0	189	219	62	350	37	0	0	360	18	BEGIN INERTIAL ATTITUDE HOLD
68	43	27	322	324	-1	110	360	239	236	0	239	247	20	325	16	0	0	334	18	LEAVE SUNLIGHT
69	2	56	330	273	2	84	360	346	261	0	345	310	-83	359	-12	0	0	348	-33	BEGIN INERTIAL ATTITUDE HOLD
69	5	32	342	264	2	84	360	346	270	0	345	311	-83	359	-12	0	0	346	-37	CSM-LEM SEPARATION

☐ Indicates Line of Sight Occluded By Earth or Moon

Table D-1 (Continued)

Phase 9

CSM Solo Lunar Orbit Operations

MISSION TIME			PHASE TIME	VEHICLE POSITION		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		LEM DIRECTION		LANDING SITE DIRECTION		REMARKS
HR	MIN	SEC	MIN	LONG	LAT	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV	AZI	ELV	
69	5	32	-0	264	2	84	360	346	270	0	345	311	-83	359	-12	1	-1	346	-37	PHASE 9.0 CSM SOLO ORBIT
69	5	32	-0	264	2	84	360	346	270	0	345	311	-83	359	-12	1	-1	346	-37	CSM-LEM SEPARATION--BEGIN PITCH AT +11/MIN
69	6	56	1	261	2	94	357	346	283	357	346	221	-82	359	-23	0	-10	343	-50	BEGIN CSM TRACKING OF LEM WITH SXT, TRANSPONDER
69	7	56	2	258	2	105	355	347	297	355	346	198	-72	359	-34	0	-21	336	-61	PITCH MANEUVER CONTINUED
69	8	56	3	255	3	116	352	348	311	352	348	191	-61	359	-45	0	-32	320	-72	PITCH MANEUVER CONTINUED
69	9	56	4	252	3	127	350	349	325	350	349	189	-50	359	-56	0	-43	277	-78	PITCH MANEUVER CONTINUED
69	11	56	6	246	3	149	347	354	353	347	354	186	-29	357	-78	0	-65	208	-64	END PITCH MANEUVER AT +11 DEG./MIN.
69	11	56	6	246	3	149	347	354	353	347	354	186	-29	357	-78	0	-65	208	-64	LOSE EARTH
69	12	56	7	243	3	149	347	354	356	347	354	186	-29	357	-78	0	-65	206	-62	BEGIN LOCAL ATTITUDE HOLD
69	13	56	8	241	3	146	347	354	356	347	354	186	-31	0	-76	2	-63	207	-64	BEGIN ROLL MANEUVER AT -15 DEG./MIN.
69	14	56	9	238	3	143	347	339	356	347	339	196	-31	322	-68	338	-58	228	-55	END ROLL MANEUVER AT -15 DEG./MIN.
69	16	56	11	232	3	137	347	339	356	347	339	198	-37	333	-64	343	-54	231	-58	BEGIN YAW MANEUVER AT -18 DEG./MIN.
69	17	56	12	229	3	127	330	336	348	330	336	218	-40	356	-62	4	-52	251	-59	YAW MANEUVER CONTINUED
69	19	56	14	223	3	91	299	314	318	299	314	257	-45	39	-57	44	-48	292	-61	YAW MANEUVER CONTINUED
69	21	56	16	217	3	359	295	234	232	295	234	296	-51	81	-52	84	-45	332	-63	LEM PASSES OUTSIDE CSM SEXTANT COVERAGE
69	23	56	18	211	3	317	325	205	196	325	205	337	-56	122	-47	123	-42	14	-65	YAW MANEUVER CONTINUED
69	25	56	20	205	3	296	359	200	181	359	200	18	-61	163	-42	161	-39	56	-66	END YAW MANEUVER AT -18 DEG./MIN.
69	26	56	21	202	3	293	359	200	181	359	200	21	-64	164	-39	162	-37	59	-67	LOCAL ATTITUDE HOLD CONTINUED
69	27	56	22	199	3	291	359	200	181	359	200	24	-66	166	-37	163	-36	62	-68	LOCAL ATTITUDE HOLD CONTINUED
69	28	31	23	198	3	289	359	200	181	359	200	26	-68	167	-35	164	-35	64	-68	LEM TRANSFER ORBIT INSERTION
69	28	51	23	197	3	288	359	200	181	359	200	28	-68	167	-34	154	-48	66	-68	LOCAL ATTITUDE HOLD CONTINUED
69	28	56	23	196	3	288	359	200	181	359	200	28	-69	167	-34	145	-56	66	-68	LOCAL ATTITUDE HOLD CONTINUED
69	29	1	23	196	3	287	359	200	181	359	200	29	-69	167	-34	96	-69	66	-68	LEM PASSES WITHIN CSM SEXTANT COVERAGE
69	29	3	23	196	3	287	359	200	181	359	200	29	-69	168	-34	45	-63	66	-68	END TRANSFER ORBIT INSERTION
69	30	3	24	193	3	284	359	200	181	359	200	34	-71	169	-31	1	-7	70	-69	LOCAL ATTITUDE HOLD CONTINUED
69	31	3	25	190	3	281	359	200	181	359	200	40	-73	170	-28	1	-7	74	-69	LOCAL ATTITUDE HOLD CONTINUED
69	33	3	27	184	3	276	359	200	181	359	200	58	-77	173	-23	3	-12	81	-69	LOCAL ATTITUDE HOLD CONTINUED--ENTER SUNLIGHT
69	37	3	31	172	3	264	359	200	181	359	200	112	-78	177	-12	8	-23	97	-69	LOCAL ATTITUDE HOLD CONTINUED
69	42	3	36	158	2	249	359	200	181	359	200	150	-68	182	2	16	-39	115	-67	LOCAL ATTITUDE HOLD CONTINUED
69	47	3	41	143	1	235	359	200	181	359	200	165	-55	187	15	32	-56	129	-63	LOCAL ATTITUDE HOLD CONTINUED
69	57	3	51	114	-1	205	359	201	181	359	200	178	-28	202	42	118	-67	146	-52	ACQUIRE EARTH
70	0	3	54	105	-1	196	359	201	181	359	200	181	-20	209	49	135	-61	150	-49	BEGIN INERTIAL ATTITUDE HOLD
70	5	3	59	90	-2	196	359	201	196	359	200	181	-19	209	49	132	-63	142	-55	INERTIAL ATTITUDE HOLD CONTINUED
70	10	3	64	76	-3	196	359	201	210	359	200	181	-19	209	49	122	-66	131	-61	BEGIN LOCAL ATTITUDE HOLD
70	12	3	66	70	-3	191	359	201	210	359	200	183	-14	215	54	128	-64	136	-59	LOCAL ATTITUDE HOLD CONTINUED
70	17	3	71	55	-3	176	359	201	210	359	200	188	-0	237	63	138	-60	144	-55	LEM PASSES OUTSIDE CSM SEXTANT COVERAGE
70	22	3	76	40	-3	161	359	201	210	359	200	194	13	271	67	145	-56	150	-51	LOCAL ATTITUDE HOLD CONTINUED
70	27	17	81	25	-3	147	359	201	210	359	200	201	26	304	62	149	-53	154	-49	LEM BRAKING
70	29	17	83	19	-3	140	359	201	210	359	200	204	32	314	58	149	-53	155	-49	LOCAL ATTITUDE HOLD CONTINUED
70	31	17	85	13	-3	134	359	201	210	359	200	208	37	322	54	147	-55	152	-52	LOCAL ATTITUDE HOLD CONTINUED
70	33	17	87	7	-3	128	359	201	210	359	200	213	42	328	50	133	-63	139	-62	LEM PASSES WITHIN CSM SEXTANT COVERAGE
70	34	17	88	4	-3	125	359	201	210	359	200	215	44	330	47	101	-70	109	-70	LOCAL ATTITUDE HOLD CONTINUED
70	35	17	89	1	-3	122	359	201	210	359	200	218	46	333	45	39	-61	40	-62	LOCAL ATTITUDE HOLD CONTINUED
70	36	17	90	358	-3	119	359	201	210	359	200	221	48	335	42	12	-34	14	-34	LOCAL ATTITUDE HOLD CONTINUED
70	37	17	91	355	-3	116	359	201	210	359	200	224	50	337	40	4	-14	5	-14	LOCAL ATTITUDE HOLD CONTINUED
70	37	46	92	354	-3	115	359	201	210	359	200	226	51	338	39	2	-9	3	-8	LEM TOUCHDOWN--BEGIN INERTIAL ATTITUDE HOLD
70	38	46	93	351	-3	115	359	201	213	359	200	226	51	338	39	358	1	360	2	END CSM TRACKING OF LEM WITH SXT, TRANSPONDER
70	43	46	98	336	-2	115	359	201	228	359	200	226	51	338	39	349	23	352	24	LEM OCCLUDED BY LUNAR SURFACE

☐ Indicates Line of Sight Occluded By Earth or Moon

Table D-1 (Continued)

Phase 9 (Continued)

CSM Solo Lunar Orbit Operations

MISSION TIME			PHASE TIME	VEHICLE POSITION		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		LEM DIRECTION		LANDING SITE DIRECTION		REMARKS
HR	MIN	SEC	MIN	LONG	LAT	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV	AZI	ELV	
70	43	46	98	336	-2	115	359	201	228	359	201	226	51	338	39	352	24	352	24	INERTIAL ATTITUDE HOLD CONTINUED
70	49	46	104	319	-1	115	359	201	246	359	201	226	51	338	39	347	37	347	37	LEAVE SUNLIGHT
71	14	46	129	245	3	115	359	201	319	359	201	227	51	338	39	297	68	297	68	LOSE EARTH
71	35	46	150	183	3	115	359	201	21	359	201	226	51	338	39	220	60	220	60	ENTER SUNLIGHT
71	46	46	161	151	2	115	359	201	53	359	201	226	51	338	39	202	47	202	47	BEGIN ROLL MANEUVER AT +12 DEG./ MIN.
71	51	46	166	136	1	115	359	261	68	359	261	244	-0	316	3	223	8	223	8	ROLL MANEUVER CONTINUED
71	56	46	171	122	-0	115	359	321	82	359	321	226	-52	331	-35	206	-25	206	-25	END ROLL MANEUVER AT +12 DEG./ MIN.
72	0	46	175	110	-1	115	359	321	94	359	321	226	-52	331	-35	202	-21	202	-21	INERTIAL ATTITUDE HOLD CONT.--ACQUIRE EARTH
72	1	46	178	107	-1	115	359	321	97	359	321	226	-52	331	-35	201	-19	201	-19	BEGIN IMU ALIGNMENT
72	18	46	193	57	-3	115	359	321	147	359	321	226	-52	331	-35	182	1	182	1	END IMU ALIGNMENT
72	24	46	199	39	-3	115	359	321	164	359	321	226	-52	331	-35	174	9	174	9	BEGIN ROLL MANEUVER AT -12 DEG./ MIN.
72	29	46	204	24	-3	115	359	261	179	359	261	245	-0	316	3	158	-3	158	-3	ROLL MANEUVER CONTINUED
72	34	46	209	10	-3	115	359	201	194	359	201	227	52	338	39	162	-42	162	-42	END ROLL MANEUVER AT -12 DEG./ MIN.
72	39	46	214	355	-3	115	359	201	208	359	201	227	52	338	39	6	-15	6	-15	BEGIN LOCAL ATTITUDE HOLD
72	39	46	214	355	-3	115	359	201	208	359	201	227	52	338	39	6	-0	6	-15	BEGIN NAVIGATION SIGHTING NO. 8
72	44	46	219	340	-2	101	359	201	208	359	201	250	59	346	26	359	5	359	5	END NAVIGATION SIGHTING
72	45	46	220	337	-2	98	359	201	208	359	201	255	60	347	23	360	6	360	6	BEGIN ROLL MANEUVER AT +12 DEG./ MIN.
72	50	46	225	323	-1	83	359	261	208	359	261	277	0	348	-1	358	2	358	2	ROLL MANEUVER CONTINUED
72	52	46	227	317	-1	77	359	285	208	359	285	284	-23	356	-5	359	2	359	2	ROLL MANEUVER CONTINUED--LEAVE SUNLIGHT
72	55	46	230	308	-0	68	359	321	208	359	321	309	-54	5	0	0	3	0	3	END ROLL MANEUVER AT +12 DEG./ MIN.
72	59	46	234	296	0	57	359	321	208	359	321	325	-47	12	9	3	7	3	7	BEGIN INERTIAL ATTITUDE HOLD
73	16	46	251	246	3	57	359	321	258	359	321	325	-47	12	9	347	-15	347	-15	INERTIAL ATTITUDE HOLD CONT.--LOSE EARTH
73	27	46	262	214	3	57	359	321	291	359	321	325	-47	12	9	335	-28	335	-28	BEGIN SOLO ASTRONAUT SLEEP PERIOD
77	43	46	518	181	3	57	359	321	321	359	321	327	-46	12	10	324	-40	324	-40	ENTER SUNLIGHT
78	7	46	542	110	-1	57	359	321	32	359	321	327	-46	12	10	356	-6	356	-6	ACQUIRE EARTH
78	30	46	565	42	-3	57	359	321	99	359	321	328	-46	12	10	30	-28	30	-28	END SOLO ASTRONAUT SLEEP PERIOD
79	0	46	595	314	-1	57	359	321	187	359	321	328	-45	12	10	27	-26	27	-26	LEAVE SUNLIGHT
79	23	46	618	247	3	57	359	321	255	359	321	329	-45	12	10	29	-28	29	-28	LOSE EARTH
79	25	46	620	241	3	57	359	321	260	359	321	329	-45	12	10	29	-28	29	-28	BEGIN ROLL MANEUVER AT -12 DEG./ MIN.
79	30	46	625	226	3	57	359	259	275	359	259	307	-1	14	-6	345	-38	345	-38	ROLL MANEUVER CONTINUED
79	36	46	631	208	3	57	359	186	293	359	186	338	49	358	-16	320	0	320	0	END ROLL MANEUVER AT -12 DEG./ MIN.
79	42	46	637	191	3	57	359	186	310	359	186	338	49	358	-16	321	0	321	0	BEGIN IMU ALIGNMENT
79	46	46	641	179	3	57	359	186	322	359	186	338	49	358	-16	321	-0	321	-0	ENTER SUNLIGHT
79	58	46	653	144	1	57	359	186	357	359	186	338	50	358	-16	323	1	323	1	END IMU ALIGNMENT
80	1	46	656	135	1	57	359	186	6	359	186	338	50	358	-16	323	1	323	1	BEGIN PITCH MANEUVER AT -12 DEG./ MIN.
80	6	46	661	120	0	116	4	184	80	4	184	214	65	357	44	302	45	302	45	PITCH MANEUVER CONTINUED
80	9	46	664	111	-0	153	6	180	125	6	180	196	31	349	80	260	52	260	52	PITCH MANEUVER CONTINUED--ACQUIRE EARTH
80	13	46	668	99	-1	201	4	176	185	4	176	194	-15	183	52	223	26	223	26	END PITCH MANEUVER AT -12 DEG./ MIN.
80	17	46	672	88	-2	201	4	176	197	4	176	194	-15	183	52	233	33	233	33	INERTIAL ATTITUDE HOLD CONTINUED
80	21	46	676	76	-2	201	4	176	209	4	176	194	-15	183	52	238	21	238	21	BEGIN LOCAL ATTITUDE HOLD
80	23	46	678	70	-3	195	4	176	209	4	176	194	-9	182	57	225	30	225	30	BEGIN NAVIGATION SIGHTING NO. 9
80	28	46	683	55	-3	180	4	176	209	4	176	193	5	180	72	233	40	233	40	BEGIN NAVIGATION SIGHTING NO. 10
80	33	46	688	41	-3	166	4	176	209	4	176	192	20	160	86	245	49	245	49	END NAV. PERIOD--BEGIN INERTIAL ATTITUDE HOLD
80	34	46	689	38	-3	166	4	176	212	4	176	192	20	160	86	245	49	245	49	BEGIN ROLL MANEUVER AT +12 DEG./ MIN.
80	40	46	695	20	-3	166	4	244	229	4	243	203	-3	266	24	254	-14	254	-14	ROLL MANEUVER CONTINUED
80	46	46	701	2	-3	166	4	311	247	4	311	187	-23	265	-44	209	-73	209	-73	END ROLL MANEUVER AT +12 DEG./ MIN.
81	3	46	718	312	-1	166	4	311	297	4	311	187	-23	265	-44	212	-70	212	-70	LEAVE SUNLIGHT
81	25	46	740	248	3	166	4	311	1	4	311	187	-23	265	-44	205	-71	205	-71	LOSE EARTH

☐ Indicates Line of Sight Occluded By Earth or Moon

Table D-1 (Continued)

Phase 9 (Continued)

CSM Solo Lunar Orbit Operations

MISSION TIME			PHASE TIME	VEHICLE POSITION		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		LEM DIRECTION		LANDING SITE DIRECTION		REMARKS
HR	MIN	SEC	MIN	LONG	LAT	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV	AZI	ELV	
85	54	46	1009	176	3	166	4	311	70	4	311	189	-24	266	-44	194	-17	194	-17	INERTIAL ATTITUDE HOLD CONTINUED
85	54	46	1009	176	3	166	4	311	70	4	311	189	-24	266	-44	194	-0	194	-17	ENTER SUNLIGHT
86	4	46	1019	147	2	166	4	311	100	4	311	189	-24	266	-44	183	-7	183	-7	BEGIN IMU ALIGNMENT
86	16	46	1031	112	-0	166	4	311	135	4	311	189	-24	266	-44	170	6	170	6	ACQUIRE EARTH
86	21	46	1036	97	-1	166	4	311	149	4	311	189	-24	266	-44	164	11	164	11	END IMU ALIGNMENT
86	28	46	1043	76	-2	166	4	311	170	4	311	189	-24	266	-44	155	18	155	18	BEGIN ROLL MANEUVER AT -12 DEG./MIN.
86	33	46	1048	62	-3	166	4	251	185	4	251	206	-5	267	16	143	-14	143	-14	ROLL MANEUVER CONTINUED
86	38	46	1053	47	-3	166	4	191	199	4	191	198	20	257	76	171	-47	171	-47	END ROLL MANEUVER AT -12 DEG./MIN.
86	40	46	1055	41	-3	166	4	191	205	4	191	198	20	257	76	170	-51	170	-51	BEGIN NAVIGATION SIGHTING NO. 11
86	45	46	1060	26	-3	166	4	191	220	4	191	198	20	257	76	164	-62	164	-62	END NAVIGATION SIGHTING PERIOD
86	47	46	1062	20	-3	166	4	191	226	4	191	198	20	257	76	160	-67	160	-67	BEGIN ROLL MANEUVER AT +12 DEG./MIN.
86	52	46	1067	6	-3	166	4	251	240	4	251	206	-4	267	16	74	-20	74	-20	ROLL MANEUVER CONTINUED
86	57	46	1072	351	-3	166	4	311	255	4	311	190	-25	266	-44	322	-24	322	-24	END ROLL MANEUVER AT +12 DEG./MIN.
87	11	46	1086	310	-1	166	4	311	296	4	311	190	-25	266	-44	275	-38	275	-38	LEAVE SUNLIGHT
87	33	46	1108	245	3	166	4	311	1	4	311	190	-25	266	-44	231	-35	231	-35	LOSE EARTH
92	2	46	1377	174	3	166	4	311	69	4	311	193	-27	266	-44	196	-18	196	-18	ENTER SUNLIGHT
92	12	46	1387	144	2	166	4	311	99	4	311	192	-27	266	-44	184	-8	184	-8	BEGIN IMU ALIGNMENT
92	23	46	1398	112	-0	166	4	311	131	4	311	192	-27	266	-44	172	4	172	4	ACQUIRE EARTH
92	29	46	1404	94	-1	166	4	311	149	4	311	193	-27	266	-44	165	10	165	10	END IMU ALIGNMENT
92	34	46	1409	80	-2	166	4	311	163	4	311	193	-27	266	-44	159	15	159	15	BEGIN ROLL MANEUVER AT -12 DEG./MIN.
92	39	46	1414	65	-3	166	4	251	178	4	251	209	-3	267	16	148	-12	148	-12	ROLL MANEUVER CONTINUED
92	44	46	1419	50	-3	166	4	191	193	4	191	198	23	258	76	173	-42	173	-42	END ROLL MANEUVER AT -12 DEG./MIN.
92	47	46	1422	41	-3	166	4	191	201	4	191	199	23	258	76	171	-48	171	-48	BEGIN LOCAL ATTITUDE HOLD
92	49	46	1424	35	-3	160	4	191	201	4	191	200	29	283	76	172	-46	172	-46	BEGIN NAVIGATION SIGHTING NO. 12
92	54	46	1429	21	-3	145	4	191	201	4	191	207	43	326	69	175	-45	175	-45	LOCAL ATTITUDE HOLD CONTINUED
92	59	46	1434	6	-3	130	4	191	201	4	191	217	55	343	56	169	-65	169	-65	LOCAL ATTITUDE HOLD CONTINUED
93	3	46	1438	354	-3	119	4	191	201	4	191	233	64	349	45	6	-18	6	-18	BEGIN NAVIGATION SIGHTING NO. 13
93	8	46	1443	339	-3	104	4	191	201	4	191	268	70	354	31	5	-1	5	-1	END NAVIGATION SIGHTING PERIOD
93	9	46	1444	336	-2	101	4	191	201	4	191	277	70	355	28	6	-1	6	-1	BEGIN ROLL MANEUVER AT +12 DEG./MIN.
93	14	46	1449	322	-2	86	4	251	201	4	251	287	11	347	6	6	4	6	4	ROLL MANEUVER CONTINUED
93	19	46	1454	307	-1	72	4	311	201	4	311	313	-40	360	2	3	11	3	11	END ROLL MANEUVER AT +12 DEG./MIN.
93	19	46	1454	307	-1	72	4	311	201	4	311	313	-40	360	2	3	-0	3	11	LEAVE SUNLIGHT
93	24	46	1459	292	-0	57	4	311	201	4	311	328	-32	11	11	8	15	8	15	BEGIN INERTIAL ATTITUDE HOLD
93	24	46	1459	292	-0	57	4	311	201	4	311	328	-32	11	11	8	-0	8	15	BEGIN SOLO ASTRONAUT SLEEP PERIOD
93	39	46	1474	248	2	57	4	311	245	4	311	328	-32	11	11	351	-1	351	-1	LOSE EARTH

☐ Indicates Line of Sight Occluded By Earth or Moon

Table D-1 (Continued)

Phase 9 (Continued)

CSM Solo Lunar Orbit Operations

MISSION TIME			PHASE TIME	VEHICLE POSITION		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		LEM DIRECTION		LANDING SITE DIRECTION		REMARKS
HR	MIN	SEC	MIN	LONG	LAT	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV	AZI	ELV	
98	59	46	1794	27	-3	57	4	311	104	4	311	330	-30	11	11	224	-34	224	-34	END SOLO ASTRONAUT SLEEP PERIOD
99	27	46	1822	304	-1	57	4	311	186	4	311	331	-29	11	11	17	22	17	22	LEAVE SUNLIGHT
99	47	46	1842	246	2	57	4	311	245	4	311	331	-29	11	11	352	0	352	0	LOSE EARTH
99	51	46	1846	234	3	57	4	311	256	4	311	331	-29	11	11	348	-4	348	-4	BEGIN ROLL MANEUVER AT -12 DEG./ MIN.
99	56	46	1851	219	3	57	4	249	271	4	250	321	8	15	-4	343	10	343	10	ROLL MANEUVER CONTINUED
100	2	46	1857	201	3	57	4	176	289	4	176	357	40	0	-16	6	28	6	28	END ROLL MANEUVER AT -12 DEG./ MIN.
100	8	46	1863	184	3	57	4	176	306	4	176	357	40	0	-16	7	37	7	37	BEGIN IMU ALIGNMENT
100	13	46	1868	169	3	57	4	176	321	4	176	357	40	0	-16	8	45	8	45	ENTER SUNLIGHT
100	24	46	1879	137	2	57	4	176	353	4	176	357	40	0	-16	13	62	13	62	END IMU ALIGNMENT
100	26	46	1881	131	1	57	4	176	359	4	176	357	40	0	-16	15	65	15	65	BEGIN PITCH MANEUVER AT -12 DEG./ MIN.
100	32	46	1887	113	0	129	357	175	88	357	175	187	68	0	56	172	33	172	33	PITCH MANEUVER CONTINUED--ACQUIRE EARTH
100	39	46	1894	93	-1	213	355	182	193	355	182	183	-16	180	40	167	-61	167	-61	END PITCH MANEUVER AT -12 DEG./ MIN.
100	45	46	1900	75	-2	213	355	182	211	355	182	183	-16	180	40	163	-70	163	-70	BEGIN LOCAL ATTITUDE HOLD
100	47	46	1902	69	-2	207	355	182	211	355	182	183	-10	180	46	165	-68	165	-68	BEGIN NAVIGATION SIGHTING NO. 14
100	52	46	1907	54	-3	192	355	182	211	355	182	183	5	184	60	168	-62	168	-62	LOCAL ATTITUDE HOLD CONTINUED
100	57	46	1912	40	-3	178	355	182	211	355	182	184	19	192	75	171	-57	171	-57	BEGIN NAVIGATION SIGHTING NO. 15
101	2	46	1917	25	-3	163	355	182	211	355	182	186	34	264	85	173	-53	173	-53	END NAVIGATION SIGHTING PERIOD
101	4	46	1919	19	-3	157	355	182	211	355	182	187	39	316	83	174	-54	174	-54	BEGIN ROLL MANEUVER AT +12 DEG./ MIN.
101	9	46	1924	4	-3	143	355	242	211	355	242	233	17	292	22	99	-31	99	-31	ROLL MANEUVER CONTINUED
101	14	46	1929	350	-3	128	355	302	211	355	302	244	-36	311	-31	2	-6	2	-6	END ROLL MANEUVER AT +12 DEG./ MIN.
101	22	46	1937	326	-2	104	355	302	211	355	302	273	-41	336	-22	357	-6	357	-6	BEGIN INERTIAL ATTITUDE HOLD
101	30	46	1945	303	-1	104	355	302	234	355	302	274	-41	336	-22	343	-13	343	-13	LEAVE SUNLIGHT
101	49	46	1964	247	2	104	355	302	290	355	302	274	-41	336	-22	314	-27	314	-27	LOSE EARTH
102	16	46	1991	167	3	104	355	302	9	355	302	274	-41	336	-22	267	-32	267	-32	ENTER SUNLIGHT
102	34	46	2009	114	0	104	355	302	62	355	302	274	-41	336	-22	237	-23	237	-23	ACQUIRE EARTH
103	4	46	2039	26	-3	104	355	302	150	355	302	274	-41	336	-22	189	0	189	0	BEGIN ROLL MANEUVER AT -12 DEG./ MIN.
103	8	46	2043	14	-3	104	355	254	161	355	254	273	7	328	1	172	1	172	1	ROLL MANEUVER CONTINUED
103	9	46	2044	11	-3	104	355	242	164	355	242	274	19	328	8	167	-4	167	-4	BEGIN CSM TRACKING OF LEM WITH TRANSPONDER
103	12	46	2047	2	-3	104	355	206	173	355	206	276	55	338	24	147	-52	147	-52	END ROLL MANEUVER AT -12 DEG./ MIN.
103	15	46	2050	354	-3	104	355	206	182	355	206	276	55	338	24	12	-36	12	-36	END CSM TRACKING OF LEM WITH TRANSPONDER
103	32	46	2067	304	-1	104	355	206	232	355	206	277	55	338	24	349	16	349	16	LEAVE SUNLIGHT
103	52	46	2087	245	2	104	355	206	291	355	206	277	55	338	24	329	43	329	43	LOSE EARTH
104	10	46	2105	192	3	104	355	206	343	355	206	277	55	338	24	293	61	293	61	BEGIN ROLL MANEUVER AT -12 DEG./ MIN.
104	12	46	2107	186	3	104	355	182	349	355	182	291	79	350	31	339	81	339	81	END ROLL MANEUVER AT -12 DEG./ MIN.
104	18	46	2113	168	3	104	355	182	7	355	182	291	79	350	31	244	88	244	88	BEGIN IMU ALIGNMENT
104	18	46	2113	168	3	104	355	182	7	355	182	291	79	350	31	244	-0	244	88	ENTER SUNLIGHT
104	34	46	2129	121	1	104	355	182	54	355	182	291	79	350	31	176	65	176	65	END IMU ALIGNMENT
104	36	46	2131	115	1	104	355	182	60	355	182	291	79	350	31	175	62	175	62	BEGIN PITCH MANEUVER AT -12 DEG./ MIN.
104	37	46	2132	112	0	117	355	183	75	355	183	232	76	349	43	176	47	176	47	ACQUIRE EARTH
104	41	46	2136	101	-0	168	359	186	137	359	186	192	30	240	81	177	-9	177	-9	PITCH MANEUVER CONTINUED
104	45	46	2140	89	-1	218	4	184	200	4	184	191	-19	190	34	170	-66	170	-66	END PITCH MANEUVER AT -12 DEG./ MIN.
104	50	46	2145	74	-2	218	4	184	214	4	184	191	-19	190	34	163	-74	163	-74	BEGIN LOCAL ATTITUDE HOLD
104	52	46	2147	68	-2	212	4	184	214	4	184	192	-13	191	40	167	-71	167	-71	BEGIN NAVIGATION SIGHTING NO. 16
104	57	46	2152	54	-3	198	4	184	214	4	184	192	1	194	55	172	-65	172	-65	END NAVIGATION SIGHTING PERIOD
104	59	46	2154	48	-3	192	4	184	214	4	184	193	7	196	60	174	-63	174	-63	BEGIN INERTIAL ATTITUDE HOLD
105	1	46	2156	42	-3	192	4	184	220	4	184	193	7	196	60	173	-67	173	-67	BEGIN ROLL MANEUVER AT +12 DEG./ MIN.
105	8	46	2163	21	-3	192	4	268	241	4	268	189	-12	242	-3	96	-3	96	-3	ROLL MANEUVER CONTINUED

☐ Indicates Line of Sight Occluded By Earth or Moon

Table D-1 (Continued)

Phase 9 (Continued)

CSM Solo Lunar Orbit Operations

MISSION TIME			PHASE TIME	VEHICLE POSITION		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		LEM DIRECTION		LANDING SITE DIRECTION		REMARKS
HR	MIN	SEC	MIN	LONG	LAT	THETA	FSI	FHI	THETA	FSI	FHI	AZI	ELV	AZI	ELV	AZI	ELV	AZI	ELV	
105	8	46	2163	21	-3	192	4	268	241	4	268	189	-12	242	-3	96	-4	96	-3	ROLL MANEUVER CONTINUED
105	9	46	2164	18	-3	192	4	280	244	4	280	186	-13	241	-13	93	8	93	8	ROLL MANEUVER CONTINUED
105	10	46	2165	15	-3	192	4	292	247	4	292	183	-14	239	-24	88	20	88	20	ROLL MANEUVER CONTINUED
105	11	46	2166	12	-3	192	4	304	250	4	304	180	-15	235	-34	82	32	82	32	ROLL MANEUVER CONTINUED
105	12	46	2167	9	-3	192	4	316	252	4	316	177	-14	229	-43	70	43	70	42	ROLL MANEUVER CONTINUED
105	13	46	2168	7	-3	192	4	328	255	4	328	174	-13	220	-52	49	48	49	48	ROLL MANEUVER CONTINUED
105	14	46	2169	4	-3	192	4	340	258	4	340	171	-12	205	-58	21	40	21	40	ROLL MANEUVER CONTINUED
105	15	46	2170	1	-3	192	4	352	261	4	352	169	-10	185	-61	4	12	4	12	END ROLL MANEUVER AT +12 DEG./MIN.
105	17	46	2172	355	-3	192	4	352	267	4	352	169	-10	185	-61	354	-44	352	-43	INERTIAL ATTITUDE HOLD CONTINUED
105	19	04	2173	351	-3	192	4	352	271	4	352	169	-10	185	-61	348	-58	346	-57	LEM LIFTOFF--BEGIN LOCAL ATTITUDE HOLD
105	24	54	2179	334	-3	174	4	352	271	4	352	171	-27	203	-78	337	-67	335	-65	LOCAL ATTITUDE HOLD CONTINUED
105	29	45	2184	319	-2	160	4	352	271	4	352	172	-42	300	-83	337	-67	337	-62	BEGIN CSM TRACKING OF LEM WITH TRANSPONDER
105	37	55	2191	299	-1	139	4	352	271	4	352	173	-62	345	-65	337	-67	341	-54	BEGIN CSM TRACKING OF LEM WITH SEXTANT
105	37	55	2191	299	-1	139	4	352	271	4	352	173	-62	345	-65	337	-67	341	-54	LEAVE SUNLIGHT
105	39	45	2194	290	-0	131	4	352	271	4	352	174	-71	348	-57	337	-66	343	-50	LOCAL ATTITUDE HOLD CONTINUED
105	44	45	2199	275	1	116	4	352	271	4	352	173	-85	352	-42	338	-66	345	-44	LOCAL ATTITUDE HOLD CONTINUED
105	49	45	2204	261	1	101	4	352	271	4	352	358	-80	355	-28	338	-65	348	-37	LOCAL ATTITUDE HOLD CONTINUED
105	54	12	2208	247	2	88	4	352	271	4	352	358	-67	356	-15	339	-65	350	-31	LOSE EARTH
105	59	12	2213	233	3	73	4	352	271	4	352	359	-53	358	-0	339	-64	352	-25	LOCAL ATTITUDE HOLD CONTINUED
106	5	12	2219	215	3	56	4	352	271	4	352	0	-35	1	17	340	-63	353	-16	BEGIN INERTIAL ATTITUDE HOLD
106	7	12	2221	209	3	56	4	352	276	4	352	0	-35	1	17	336	-68	353	-20	BEGIN PITCH MANEUVER AT -12 DEG./MIN.
106	8	12	2222	206	3	44	6	353	267	6	353	0	-23	1	29	342	-59	353	-9	PITCH MANEUVER CONTINUED
106	10	12	2224	200	3	20	8	356	249	8	356	0	1	2	53	348	-42	353	12	PITCH MANEUVER CONTINUED
106	12	12	2226	194	3	355	9	360	230	9	360	0	26	5	78	351	-23	352	33	END PITCH MANEUVER AT -12 DEG./MIN.
106	13	12	2227	192	3	355	9	360	233	9	360	0	26	5	78	351	-26	352	32	BEGIN IMU ALIGNMENT--TRACKING INTERRUPTED
106	19	12	2233	174	3	355	9	360	250	9	360	0	26	5	78	351	-44	351	23	END IMU ALIGNMENT--TRACKING REINSTATED
106	21	12	2235	168	3	349	9	360	250	9	360	1	31	18	84	351	-44	351	26	BEGIN ROLL MANEUVER AT +12 DEG./MIN.
106	22	12	2236	165	3	346	9	12	250	9	12	353	34	288	80	3	-45	346	25	ENTER SUNLIGHT
106	23	12	2237	162	3	343	9	24	250	9	24	344	34	271	69	14	-44	340	22	END ROLL MANEUVER AT +12 DEG./MIN.
106	25	12	2239	156	3	343	9	24	256	9	24	344	34	271	69	20	-49	341	20	BEGIN LOCAL ATTITUDE HOLD
106	33	12	2247	133	2	319	9	24	256	9	24	330	55	215	62	22	-51	335	29	LOCAL ATTITUDE HOLD CONTINUED
106	40	12	2254	112	0	299	9	24	256	9	24	300	71	192	46	24	-52	329	37	ACQUIRE EARTH
106	43	12	2257	103	-0	290	9	24	256	9	24	273	74	186	38	24	-52	326	41	LOCAL ATTITUDE HOLD CONTINUED
106	48	12	2262	89	-1	275	9	24	256	9	24	223	71	179	25	22	-50	320	46	LOCAL ATTITUDE HOLD CONTINUED
106	53	12	2267	74	-2	261	9	24	256	9	24	197	61	172	12	18	-48	314	51	LOCAL ATTITUDE HOLD CONTINUED
106	58	12	2272	59	-3	246	9	24	256	9	24	185	48	167	-2	15	-44	306	56	LOCAL ATTITUDE HOLD CONTINUED
107	3	58	2278	42	-3	229	9	24	256	9	24	176	33	160	-17	10	-38	297	61	BEGIN INERTIAL ATTITUDE HOLD
107	8	58	2283	28	-3	229	9	24	271	9	24	176	33	160	-17	15	-45	314	54	INERTIAL ATTITUDE HOLD CONTINUED
107	13	58	2288	13	-3	229	9	24	286	9	24	176	33	160	-17	20	-50	332	40	INERTIAL ATTITUDE HOLD CONTINUED
107	18	58	2293	358	-3	229	9	24	300	9	24	176	32	160	-17	24	-53	29	-48	INERTIAL ATTITUDE HOLD CONTINUED
107	23	58	2298	343	-3	229	9	24	315	9	24	175	32	160	-17	24	-53	130	-56	INERTIAL ATTITUDE HOLD CONTINUED
107	28	58	2303	329	-2	229	9	24	330	9	24	175	32	160	-17	22	-51	146	-46	INERTIAL ATTITUDE HOLD CONTINUED
107	37	48	2312	303	-1	229	9	24	355	9	24	175	32	160	-17	15	-46	158	-32	BEGIN LOCAL ATTITUDE HOLD
107	39	48	2314	297	-1	223	9	24	355	9	24	173	27	157	-23	10	-39	156	-34	LEAVE SUNLIGHT
107	50	50	2325	264	1	191	9	24	355	9	24	160	-3	134	-50	352	-7	146	-46	BEGIN ROLL MANEUVER AT -12 DEG./MIN.
107	54	16	1	254	2	181	9	343	355	9	343	170	-25	214	-69	0	0	202	-57	ROLL MANEUVER CONTINUED
107	56	16	3	248	2	175	9	319	355	9	319	186	-31	251	-52	0	0	230	-44	END ROLL MANEUVER AT -12 DEG/MIN--LOSE EARTH
107	57	16	4	246	2	172	9	319	355	9	319	188	-33	256	-52	0	0	231	-45	BEGIN INERTIAL ATTITUDE HOLD

☐ Indicates Line of Sight Occluded By Earth or Moon

Table D-1 (Continued)
Phase 10
LM Descent

Mission Time			Phase Time		Vehicle Position		Inertial Attitude			Local Attitude			Earth Direction		Sun Direction		CSM Direction		Landing Site Direction		Remarks
Hr	Min	Sec	Min	Sec	Long	Lat	Pitch	Roll	Yaw	Pitch	Roll	Yaw	Azi	Elv	Azi	Elv	Azi	Elv	Azi	Elv	
																					PHASE 8.2 CREW TRANSFER
66	17	43	0	00	37.3	-3.4															CSM ACTIVITIES
68	40	56	143	13	-39.9	-1.1	-73	0	69	-147	0	69									ORIENT TO FIRST STAR
68	47	52	150	09	-41.8	0.2	-71	0	88	-151	0	88									DRIFT FOR IMU ALIGNMENT
68	49	25	151	42	-49.1	0.2	-71	0	88	-158	0	88									ORIENT TO SECOND STAR
68	52	19	154	36	-59.2	0.2	16	0	114	137	0	114									DRIFT FOR IMU ALIGNMENT
68	53	52	156	09	-61.8	0.2	16	0	114	135	0	114									ORIENT TO LM SEPARATION ATTITUDE(CSM)
																					PHASE 10.1 LM SEPARATION
69	05	32	0	00	-94.8	2.1	-96	0	-45	0	0	-45	126	-3			156	0			BEGIN SEPARATION MANEUVER
69	05	34	0	02	-94.8	2.1	-96	0	-45	0	0	-45	126	-4			-25	-8			BEGIN SEPARATED COAST-INERTIAL ATTITUDE HOLD
69	07	09	1	37	-99.8	2.4	-96	0	-45	5	0	-45	126	-4			156	14			BEGIN PITCH TO VISUAL CHECK ATTITUDE
69	07	25	1	53	-100.5	2.4	24	0	-45	126	0	-45	-25	62			-53	58			BEGIN VISUAL CHECK-YAW MANEUVER(405DEG)
69	08	23	2	51	-103.0	2.5	24	0	0	129	0	0	20	62			170	-38			INERTIAL ATTITUDE HOLD
69	13	32	8	00	-120.0	3.1	24	0	0	144	0	0					-156	30			ORIENT TO FIRST STAR
69	14	04	8	32	-120.5	3.1	-71	0	30	49	0	30									DRIFT FOR IMU ALIGNMENT
69	17	04	11	32	-128.5	3.3	-71	0	30	58	0	30									ORIENT TO SECOND STAR
69	17	30	11	58	-129.5	3.3	5	0	43	135	0	43			Sun						DRIFT FOR IMU ALIGNMENT
69	20	04	14	32	-137.0	3.4	5	0	43	142	0	43			Occulted						ORIENT TO FIRST STAR
69	20	30	14	58	-138.5	3.4	-71	0	30	68	0	30									DRIFT FOR IMU ALIGNMENT
69	23	04	17	32	-146.0	3.4	-71	0	30	75	0	30		Earth			-152	40			ORIENT TO TOI ATTITUDE
69	23	14	17	42	-146.5	3.4	-75	0	0	71	0	0		Occulted			-154	42			INERTIAL ATTITUDE HOLD
																					PHASE 10.2 TRANSFER ORBIT INSERTION
69	28	31	0	00	-162.4	3.3	-75	0	0	89	0	0					18	-10			BEGIN TOI MANEUVER
																					PHASE 10.3 COAST TO POWERED DESCENT
69	29	03	0	00	-165.0	3.2	-76	0	0	89	0	0					-147	40			BEGIN PITCH TO CSM LINE-OF-SIGHT
69	29	31	0	28	-167.0	3.2	-150	0	0	16	0	0					-155	-40			INERTIAL ATTITUDE HOLD
70	10	08	41	05	66.0	-2.7	-150	0	0	144	0	0	164	-56	4	-50	0	1			ORIENT TO FIRST STAR
70	11	04	42	01	63.0	-2.8	16	0	-6	-44	0	-6									DRIFT FOR IMU ALIGNMENT
70	14	04	45	01	55.0	-3.1	16	0	-6	-39	0	-6									ORIENT TO SECOND STAR
70	14	13	45	10	54.8	-3.1	9	0	21	-46	0	21									DRIFT FOR IMU ALIGNMENT
70	17	04	48	01	45.0	-3.4	9	0	21	-36	0	21									ORIENT TO FIRST STAR
70	17	13	48	10	44.7	-3.4	16	0	-6	-29	0	-6									DRIFT FOR IMU ALIGNMENT
70	20	04	51	01	35.0	-3.7	16	0	-6	-19	0	-6									ORIENT TO POWERED DESCENT ATTITUDE
70	20	36	51	33	33.5	-3.7	109	0	0	88	0	0	10	-21	4	51	2	72			INERTIAL ATTITUDE HOLD
																					PHASE 10.4 BRAKING
70	27	17	0	00	15.4	-3.2	109	0	0	94	0	0	9	-22	5	51	3	66	180	-76	BEGIN BRAKING MANEUVER
70	27	37	0	20	14.3	-3.2	106	0	0	92	0	0	9	-18	6	54	3	69	180	-79	BRAKING MANEUVER CONTINUES
70	28	07	0	50	12.6	-3.2	102	0	0	90	0	0	9	-14	6	58	3	72	180	-82	BRAKING MANEUVER CONTINUES
70	28	37	1	20	11.1	-3.1	98	0	0	87	0	0	9	-10	7	62	3	74	180	-85	BRAKING MANEUVER CONTINUES
70	29	07	1	50	9.6	-3.1	94	0	0	85	0	0	9	-7	8	65	4	77	180	-87	BRAKING MANEUVER CONTINUES
70	29	37	2	20	8.3	-3.1	91	0	0	83	0	0	9	-3	9	69	4	78	180	-89	BRAKING MANEUVER CONTINUES
70	30	07	2	50	7.0	-3.0	88	0	0	81	0	0	9	0	10	72	4	79	0	-89	BRAKING MANEUVER CONTINUES
70	30	37	3	20	5.8	-3.0	85	0	0	80	0	0	9	3	12	75	3	80	0	-87	BRAKING MANEUVER CONTINUES
70	31	07	3	50	4.8	-3.0	82	0	0	78	0	0	9	5	14	77	3	80	0	-86	BRAKING MANEUVER CONTINUES
70	31	37	4	20	3.8	-3.0	80	0	0	77	0	0	9	8	17	80	3	80	0	-84	BRAKING MANEUVER CONTINUES
70	32	07	4	50	3.0	-2.9	78	0	0	75	0	0	9	10	21	82	2	79	0	-84	BRAKING MANEUVER CONTINUES
70	32	37	5	20	2.3	-2.9	76	0	0	74	0	0	9	12	27	84	1	77	0	-83	BRAKING MANEUVER CONTINUES
70	33	07	5	50	1.7	-2.9	74	0	0	72	0	0	9	14	37	85	0	73	0	-83	BRAKING MANEUVER CONTINUES
70	33	37	6	20	1.2	-2.9	72	0	0	71	0	0	9	15	53	87	-1	68	0	-84	
																					PHASE 10.5 FINAL APPROACH
70	34	17	0	00	0.8	-2.9	71	0	0	71	0	0	13	46	174	61	-8	86	0	-55	HI-GATE-BEGIN PITCHOVER TO FINAL APPROACH ATTITUDE
70	34	25	0	08	0.8	-2.9	42	0	0	41	0	0	13	45	175	61	-7	82	0	-55	
70	35	05	0	48	0.6	-2.9	43	0	0	42	0	0	13	44	175	62	2	70	0	-57	BEGIN VISIBILITY ATTITUDE
70	35	35	1	18	0.6	-2.9	44	0	0	44	0	0	13	43	174	63	0	50	0	-58	
70	35	55	1	38	0.5	-2.9	52	0	0	52	0	0	11	35	171	72	-1	23	0	-58	
																					PHASE 10.6 LANDING
70	36	02	0	00	0.4	-2.9	52	0	0	52	0	0	11	35	172	72	0	24	0	-62	LO-GATE-BEGIN PITCHOVER TO LANDING ATTITUDE
70	36	20	0	18	0.4	-2.9	0	0	0	0	0	0	11	87	173	20	0	76	0	-10	INERTIAL ATTITUDE HOLD
70	36	52	0	50	0.4	-2.8	0	0	0	0	0	0	11	87	173	20	0	76	0	-14	PITCHUP TO BRAKING ATTITUDE
70	37	02	1	00	0.3	-2.8	25	0	0	25	0	0	11	62	175	45	0	50	0	-38	INERTIAL ATTITUDE HOLD
70	37	10	1	08	0.3	-2.8	25	0	0	25	0	0	11	62	177	45	0	50	0	-47	PITCHOVER TO PRETOUCHDOWN ATTITUDE
70	37	17	1	15	0.3	-2.8	0	0	0	0	0	0	11	87	178	19	0	75	0	-90	INERTIAL ATTITUDE HOLD TO TOUCHDOWN

Table D-1 (Continued)
Phase 12
LM Ascent

Mission Time			Phase Time	Vehicle Position		Inertial Attitude			Local Attitude			Earth Direction		Sun Direction		CSM Direction		Landing Site Direction		Remarks
Hr	Min	Sec	Min Sec	Long	Lat	Pitch	Roll	Yaw	Pitch	Roll	Yaw	Azi	Elv	Azi	Elv	Azi	Elv	Azi	Elv	
																				PHASE 12.1 POWERED ASCENT
105	19	04	0 00	0.3	-2.9	0	0	0	0	0	0	89	82	177	37	-3	23	0	-90	BEGIN VERTICAL RISE
105	19	16	0 12	0.3	-2.9	0	0	0	0	0	0	89	82	177	37	-3	21	0	-90	BEGIN RAPID PITCHOVER
105	19	22	0 18	0.3	-2.9	-57	-12	0	-57	-12	0	164	30	-178	-19	32	74			BEGIN GRADUAL PITCHOVER
																				PHASE 12.2 COAST TO CSI
105	25	54	0 00	-9.2	-3.1	-104	-6	0	-95	-6	0	174	-15	-171	-66	136	81			ORIENT TO CSM TRACKING ATTITUDE
105	26	17	0 23	-9.2	-3.2	-40	0	0	-31	0	0	168	49	178	-2	0	32			INERTIAL ATTITUDE HOLD
105	47	48	21 54	-76.9	0.1	-40	0	0	37	0	0	168	49			0	-11			PITCH TO CSI ATTITUDE
																				PHASE 12.3 CSI MANEUVER
105	53	29	0 00	-99.4	1.5	-100	0	0	0	0	0	172	-10			0	14			BEGIN CSI THRUSTING
																				PHASE 12.4 COAST TO CDH
105	54	22	0 00	-102.2	1.6	-102	0	0	0	0	0					0	13			BEGIN COAST TO CDH-INERTIAL ATTITUDE HOLD
106	06	35	12 13	-141.5	3.2	-102	0	0	40	0	0			Sun Occulted		0	-7			ORIENT TO TRACKING ATTITUDE
106	06	55	12 33	-141.6	3.2	-152	0	0	-10	0	0					0	-23			INERTIAL ATTITUDE HOLD
106	20	54	26 32	173.6	3.2	-152	0	0	34	0	0					0	-23			ORIENT TO FIRST STAR
106	21	35	27 54	171.6	3.1	66	0	-5	-86	0	-5					180	-80			DRIFT FOR IMU ALIGNMENT
106	24	35	30 13	162.0	2.9	86	0	-5	-76	0	-5					180	-75			ORIENT TO SECOND STAR
106	25	04	30 42	160.4	2.8	0	0	3	-160	0	3	Earth Occulted				180	12			DRIFT FOR IMU ALIGNMENT
106	27	35	33 13	152.4	2.6	0	0	3	-152	0	3					180	16			ORIENT TO THIRD STAR
106	27	56	33 34	151.3	2.6	-19	0	10	-170	0	10					180	36			DRIFT FOR IMU ALIGNMENT
106	30	35	36 13	142.4	2.3	-19	0	10	-161	0	10			2	10	180	41			ORIENT TO TRACKING ATTITUDE
106	31	26	37 04	139.7	2.2	132	0	0	-8	0	0			2	10	0	72			INERTIAL ATTITUDE HOLD
106	42	21	47 59	109.6	0.3	132	0	0	22	0	0			2	10	0	4			PITCH TO CDH ATTITUDE
																				PHASE 12.5 CDH MANEUVER
106	43	21	0 00	106.1	0.7	109	0	0	3	0	0	8	-18	2	33	0	13			BEGIN CDH MANEUVER
																				PHASE 12.6 COAST TO TPI
106	44	17	0 00	103.3	-0.1	108	0	0	5	0	0	8	-17	2	34	0	11			BEGIN COAST TO TPI-INERTIAL ATTITUDE HOLD
106	58	53	14 36	52.5	-2.7	108	0	0	55	0	0	8	-17	2	34	0	-6			PITCH TO TPI ATTITUDE
																				PHASE 12.7 TPI MANEUVER
107	01	31	0 00	51.5	-2.8	101	0	0	50	0	0	8	-10	3	41	0	-11			BEGIN TPI MANEUVER
																				PHASE 12.8 COAST TO TERMINAL RENDEZVOUS
107	01	54	0 00	50.3	-2.8	102	0	0	51	0	0	8	-10	3	40	0	-10			PITCH TO COASTING ATTITUDE
107	02	13	0 19	49.4	-2.8	82	0	0	33	0	0	8	8	4	60	0	7			MAINTAIN COASTING ATTITUDE-INERTIAL ATTITUDE HOLD
107	10	11	8 17	25.6	-3.3	82	0	0	56	0	0	8	9	4	60	0	-6			PITCH AND YAW TO FIRST MC ATTITUDE
107	10	26	8 32	24.8	-3.4	82	0	0	57	0	0	8	9	4	60	0	-6			MAINTAIN FIRST MC ATTITUDE-INERTIAL ATTITUDE HOLD
107	11	16	9 22	22.0	-3.5	82	0	0	60	0	0	8	9	4	60	0	-15			FIRST MC
107	11	41	9 47	20.7	-3.5	82	0	0	61	0	0	8	9	4	60	0	-15			PITCH AND YAW TO COASTING ATTITUDE
107	11	56	10 02	20.0	-3.5	82	0	0	62	0	0	8	9	4	60	0	-15			MAINTAIN COASTING ATTITUDE-INERTIAL ATTITUDE HOLD
107	19	44	17 50	-3.3	-3.3	82	0	0	95	0	0	8	9	4	60	0	-19			PITCH AND YAW TO SECOND MC ATTITUDE
107	19	59	18 05	-4.1	-3.3	82	0	0	94	0	0	8	9	4	60	0	-19			MAINTAIN SECOND MC ATTITUDE-INERTIAL ATTITUDE HOLD
107	20	39	18 45	-6.1	-3.3	82	0	0	92	0	0	8	9	4	60	0	-19			SECOND MC
107	20	53	18 59	-6.3	-3.3	82	0	0	92	0	0	8	9	4	60	0	-19			PITCH AND YAW TO COASTING ATTITUDE
107	21	08	19 14	-7.1	-3.3	82	0	0	91	0	0	8	9	4	60	0	-19			MAINTAIN COASTING ATTITUDE-INERTIAL ATTITUDE HOLD
																				PHASE 12.9 TERMINAL RENDEZVOUS
107	30	02	0 00	-34.0	-2.3	82	0	0	116	0	0	8	9	4	60	0	-15			FIRST RENDEZVOUS GATE BYPASS-INERTIAL ATTITUDE HOLD
107	36	04	6 02	-52.1	-1.6	82	0	0	134	0	0	8	10	4	59	0	-12			COAST TO SECOND RENDEZVOUS GATE ATTITUDE
107	36	06	6 04	-52.2	-1.5	82	0	0	134	0	0	8	10	4	61	0	-12			INERTIAL ATTITUDE HOLD
107	36	24	6 22	-52.8	-1.4	81	0	0	134	0	0	8	10	4	61	0	-12			SECOND RENDEZVOUS GATE BURN
107	36	28	6 26	-53.0	-1.4	81	0	0	134	0	0	8	10	4	61	0	-12			MAINTAIN COASTING ATTITUDE-INERTIAL ATTITUDE HOLD
107	46	01	15 59	-81.0	0.4	81	0	0	162	0	0	8	12			0	-4			ORIENT TO THIRD RENDEZVOUS GATE ATTITUDE
107	46	03	16 01	-81.1	0.4	78	0	0	159	0	0	8	12			0	-3			INERTIAL ATTITUDE HOLD
107	46	21	16 19	-82.0	0.4	78	0	0	160	0	0	8	13			0	-2			THIRD RENDEZVOUS GATE BURN
107	46	29	16 27	-82.4	0.4	78	0	0	160	0	0	8	13			0	-2			MAINTAIN COASTING ATTITUDE-INERTIAL ATTITUDE HOLD
107	55	20	25 18	-108.3	1.9	78	0	0	-174	0	0	8	13			0	0			ORIENT TO FOURTH RENDEZVOUS GATE ATTITUDE
107	55	22	25 20	-108.4	1.9	77	0	0	-175	0	0	8	14			0	1			INERTIAL ATTITUDE HOLD
107	55	40	25 38	-109.3	1.9	77	0	0	-174	0	0	8	15	Sun Occulted		0	1			FOURTH RENDEZVOUS GATE BURN
																				PHASE 12.10 DOCKING
107	55	44	0 00	-109.5	1.9	77	0	0	-174	0	0	8	15			0	1			TRANSLATE TO 50 FT. IN FRONT OF CSM-ROLL AND YAW
107	58	44	3 00	-118.3	2.0	80	6	11	-162	6	11					0	0			MAINTAIN 50 FT. RANGE TO CSM
108	00	14	4 30	-122.7	2.1	82	9	19	-155	9	19					0	0			PITCH TO ACQUIRE DOCKING TARGET THRU OVERHEAD WINDOW
108	00	34	4 50	-128.6	2.1	-8	9	19	116	9	19	Earth Occulted				0	90			TRANSLATE TOWARD CSM DOCKING HATCH-INERTIAL ATTITUDE HOLD
108	02	14	6 30	-128.6	2.2	-8	9	19	121	9	19					0	90			VERIFY INITIAL DOCKED CONFIGURATION

Table D-1 (Continued)

Phases 13 & 14

Lunar Orbit Coast to TEI & Transearth Injection

MISSION TIME			PHASE TIME	VEHICLE POSITION		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		LEM DIRECTION		LANDING SITE DIRECTION		REMARKS
HR	MIN	SEC	MIN	LONG	LAT	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV	AZI	ELV	
108	02	14	9	231	3	172	9	319	10	9	319	188	-33	256	-52	0	0	221	-42	PHASE 13 LUNAR ORBIT COAST/TRANSEARTH INJECTION
108	2	14	9	231	3	172	9	319	10	9	319	188	-33	256	-52	0	0	221	-42	INITIAL DOCKING
108	7	16	14	216	3	172	9	319	25	9	319	188	-33	256	-52	0	0	212	-39	INERTIAL ATTITUDE HOLD CONTINUED
108	12	14	19	201	3	172	9	319	39	9	319	188	-33	256	-52	0	0	204	-35	DOCKING COMPLETE
108	20	16	27	178	3	172	9	319	63	9	319	188	-33	256	-52	0	0	193	-27	INERTIAL ATTITUDE HOLD CONTINUED
108	25	16	32	163	3	172	9	319	78	9	319	188	-33	256	-52	0	0	188	-21	ENTER SUNLIGHT
108	42	16	49	113	1	172	9	319	127	9	319	188	-33	256	-52	0	0	171	-1	ACQUIRE EARTH
108	49	16	56	93	-1	172	9	319	148	9	319	188	-33	256	-52	0	0	164	8	INERTIAL ATTITUDE HOLD CONTINUED
109	0	45	67	60	-2	172	9	319	180	9	319	188	-33	256	-52	0	0	151	21	LEM JETTISON
109	4	16	71	48	-3	172	9	319	192	9	319	188	-33	256	-52	0	0	146	25	INERTIAL ATTITUDE HOLD CONTINUED
109	8	16	75	37	-3	172	9	319	204	9	319	189	-33	256	-52	0	0	139	30	BEGIN LOCAL ATTITUDE HOLD
109	14	16	81	19	-3	155	9	319	204	9	319	205	-45	284	-49	0	0	139	28	LOCAL ATTITUDE HOLD CONTINUED
109	19	16	86	4	-3	140	9	319	204	9	319	225	-53	303	-43	0	0	107	40	LOCAL ATTITUDE HOLD CONTINUED
109	24	16	91	350	-3	125	9	319	204	9	319	249	-57	318	-34	0	0	358	9	LOCAL ATTITUDE HOLD CONTINUED
109	29	16	96	335	-3	111	9	319	204	9	319	276	-56	330	-24	0	0	352	6	LOCAL ATTITUDE HOLD CONTINUED
109	41	16	108	300	-1	75	9	318	204	9	319	322	-38	354	3	0	0	359	16	LEAVE SUNLIGHT
109	58	16	125	250	2	25	9	318	204	9	319	358	-1	33	36	0	0	17	31	LOSE EARTH
110	27	16	154	164	3	300	9	319	204	9	319	79	41	138	27	0	0	66	49	ENTER SUNLIGHT
110	34	07	161	144	2	280	9	319	204	9	319	105	38	154	12	0	0	81	50	BEGIN IMU ALIGNMENT
110	39	16	166	129	2	265	9	319	204	9	319	121	31	163	2	0	0	92	49	IMU ALIGNMENT CONTINUED
110	44	16	171	114	1	251	9	319	204	9	319	134	23	173	-10	0	0	102	48	ACQUIRE EARTH
110	45	16	172	111	0	248	9	319	204	9	319	136	21	175	-12	0	0	104	48	END IMU ALIGNMENT
110	47	16	174	105	0	242	9	319	204	9	319	141	17	179	-16	0	0	108	47	BEGIN ROLL MANEUVER AT -12 DEG./ MIN.
110	53	16	180	88	-1	224	9	265	204	9	265	160	-18	210	-8	0	0	110	-6	ROLL MANEUVER CONTINUED
110	59	16	186	70	-2	207	9	211	204	9	211	193	-12	217	33	0	0	139	-51	END ROLL MANEUVER AT -12 DEG./MIN.
111	0	16	187	67	-2	204	9	211	204	9	211	194	-9	219	35	0	0	140	-51	BEGIN NAVIGATION SIGHTING NO. 17
111	5	16	192	53	-3	189	9	211	204	9	211	202	4	233	46	0	0	148	-47	BEGIN NAVIGATION SIGHTING NO. 18
111	10	16	197	38	-3	174	9	211	204	9	211	210	16	252	54	0	0	155	-44	BEGIN NAVIGATION SIGHTING NO. 19
111	15	16	202	23	-3	160	9	211	204	9	211	219	28	277	57	0	0	159	-43	LOCAL ATTITUDE HOLD CONTINUED
111	20	16	207	8	-3	145	9	211	204	9	211	232	38	303	55	0	0	149	-53	LOCAL ATTITUDE HOLD CONTINUED
111	25	16	212	354	-3	130	9	211	204	9	211	248	46	324	48	0	0	13	-10	BEGIN NAVIGATION SIGHTING NO. 20
111	29	16	216	342	-3	119	9	211	204	9	211	265	51	336	40	0	0	8	5	END NAVIGATION SIGHTING PERIOD
111	32	16	219	333	-3	110	9	211	204	9	211	279	52	344	34	0	0	8	5	LOCAL ATTITUDE HOLD CONTINUED
111	37	16	224	318	-2	95	9	211	204	9	211	302	50	354	22	0	0	11	2	LOCAL ATTITUDE HOLD CONTINUED
111	38	16	225	315	-2	92	9	211	204	9	211	306	49	355	19	0	0	12	2	BEGIN ROLL MANEUVER AT +30 DEG./ MIN.
111	41	16	228	306	-1	83	9	301	204	9	301	307	-29	348	0	0	0	1	14	END ROLL MANEUVER AT +30 DEG./ MIN.
111	42	56	229	304	-1	80	9	301	204	9	301	309	-28	351	2	0	0	2	14	BEGIN IMU FINE ALIGNMENT
111	43	16	230	301	-1	78	9	300	204	9	301	312	-26	353	3	0	0	3	15	LEAVE SUNLIGHT
111	48	16	235	286	-0	63	9	300	204	9	301	326	-19	6	11	0	0	9	18	END IMU--BEGIN INERTIAL ATTITUDE HOLD
111	50	16	237	280	0	63	9	300	209	9	301	326	-19	6	11	0	0	6	16	BEGIN ORIENTATION FOR TEX
111	58	16	245	257	2	146	3	195	316	3	195	216	50	317	66	0	0	300	75	END ORIENTATION--BEGIN THRUSTING PREPARATIONS
112	1	16	248	248	2	146	3	195	325	3	195	216	50	317	66	0	0	282	76	LOSE EARTH
112	12	16	259	215	3	146	3	195	357	3	195	216	50	317	66	0	0	227	69	PHASE 14.0 TRANSEARTH INJECTION
112	12	16	259	215	3	146	3	195	357	3	195	216	50	317	66	0	-0	227	69	SPS ENGINE IGNITION FOR TRANSEARTH INJECTION

☐ ·Indicates Line of Sight Occluded By Earth or Moon

Table D-1 (Continued)

Phases 15

Transearth Coast

MISSION TIME			PHASE TIME	VEHICLE ALTITUDE		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		MOON DIRECTION		REMARKS
HR	MIN	SEC	MIN	EARTH	MOON	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV	
112	14	10	0	195.4	0.1	114	20	9	359	0	195	218	55	323	62	272	75	PHASE 15.0 TRANSEARTH COAST
112	14	10	0	195.4	0.1	114	20	9	359	0	195	218	55	323	62	272	75	SPS ENGINE CUTOFF
112	18	13	4	195.6	0.1	114	20	9	16	0	195	218	55	323	62	221	68	BEGIN ORIENTATION FOR FTC
112	22	22	8	195.7	0.2	118	42	47	32	337	234	236	34	291	22	230	41	SUNRISE
112	26	31	12	195.7	0.3	126	64	80	44	315	274	246	9	285	-22	237	27	ORIENTATION CONTINUED
112	30	40	16	195.8	0.5	177	82	70	53	292	311	253	-21	287	-65	252	9	ORIENTATION CONTINUED
112	34	13	20	195.8	0.6	270	73	12	40	274	325	257	-52	90	-79	268	-16	END ORIENTATION FOR FTC
112	34	13	20	195.8	0.6	270	73	12	40	274	325	257	-52	90	-79	268	-16	BEGIN ESTABLISHMENT OF FTC
112	35	22	21	195.8	0.7	270	73	12	104	278	66	257	-52	90	-79	268	-14	EARTHRISE
112	49	13	35	195.7	1.3	270	73	12	99	278	61	257	-51	90	-79	267	4	END ESTABLISHMENT OF FTC
121	23	2	549	189.5	20.0	270	73	172	107	274	127	99	31	90	81	100	-70	END FTC
121	29	53	556	189.4	20.2	270	73	172	107	274	127	99	31	90	81	100	-70	BEGIN ORIENTATION FOR FINE ALIGNMENT
121	34	53	561	189.3	20.4	322	30	198	269	317	359	186	76	220	29	43	0	ORIENTATION CONTINUED
121	39	53	566	189.3	20.5	336	341	267	270	8	70	259	29	205	19	358	-7	ORIENTATION CONTINUED
121	44	53	571	189.2	20.7	7	295	1	272	59	139	272	-38	246	6	52	-32	ORIENTATION CONTINUED
121	45	53	572	189.2	20.7	28	288	34	273	69	153	276	-52	254	-6	67	-22	END ORIENTATION FOR FINE ALIGNMENT
121	45	53	572	189.2	20.7	28	288	34	273	69	153	276	-52	254	-6	67	-22	BEGIN FINE ALIGNMENT
121	56	49	583	189.0	21.1	28	288	34	354	313	318	276	-52	254	-6	67	-22	END ALIGNMENT
121	56	59	583	189.0	21.1	28	288	34	273	69	153	276	-52	254	-6	67	-22	BEGIN ORIENTATION FOR MC NO. 4
121	57	59	584	189.0	21.1	30	290	37	267	68	159	273	-53	253	-6	66	-22	END ORIENTATION FOR MCC NO. 4
122	11	44	598	188.8	21.6	30	290	36	268	68	158	273	-52	253	-5	66	-23	MCC NO. 4
122	14	47	601	188.8	21.7	30	290	36	268	68	158	273	-52	253	-5	66	-23	BEGIN ORIENTATION FOR FTC
122	19	47	606	188.7	21.8	346	334	97	264	18	257	106	-25	161	-23	10	16	ORIENTATION CONTINUED
122	24	47	611	188.6	22.0	331	22	193	262	327	354	174	70	208	24	33	4	ORIENTATION CONTINUED
122	29	47	616	188.6	22.1	295	67	318	249	277	78	258	-19	244	-68	306	79	ORIENTATION CONTINUED
122	30	47	617	188.6	22.2	270	73	1	111	274	320	260	-40	0	-90	263	62	END ORIENTATION FOR FTC
122	30	47	617	188.6	22.2	270	73	1	111	274	320	260	-40	0	-90	263	62	BEGIN ESTABLISHMENT OF FTC
122	45	47	632	188.4	22.7	270	73	1	161	65	148	260	-40	0	-90	263	62	END ESTABLISHMENT OF FTC
151	18	46	2345	348.0	157.8	270	73	71	158	71	225	100	-54	90	-18	107	-65	END FTC
151	26	49	2353	347.8	157.6	270	73	71	158	71	225	99	-54	90	-18	107	-65	BEGIN ORIENTATION FOR FINE ALIGNMENT
151	31	49	2358	347.7	157.5	277	75	154	150	70	322	100	35	96	71	100	23	ORIENTATION CONTINUED
151	36	49	2363	347.5	157.3	286	76	235	143	69	58	251	54	266	19	241	64	ORIENTATION CONTINUED
151	41	49	2368	347.4	157.2	297	77	314	137	68	153	254	-33	253	-69	254	-22	ORIENTATION CONTINUED
151	42	49	2369	347.3	157.2	299	77	329	136	68	172	248	-50	197	-84	250	-39	END ORIENTATION FOR FINE ALIGNMENT
151	42	49	2369	347.3	157.2	299	77	329	136	68	172	248	-50	197	-84	250	-39	BEGIN FINE ALIGNMENT
151	53	45	2380	347.0	156.9	299	77	329	130	72	191	248	-50	197	-84	250	-39	END ALIGNMENT
151	53	55	2380	347.0	156.9	299	77	329	136	68	172	248	-50	197	-84	250	-39	BEGIN ORIENTATION FOR MCC NO. 5
151	54	55	2381	347.0	156.9	301	79	327	137	66	171	247	-50	203	-84	249	-38	END ORIENTATION FOR MCC NO. 5
152	11	44	2398	346.5	156.4	301	79	327	137	66	171	247	-50	203	-84	249	-38	MCC NO. 5
152	14	47	2401	346.4	156.3	301	79	327	137	66	171	247	-50	203	-84	249	-38	BEGIN ORIENTATION FOR FTC
152	19	47	2406	346.3	156.2	290	79	338	142	66	167	250	-51	203	-86	251	-40	ORIENTATION CONTINUED
152	24	47	2411	346.1	156.1	281	78	348	147	67	163	253	-53	204	-88	253	-41	ORIENTATION CONTINUED
152	29	47	2416	346.0	156.0	272	77	357	152	68	159	256	-54	204	-90	256	-42	ORIENTATION CONTINUED
152	30	47	2417	346.0	155.9	270	77	359	153	68	159	256	-54	0	-90	256	-42	END ORIENTATION
152	30	47	2417	346.0	155.9	270	77	359	153	68	159	256	-54	0	-90	256	-42	BEGIN ESTABLISHMENT OF FTC
152	45	47	2432	345.5	155.5	270	77	359	151	74	173	256	-54	0	-90	256	-42	END ESTABLISHMENT
197	4	17	5090	26.8	172.1	270	77	45	180	68	205	90	-65	90	-42	269	41	END FTC
197	5	31	5091	26.7	172.2	270	77	45	180	68	205	90	-64	90	-42	269	41	BEGIN ORIENTATION FOR HEAT SHIELD COOLDOWN
197	10	29	5096	26.2	172.6	348	35	336	86	42	293	165	-40	150	-23	328	22	CONTINUE ORIENTATION
197	13	59	5100	25.8	172.9	358	359	335	70	8	302	194	-17	180	-0	359	-1	END ORIENTATION

☐ Indicates Line of Sight Occluded By Earth or Moon

Table D-1 (Continued)

Phase 15 (Continued)

Transearth Coast

MISSION TIME			PHASE TIME	VEHICLE ALTITUDE		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		MOON DIRECTION		REMARKS
HR	MIN	SEC	MIN	EARTH	MOON	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV	
197	13	59	5100	25.8	172.9	358	359	335	70	8	302	194	-17	180	-0	359	-1	HEAT SHIELD COOL DOWN
198	38	06	5184	15.9	181.4	358	359	335	80	8	302	184	-12	180	0	0	0	BEGIN ORIENTATION FOR FINE ALIGNMENT
198	43	0	5189	15.2	182.0	352	335	351	63	350	319	205	-14	205	-2	25	2	ORIENTATION CONTINUED
198	48	0	5194	14.6	182.6	343	310	2	44	334	329	225	-27	228	-16	48	17	ORIENTATION CONTINUED
198	53	0	5199	13.9	183.2	316	288	355	20	320	332	248	-47	252	-37	71	37	ORIENTATION CONTINUED
198	54	0	5200	13.8	183.3	303	285	346	14	319	331	254	-51	257	-41	77	42	END ORIENTATION
198	54	0	5200	13.8	183.3	303	285	346	14	319	331	254	-51	257	-41	77	42	BEGIN FINE ALIGNMENT
198	57	27	5203	13.3	183.8	303	285	346	15	319	331	253	-50	257	-41	77	42	SUNSET
199	4	56	5211	12.2	184.8	303	285	346	17	319	331	251	-49	257	-41	77	42	END FINE ALIGNMENT
199	5	6	5211	12.2	184.8	303	285	346	17	319	331	251	-49	257	-41	77	42	BEGIN ORIENTATION FOR MC NO. 6
199	6	6	5212	12.1	185.0	301	287	350	17	321	337	247	-54	255	-47	75	48	END ORIENTATION FOR MC NO. 6
199	23	26	5229	9.5	187.6	301	287	350	23	321	337	243	-49	255	-47	75	48	MC NO. 6
199	26	25	5232	9.0	188.0	301	287	350	24	321	337	242	-48	255	-47	75	48	BEGIN ORIENTATION FOR SEPARATION
199	31	25	5237	8.2	188.9	262	298	314	9	331	328	257	-53	273	-50	94	51	ORIENTATION CONTINUED
199	36	25	5242	7.4	189.8	246	314	303	357	344	323	275	-54	291	-47	112	48	ORIENTATION CONTINUED
199	41	25	5247	6.6	190.7	238	331	298	347	357	322	290	-51	303	-39	125	40	ORIENTATION CONTINUED
199	42	25	5248	6.4	190.9	237	335	298	346	0	322	293	-50	305	-38	127	38	END ORIENTATION
199	43	36	5249	6.2	191.1	237	335	298	347	0	322	291	-50	305	-38	127	38	BEGIN FINE ALIGNMENT
199	54	32	5260	4.4	193.4	237	335	298	357	0	322	275	-52	305	-38	127	38	END ALIGNMENT
199	59	20	5265	3.5	194.5	237	335	298	3	0	322	265	-52	305	-38	127	38	SUNRISE
200	16	28	5282	0.7	199.3	237	335	298	46	0	322	211	-33	305	-38	127	38	CM/SM SEPARATION
200	16	35	5282	0.7	199.4	237	335	298	46	0	322	210	-33	305	-38	127	38	BEGIN ORIENTATION FOR ENTRY
200	17	35	5283	0.5	199.7	313	329	16	117	0	0	180	27	193	-51	11	52	END ORIENTATION
200	23	27	5289	0.1	201.6	313	329	16	147	-0	0	180	57	193	-51	11	52	ENTRY INTERFACE

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Table D-1 (Continued)

Phases 16 & 17

Entry & Parachute Descent

MISSION TIME			PHASE TIME	VEHICLE POSITION		INERTIAL ATTITUDE			LOCAL ATTITUDE			EARTH DIRECTION		SUN DIRECTION		STATION ONE DIRECTION		SPLASHDOWN SITE DIRECTION		REMARKS	
HR	MIN	SEC	MIN	LONG	LAT	THETA	PSI	PHI	THETA	PSI	PHI	AZI	ELV	AZI	ELV	AZI	ELV	AZI	ELV		
200	23	26	0	170	28	318	32	195	146	0	-0	180	56	194	-52	318	48	327	49	PHASE 16.0 ENTRY	SH1
200	23	26	0	170	28	318	32	195	146	0	-0	180	56	194	-52	318	48	327	49	BEGIN ENTRY	SH1
200	23	56	1	173	27	320	32	194	148	0	-0	180	58	195	-53	257	54	327	46	ENTER S-BAND BLACKOUT REGION	SH1
200	24	16	1	175	27	322	24	178	150	8	344	149	54	193	-48	162	-7	323	51	AUTOMATIC STEERING	SH1
200	24	40	1	177	26	320	35	199	151	358	4	190	61	195	-55	166	-16	328	37	AUTOMATIC STEERING	SH1
200	25	6	2	179	25	305	1	127	178	27	275	92	4	185	-15	0	-0	341	53	AUTOMATIC STEERING	.....
200	25	12	2	179	25	283	360	81	200	18	220	64	-40	175	2	0	-0	16	31	INITIATE UPCONTROL PHASE	.....
200	25	24	2	180	24	320	39	203	154	355	9	202	62	198	-57	0	-0	330	31	AUTOMATIC STEERING	.....
200	25	56	3	182	23	318	41	210	156	353	14	214	61	195	-57	0	-0	333	26	AUTOMATIC STEERING	.....
200	26	20	3	183	23	319	43	215	157	351	18	221	59	192	-59	0	-0	334	23	AUTOMATIC STEERING	.....
200	26	36	3	184	22	321	41	208	156	353	14	213	62	194	-60	0	-0	332	25	AUTOMATIC STEERING	.....
200	26	52	3	185	22	308	51	257	163	341	44	249	39	178	-54	0	-0	348	10	CONSTANT BANK ANGLE	.....
200	26	56	4	185	22	305	52	266	165	339	49	253	34	175	-52	353	9	351	8	CONSTANT BANK ANGLE	SH2
200	27	12	4	186	21	309	52	261	163	340	46	251	36	175	-54	350	12	350	9	CONSTANT BANK ANGLE	SH2
200	27	36	4	187	21	315	52	253	161	341	42	247	40	174	-57	345	17	347	11	CONSTANT BANK ANGLE	SH2
200	27	46	4	188	20	317	52	249	161	342	39	245	41	174	-58	341	20	346	11	BEGIN CONTROLLED SKIPOUT	SH2
200	28	26	5	190	19	319	55	259	161	340	46	248	35	165	-56	251	49	349	9	CONTROLLED SKIPOUT CONTINUED	SH2
200	28	56	6	191	18	324	54	251	160	341	43	246	38	163	-59	190	18	347	10	END CONTROLLED SKIPOUT	SH2
200	29	16	6	192	18	329	54	244	158	342	40	243	40	162	-61	182	10	346	11	CONSTANT BANK ANGLE	SH2
200	29	40	6	193	17	329	56	254	159	340	45	246	35	154	-58	183	7	349	8	CONSTANT BANK ANGLE	SH2
200	29	54	6	194	17	329	56	258	160	339	48	248	33	149	-56	184	6	350	7	BEGIN GLIDE PHASE	SH2
200	30	6	7	195	16	344	45	200	152	351	18	216	55	187	-75	0	-0	331	22	GLIDE PHASE	.....
200	30	30	7	196	16	343	51	219	154	346	30	232	46	159	-69	0	-0	339	16	GLIDE PHASE	.....
200	30	56	8	197	15	333	57	263	161	338	52	250	29	136	-52	0	-0	353	6	GLIDE PHASE	.....
200	31	20	8	198	14	337	55	253	160	339	48	247	32	133	-54	347	5	351	7	GLIDE PHASE	PSH
200	31	36	8	199	14	332	54	265	163	337	56	252	26	131	-47	350	1	354	4	GLIDE PHASE	PSH
200	31	50	8	199	14	335	6	130	168	25	293	101	12	227	-25	319	67	322	62	LEAVE S-BAND BLACKOUT REGION	PSH
200	32	12	9	200	13	348	23	157	154	12	336	134	52	237	-57	303	55	313	51	GLIDE PHASE	PSH
200	32	28	9	200	13	341	16	141	161	21	310	110	32	235	-34	305	76	318	64	GLIDE PHASE	PSH
200	32	42	9	200	13	328	62	288	167	335	66	258	18	124	-42	324	-7	349	3	GLIDE PHASE	PSH
200	32	56	10	201	13	341	57	263	160	338	54	250	27	121	-49	295	0	337	11	GLIDE PHASE	PSH
200	33	6	10	201	13	335	57	282	164	335	67	255	16	121	-37	281	-12	338	5	GLIDE PHASE	PSH
200	33	16	10	201	13	342	8	128	163	25	291	106	13	236	-22	130	28	15	60	GLIDE PHASE	PSH
200	33	36	10	201	12	354	17	138	150	21	313	122	27	254	-34	143	6	88	69	GLIDE PHASE	PSH
200	33	46	10	201	12	344	65	307	159	332	78	252	2	108	-27	231	-23	303	-1	GLIDE PHASE	PSH
200	33	56	11	201	12	4	57	275	147	333	62	240	10	90	-34	223	-21	274	9	GLIDE PHASE	PSH
200	34	6	11	201	12	354	2	121	149	30	283	116	-3	253	-10	132	-35	116	20	GLIDE PHASE	PSH
200	34	16	11	201	12	4	10	126	137	28	293	127	-1	274	-8	134	-39	132	16	GLIDE PHASE	PSH
200	34	26	11	201	12	8	17	124	132	27	283	132	-11	282	10	135	-39	135	0	GLIDE PHASE	PSH
200	34	36	11	201	12	45	58	321	131	335	95	223	-22	42	-3	216	-9	225	-23	GLIDE PHASE	PSH
200	34	59	0	201	12	36	351	116	90	329	86	182	-31	30	43	247	2	185	-31	PHASE 17.0 PARACHUTE DESCENT	PSH
200	34	59	0	201	12	36	351	116	90	329	86	182	-31	30	43	247	2	185	-31	DROGUE CHUTE DEPLOYMENT	PSH
200	36	31	1	201	12	86	25	317	88	331	86	180	-29	344	3	0	-0	185	-29	MAIN CHUTE DEPLOYMENT	.....
200	38	26	3	201	12	89	13	6	88	331	86	180	-29	351	-4	0	-0	189	-29	DESCENT ATTITUDE	.....
200	41	16	6	201	12	90	14	1	88	331	86	180	-29	350	-3	0	-0	274	-3	SPLASHDOWN	.....

☐ Indicates Line of Sight Occluded By Earth or Moon

D.4 REFERENCES

D.1 Shapiro, M. and Bigliani, R. "Recommended LM Attitude for the DRM II Mission." LMO-500-372. 22 November 1965.

D.2 Nathan, A. "Trajectory and Attitude Constraints for the LM Volume II. Attitude Constraints." GAEC Report No. LED-500-7, 1 August 1965.

D.3 Botkin, E. "LM Alignment Optical Telescope (AOT). Utilization at the Lunar Site." GAEC LMO-500-317, 31 August 1965.

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APPENDIX E CSM/LM DUTY CYCLES

E.1 INTRODUCTION

The Subsystem duty cycles described in this appendix are included to provide information for the evaluation of subsystem usage during the design reference mission. The data has been derived from the Volume III mission timeline and the Volume II preflight sequence of operations.

The mission timeline is based upon trajectory requirements and the ground rules defined in Volume I and Appendices. Subsystem utilization has been minimized within the bounds of the ground rules; in some instances, the minimum "on time" criteria were not observed due to excessive crew task loading. In other instances, routine tasks or tasks called by the ground rules have not been performed due to crew sleep cycles or interference by essential spacecraft operations.

E.1.1 Data Presentation

The duty cycles are presented in the form of plots generated by computer CRT.

E.1.1.1 Duty Cycle Plots

The duty cycle CRT plots have as axes the subsystem or component and the mission time. Mission time is plotted horizontally. The time ranges have been selected to give the best visibility for the activities depicted in that interval: therefore, the scale may vary from page to page. The mission time and subdivision scale are shown at the bottom of each page.

The subsystem or components are listed vertically. Each has been assigned a line number and title which remains constant for all pages.

"On time" equipment is shown as a horizontal bar opposite the subsystem or component. Operations which have a short "on time" or are instantaneous are depicted by a symbol instead of a bar. Switching operations and mode changes may be inferred by counting bars. The mission phase number, phase title, and major mission events appear in line 50 of each page. Specific information affecting duty cycles are printed on the plots.

Section E.2 contains descriptive information required for interpretation of the duty cycle plots. Equipment configuration are discussed and, where applicable, the percent duty cycles are specified.

E.1.1.2 Low Usage CSM Equipment

Table E-1 contains a listing of certain low usage CSM equipments. These equipments were tabulated rather than plotted to conserve space.

E.1.2 Section Criteria

The data selected for inclusion in the CRT plots (Figure E-1, and E-2) have been restricted to items which are power consumption related, have a direct impact upon consumables expenditures, or are reliability sensitive. Duty cycles for components which are passive or do not meet these criteria may be derived from the mission timeline.

Since the Design Reference Mission is a nominal mission, unused contingency modes or equipment are not shown.

E.2 DUTY CYCLE DESCRIPTION

E.2.1 CSM

E.2.1.1 Guidance, Navigation and Control System

Five modes have been utilized to depict duty cycles for the Guidance, Navigation and Control Subsystem.

Mode	Title	Activity	AGE Equipment
A	Maneuver and Monitor	Accomplish and confirm course corrections, major maneuvers	AGC - Operate IMU - Operate D&C - Operate
B	IMU Alignment	Coarse IMU alignment, Fine IMU alignment, Landmark Tracking	AGC - Operate Optics - Operate IMU - Operate D&C - Operate
C	Monitor and Compute	Computation, update	AGC - Operate IMU - Standby D&C - Operate

Mode	Title	Activity	AGE Equipment
D	Navigate	Midcourse navigation	AGC - Operate IMU - Standby Optics - Operate D&C - Operate
E	Standby	Inactivity	IMU - Standby AGC - Standby D&C - Standby

The entry monitor is used for all SPS-powered maneuvers. Just prior to being placed in the operate mode, a self test is made which has a duration of 13 seconds. The entry monitor "on time" shown starts at initiation of the self test.

E.2.1.2 Stabilization and Control System

The SCS is used for primary attitude control during one set of star navigation sightings, lunar orbit, and heat shield cool down portions of the mission. When the SCS is used as primary attitude control, the 4.2° D.B. attitude hold mode is used.

Since the SCS has a larger number of operating modes than specific major components, the duty cycles are depicted on the major component level for clarity as follows:

- Gyro Display Coupler Electronics (GDC)
- Electronic Control Assembly Electronics (ECA)
- FDAI (1)
- FDAI (2)
- Thrust Vector Control Amplifiers (TVC) (both)
- Hand Controllers (both)
- BMAG's Warm up (both)
- BMAG's Operate (both)

E.2.1.3 Communications

During a nominal mission the communications system uses only transmit and receive primary modes. The spacecraft will have 100% ranging, voice, and updata communications capability except when lunar occlusion exists. Lo-bit rate down data shall be transmitted continuously except during hi-bit rate transmissions.

The VHF "on time" shown depicts the switch on and off intervals. Voice transmission may be assumed to occur 16 - 20 percent of the available time. During astronaut sleep cycles in lunar orbit the receive only VHF mode is used and so noted on the CRT plots.

The following equipment operates continously during all mission phases:

- Signal Conditioning
- Central Timing
- Pre-modulation Processor
- S-Band Transponder

Other communication and modal duty cycles are shown in the accompanying plots. It should be noted that for tape playback operation 3.75 minutes are required to playback two hours of recorded data plus rewind time of 3.75 minutes. Unless otherwise noted on the plots, the tape recorder runs at 3.75 in/sec record speed and 120 in/sec playback speed.

Recovery aids are actuated at main chute deployment. Since recovery occurs at one hour after touchdown, it has been assumed that only HF/AM voice mode is used prior to pickup and the HF single side band mode is not. Recovery equipments are shown in Table E-1.

E.2.1.4 Electrical Power System

The three fuel cell modules are activated at T - 015:15:00 hours and are operated on GSE reactants until T - 012:20:00 hours. The fuel cells acquire only a portion of the spacecraft loads sufficient to maintain temperature upon transfer to SC reactants. At T - 000:15:00 hours, the fuel cells pick up all spacecraft loads.

For peak power periods of spacecraft operation, the EPS is configured in the powered-up mode. During these mode times the following equipment is utilized:

- Batteries A and C on busses
- Inverters 1 and 2 busses
- Inverter 3 idle
- Battery charger duty cycles are plotted.

E.2.1.5 Service Propulsion System

The SPS gimbal motors duty cycles are shown for those applicable phases. The gimbal motor "on time" is shown, but the time for clutch engagement is not. Clutch engagement time would be dependent on burn duration plus time to acquire nozzle orientation.

The SPS propellant gauging system is activated at gimbal motor turn on and utilized for eight minutes following a burn. SPS controls and displays are checked periodically and used for a period of 15 seconds during such checks.

E.2.1.6 Reaction Control System

The reaction control system heaters are thermostatically controlled when their utilization is necessary. As is shown in the following plots, the heaters are armed whenever the spacecraft is in an attitude hold. During these periods, the quad heater normal to the sun has a 0% duty cycle, the quad opposite to the sun has approximately a 100% duty cycle, and the two remaining heaters have approximately a 50% duty cycle.

Refer to Table E-1 for CM RCS usage.

E.2.1.7 Sequential Events Control System

The SECS is composed of several subsystems the logic of which is specified by the Master Events Sequence Controller. The utilization of the MESC is shown and which logic is used may be inferred from the mission event and is noted on the plots. Pyrotechnic battery usage may be inferred from SECS utilization.

E.2.1.8 Environmental Control System

The ECS becomes operational at T - 001:20:00 with closure of the CM hatch. Transfer to onboard ECS consumables occurs at T - 000:01:00.

Most ECS equipment operates at 100% duty cycle for the entire mission except the following:

- Cyclic Accumulator
  10 seconds every 10 minutes
- Potable Water Heater
  10 watts constant power plus 35 watts additional power to make up 10 ounces of water in 30 minutes for meals.
- Radiator Heaters
  Thermostatically controlled and having the same armed time as the RCS quad heaters.
- Post Landing Fan
  Actuated at touchdown and operational until pickup.

Refer to Table E-1 for the ECS pump utilization.

E.2.1.9 Lighting, Displays and Controls, Instrumentation

The following duty cycles are necessary as indicated for the reference mission:

- Caution and Warning System
  100% from T - 001:20:00 to touchdown.
- Instrumentation
  100% from T - 011:20:00 to touchdown.

- Variable MDC Floodlights
  10% from T - 001:20:00 to touchdown
- Scientific Instrumentation
  A block power allotment of 10 KWH for the mission has been made with no specific usage known.

Refer to the Table E-1 for additional equipment usage.

E.2.1.10 Cryogenic Storage System

No duty cycles for the cryogenic storage system are shown. The duty cycles for this system are defined by first constructing a preliminary power profile using data from this report. Analysis of the preliminary profile will yield a final power profile and the duty cycle for this system.

TABLE E-1

CSM MISC EQUIPMENT DUTY CYCLES

	MISSION		TIME IN HMS	
	ON	OFF	DURATION	CUM TIME
EMERG DETEC SYS	-00.25.00	001.58.30	002.23.30	002.23.30
LM POWER	002.18.33	066.21.43	064.03.10	064.03.10
URINE DUMP HEATER	004.32.32	199.58.53	195.26.21	195.26.21
TUNNEL LIGHTS	002.09.56	002.21.33	000.11.37	000.11.37
	065.47.39	069.03.58	003.16.19	003.27.56
	108.02.43	109.00.21	000.57.38	004.25.34
DOCKING LIGHTS	002.00.00	002.06.15	000.06.15	000.06.15
	069.04.00	069.12.30	000.08.30	000.14.45
	107.55.28	108.02.47	000.07.19	000.22.04
DOCKING PROBE CIRCUIT	001.00.13	001.00.19	000.00.06	000.00.06
	001.59.58	002.13.03	000.13.05	000.13.11
	069.05.30	069.05.56	000.00.26	000.13.37
	108.00.00	108.02.39	000.02.39	000.16.16
RENDEZVOUS RADAR	063.25.03	065.27.01	000.01.58	000.01.58
	069.08.13	070.38.03	001.29.50	001.31.48
	072.19.03	073.01.27	000.42.24	002.14.12
	103.02.06	103.15.45	000.13.39	002.27.51
	105.29.40	108.02.55	002.33.15	005.01.06
RENDEZVOUS LIGHTS	069.03.52	070.34.17	001.30.25	001.30.25
	107.30.08	108.02.45	000.31.37	002.02.02
HF (AM OR BEACON)	200.38.22	201.38.22	001.00.00	001.00.00
VHF BEACON	200.36.47	201.38.22	001.01.35	001.01.35
POST LANDING FAN	200.38.24	201.38.22	000.58.00	000.58.00
ECS PUMP	-01.45.00	200.38.22	202.23.22	202.23.22
CM-RCS HEATER	199.27.33	199.54.54	000.27.31	000.27.31
CM-RCS ON	200.16.28	200.38.22	000.16.54	000.16.54
CM-RCS DUMP	200.36.41	200.38.22	000.01.41	000.01.41

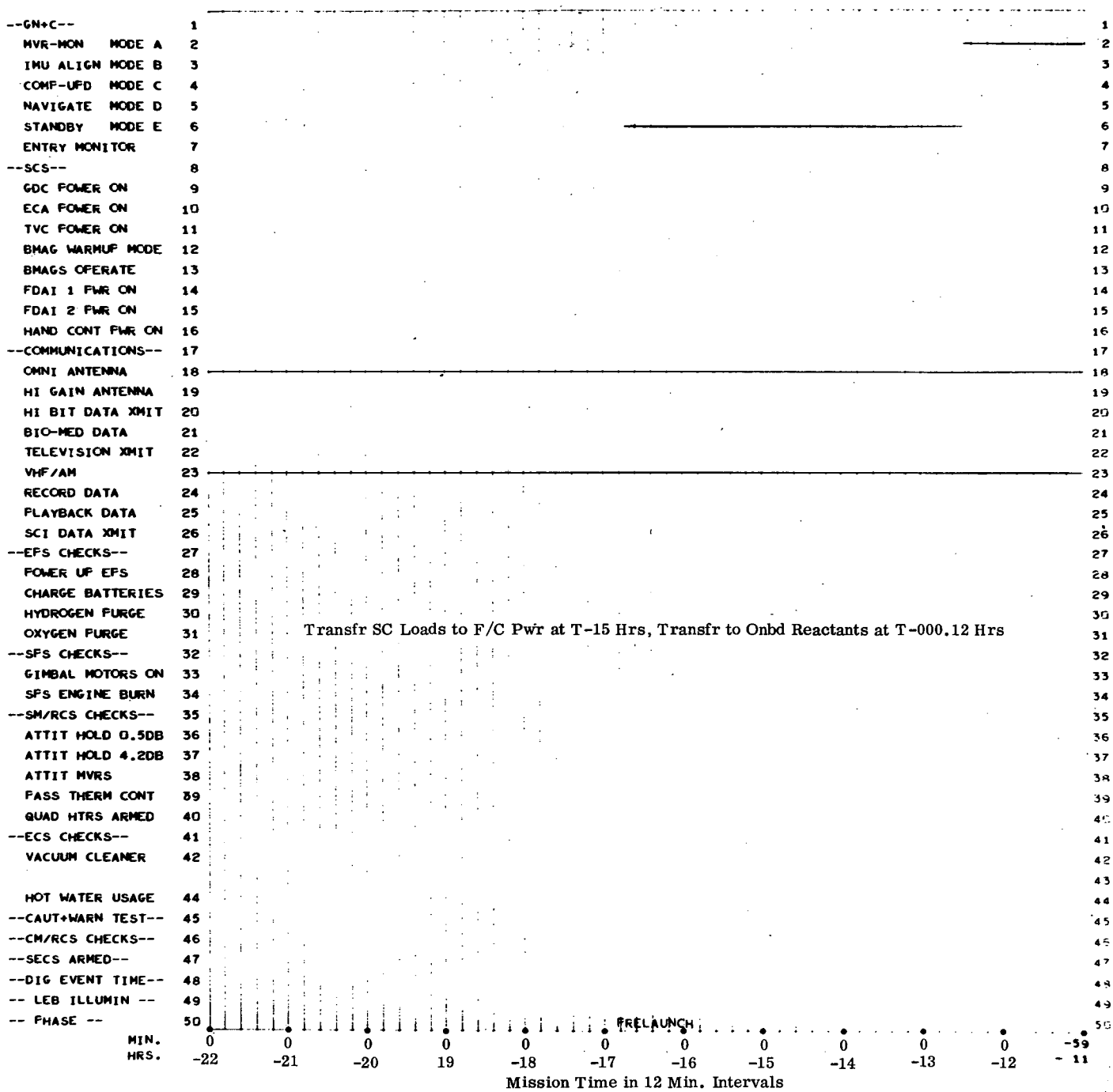


Figure E-1 CSM Duty Cycles

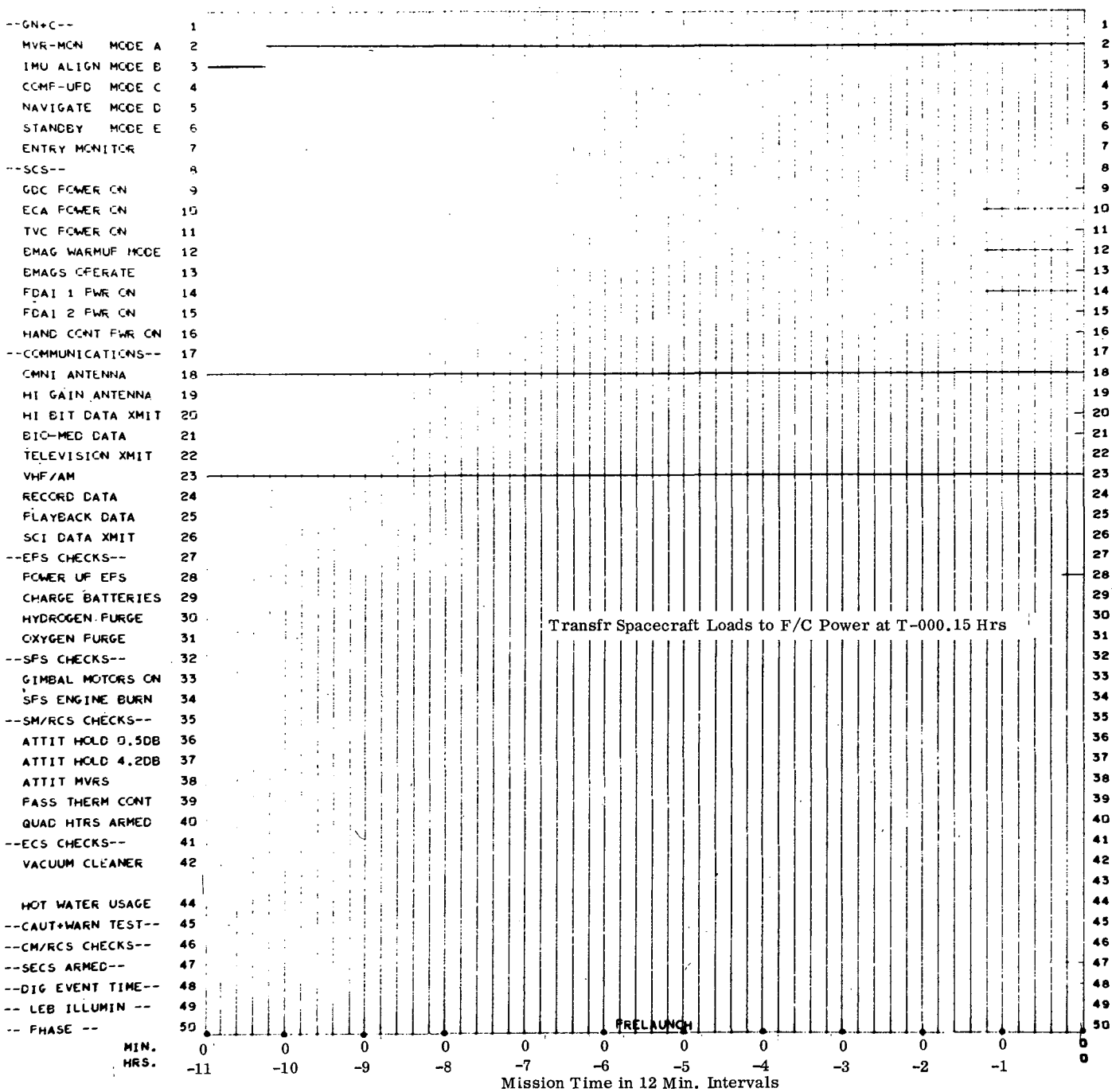
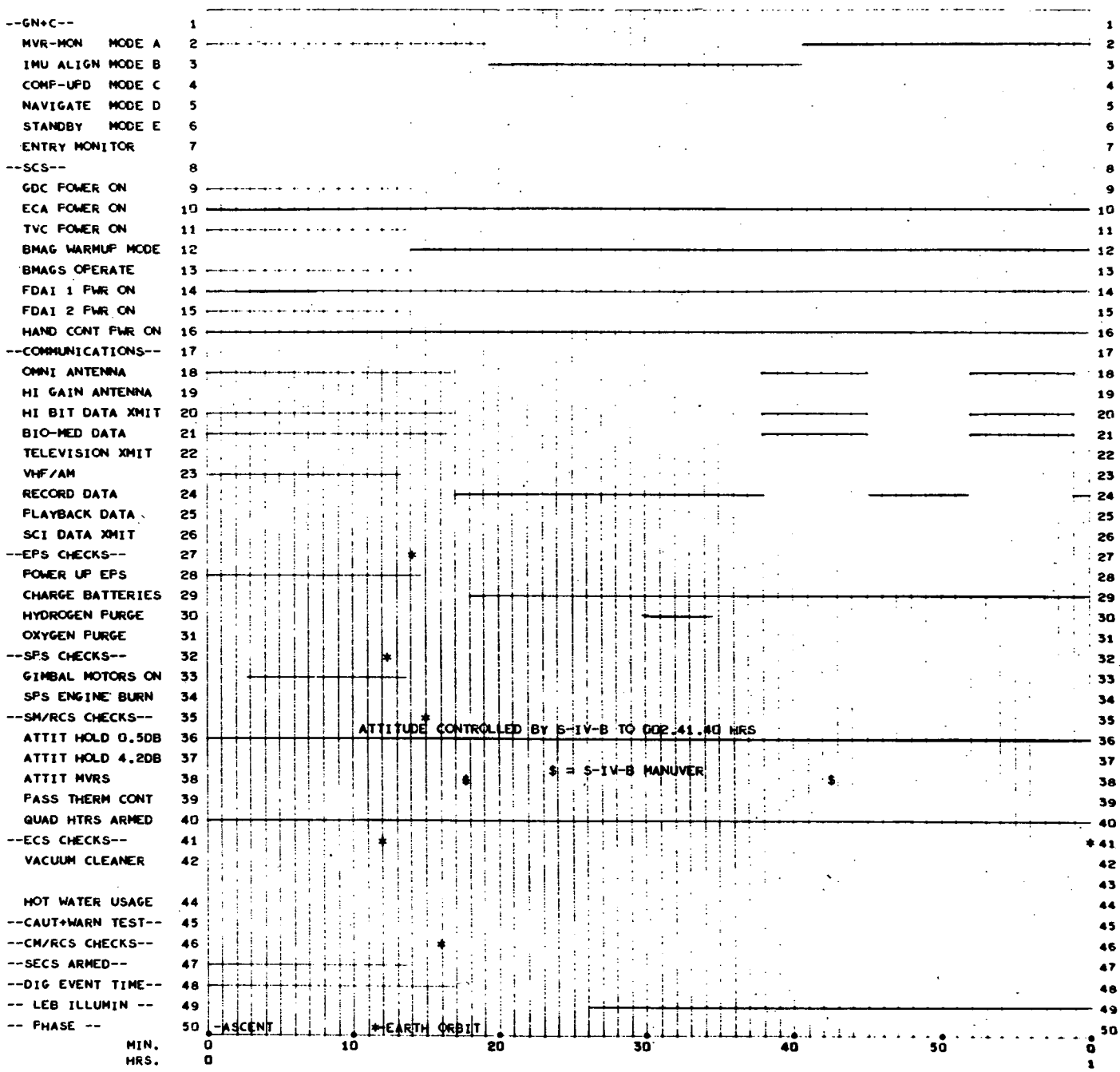
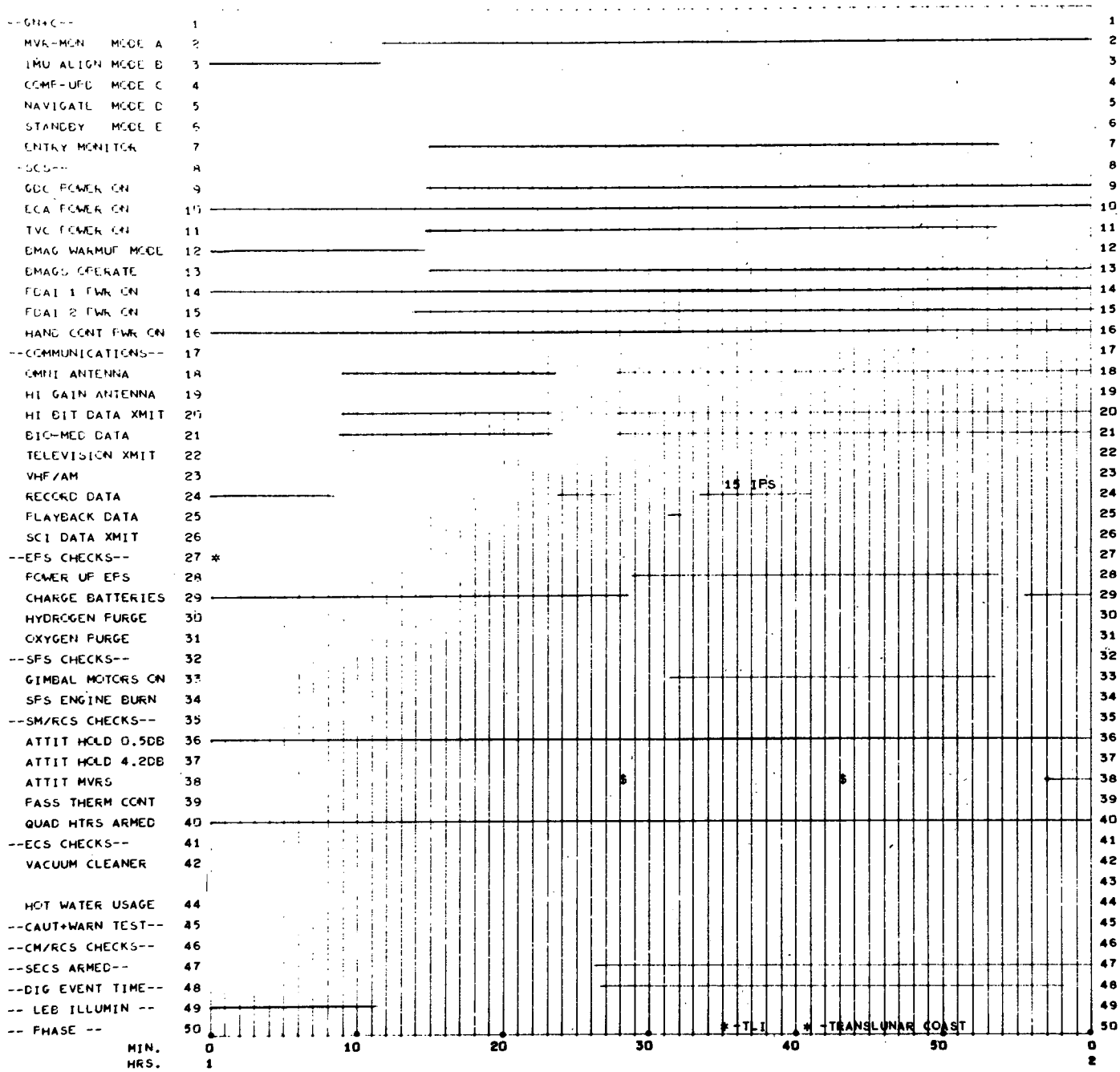


Figure E-1 CSM Duty Cycles (Continued)



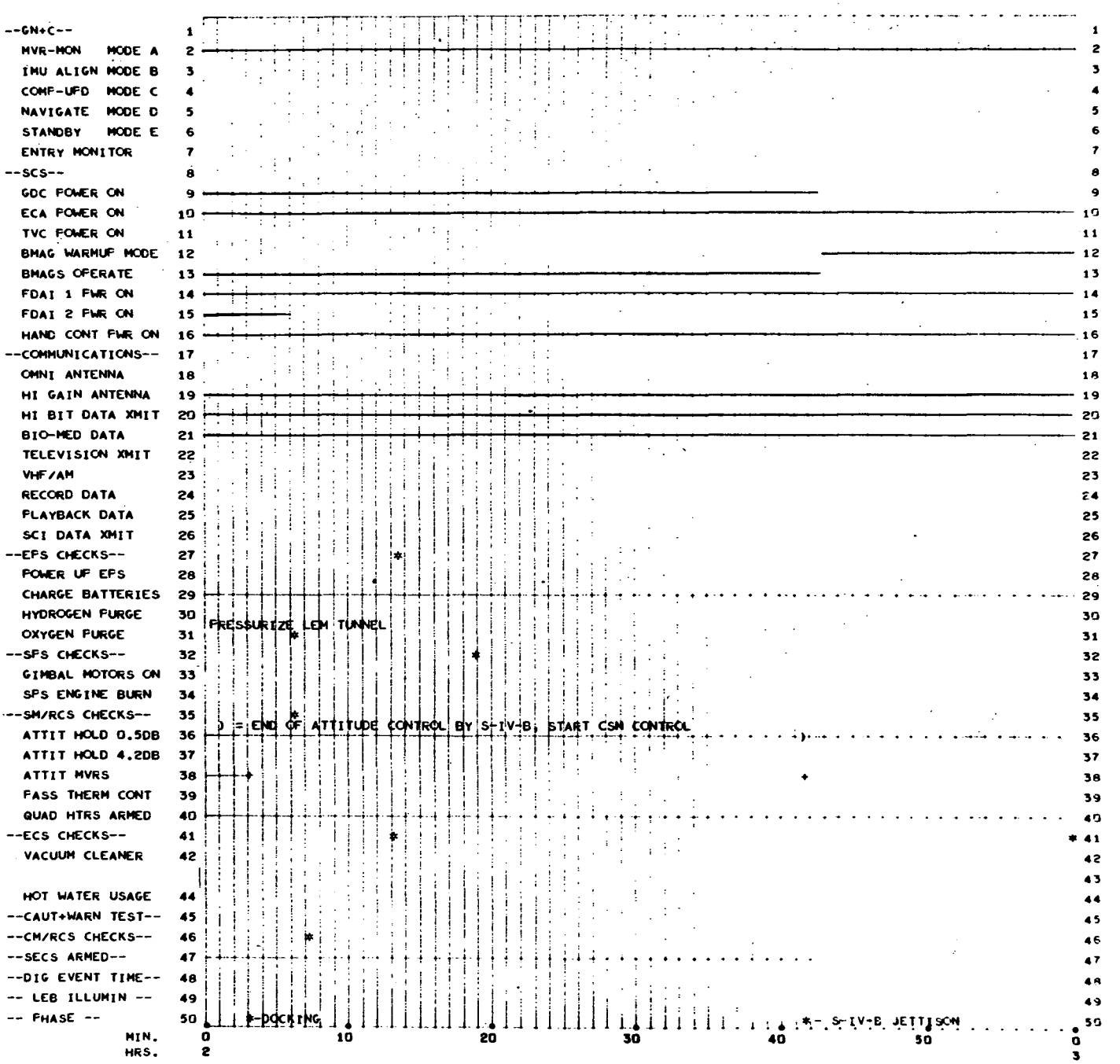
Mission Time in 1 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



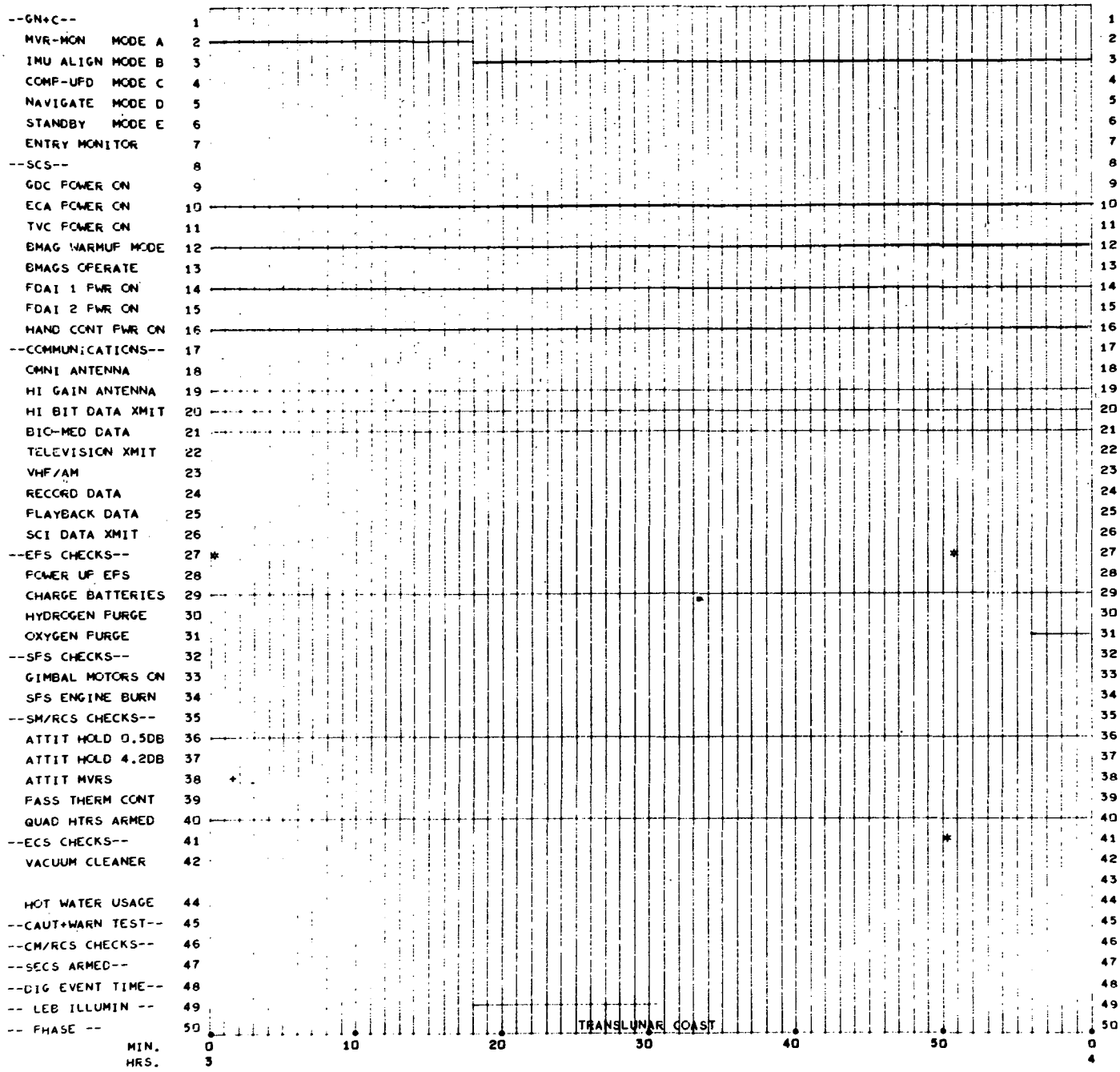
Mission Time in 1 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



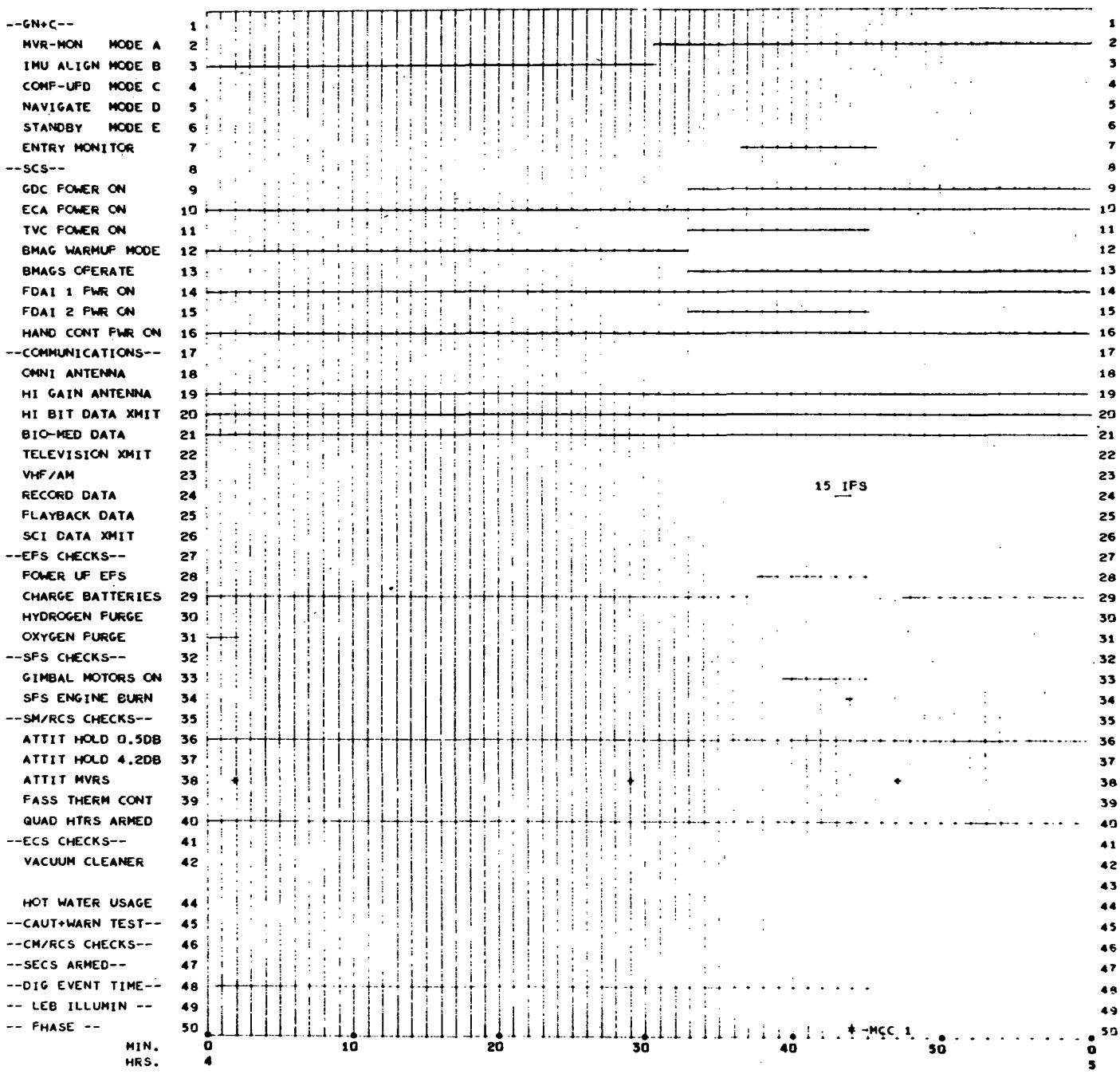
Mission Time in 1 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



Mission Time in 1 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



Mission Time in 1 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)

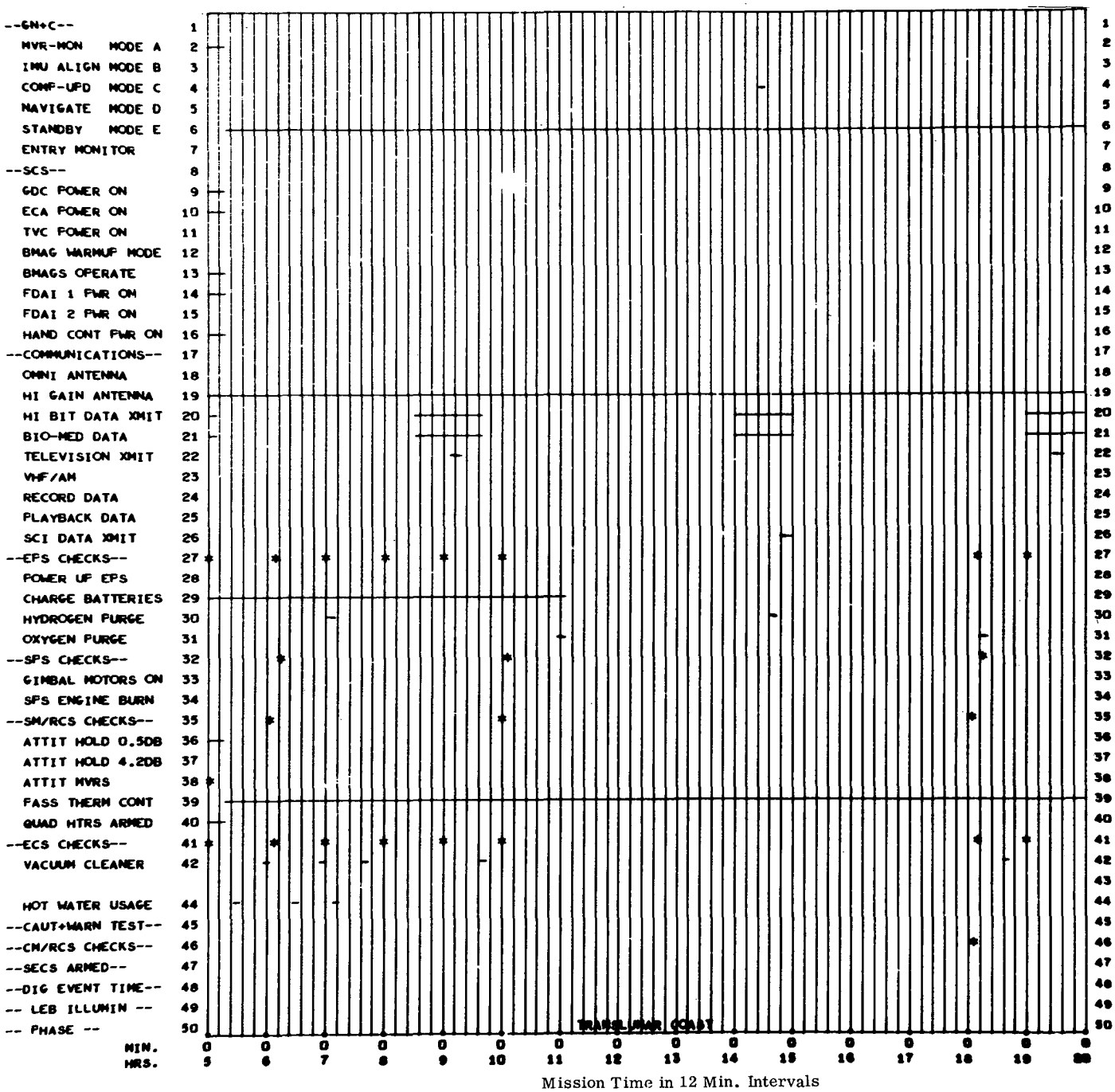
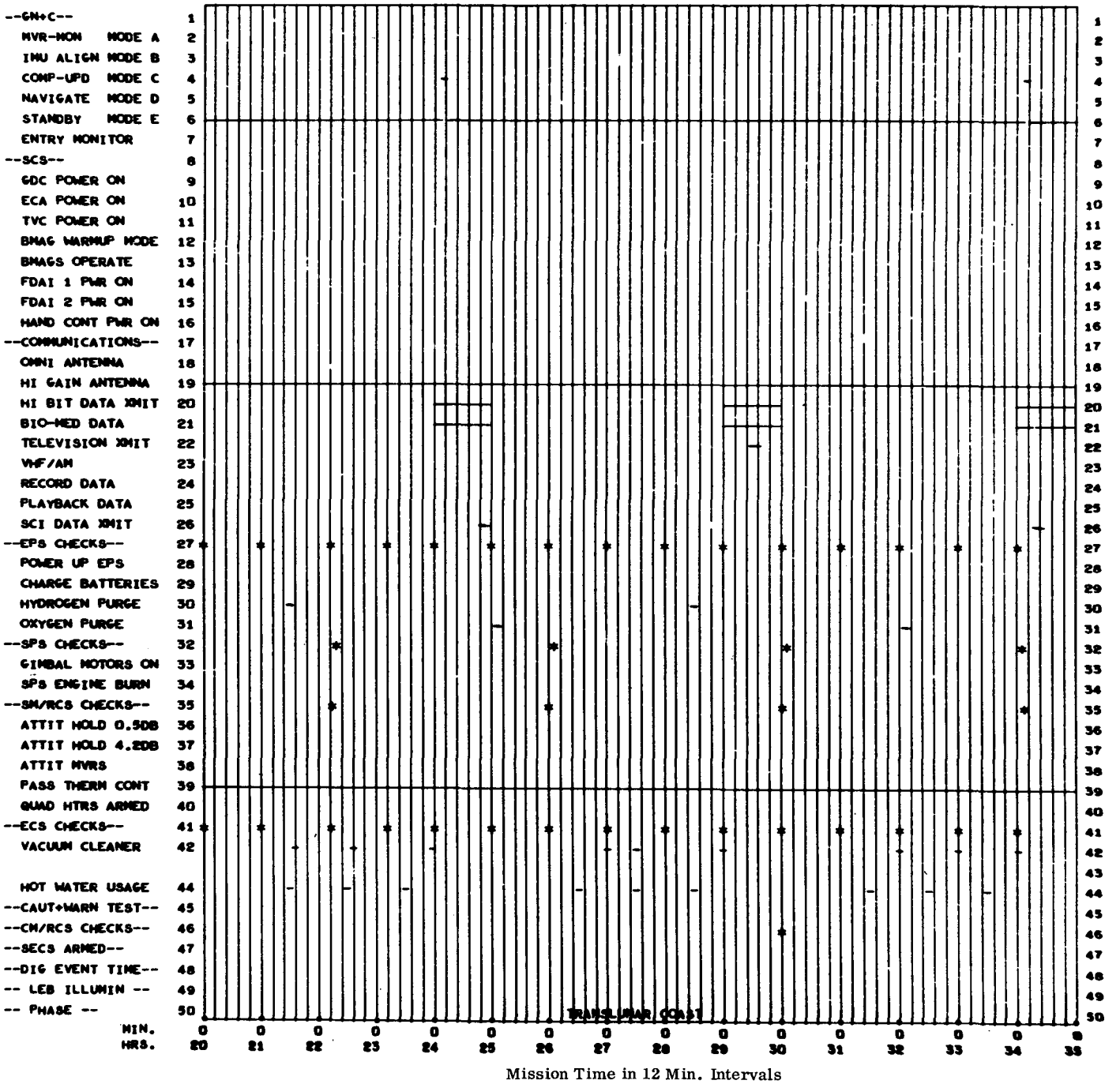


Figure E-1 CSM Duty Cycles (Continued)



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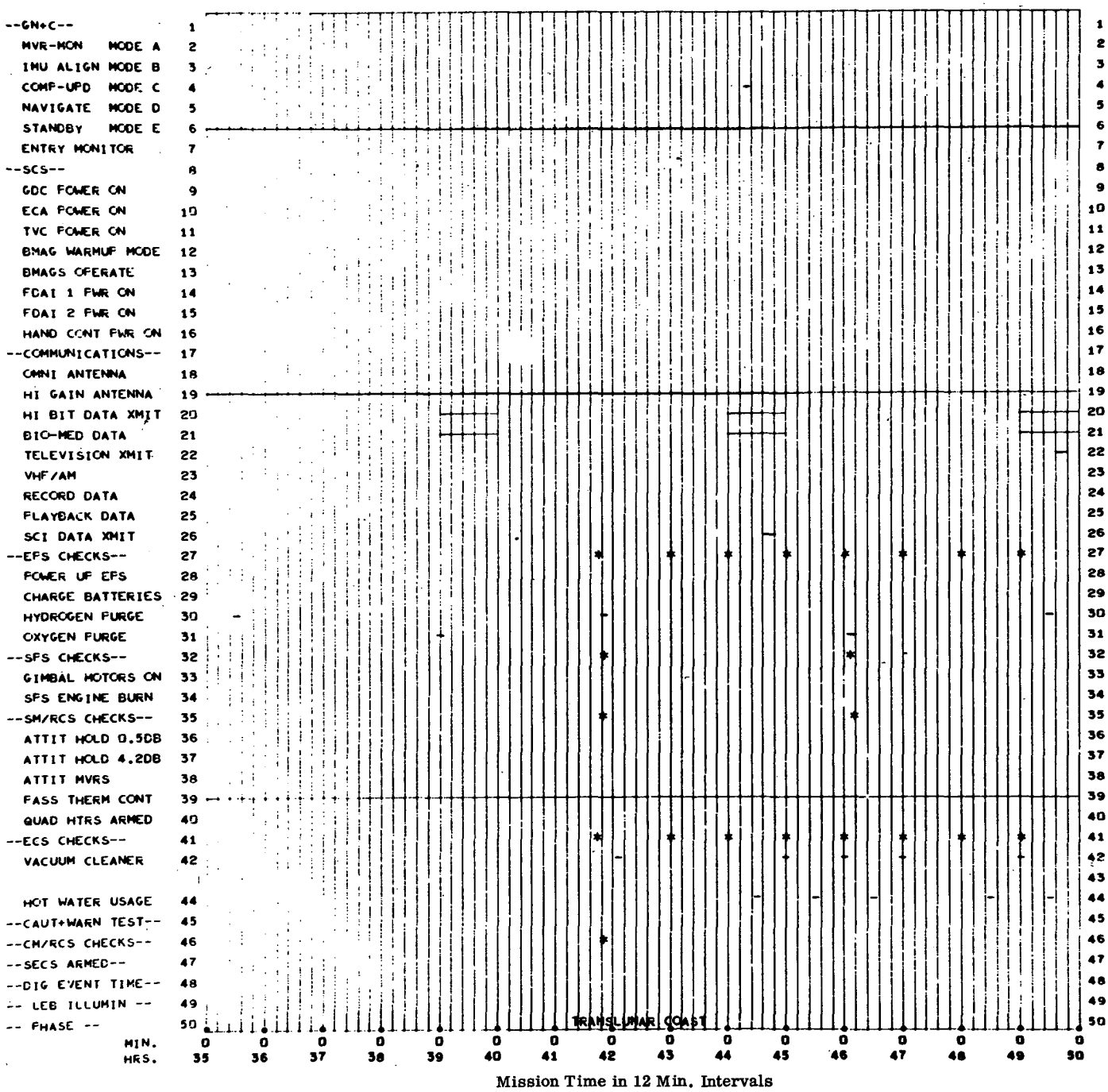

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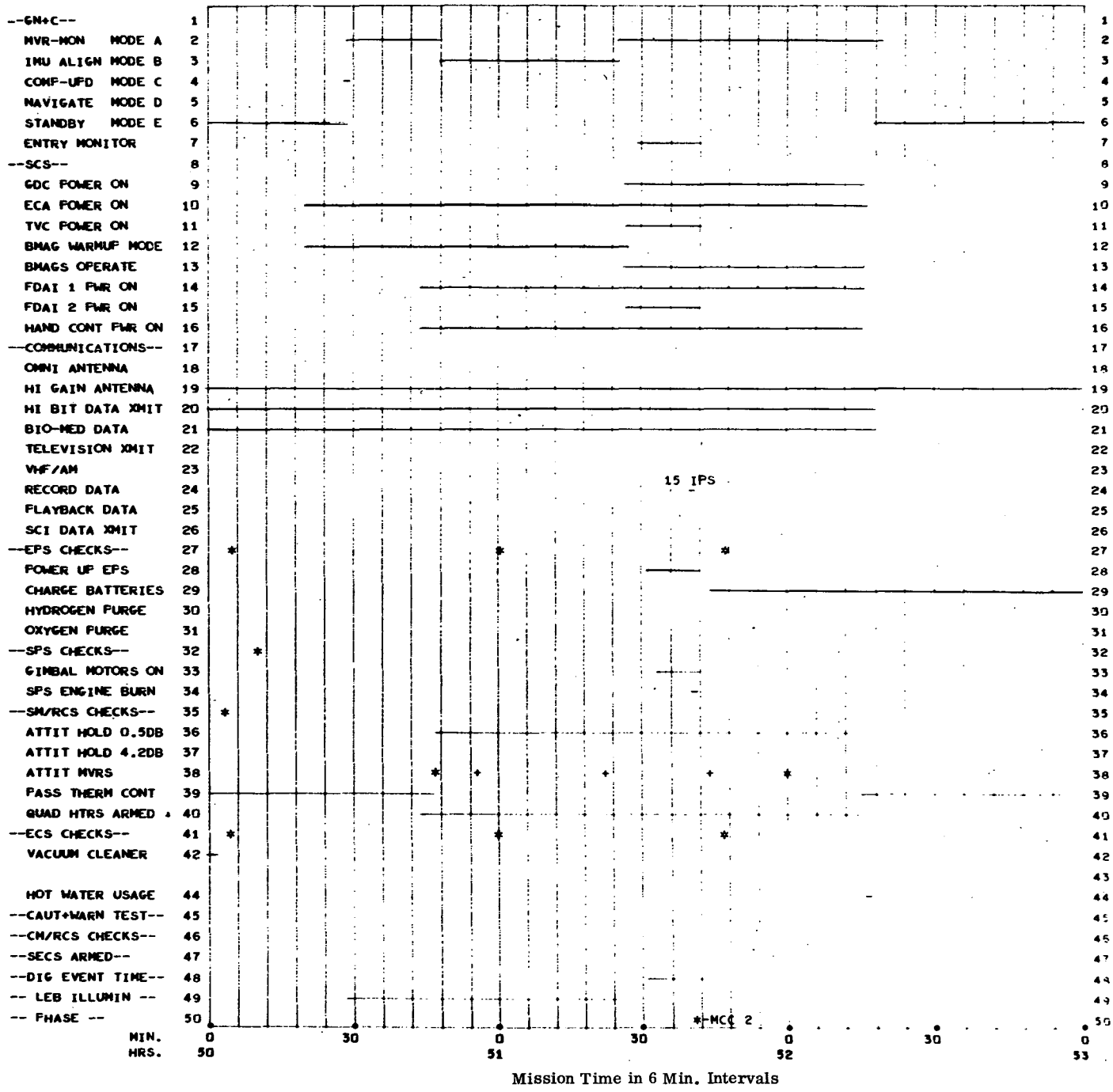

Mission Time in 6 Min. Intervals

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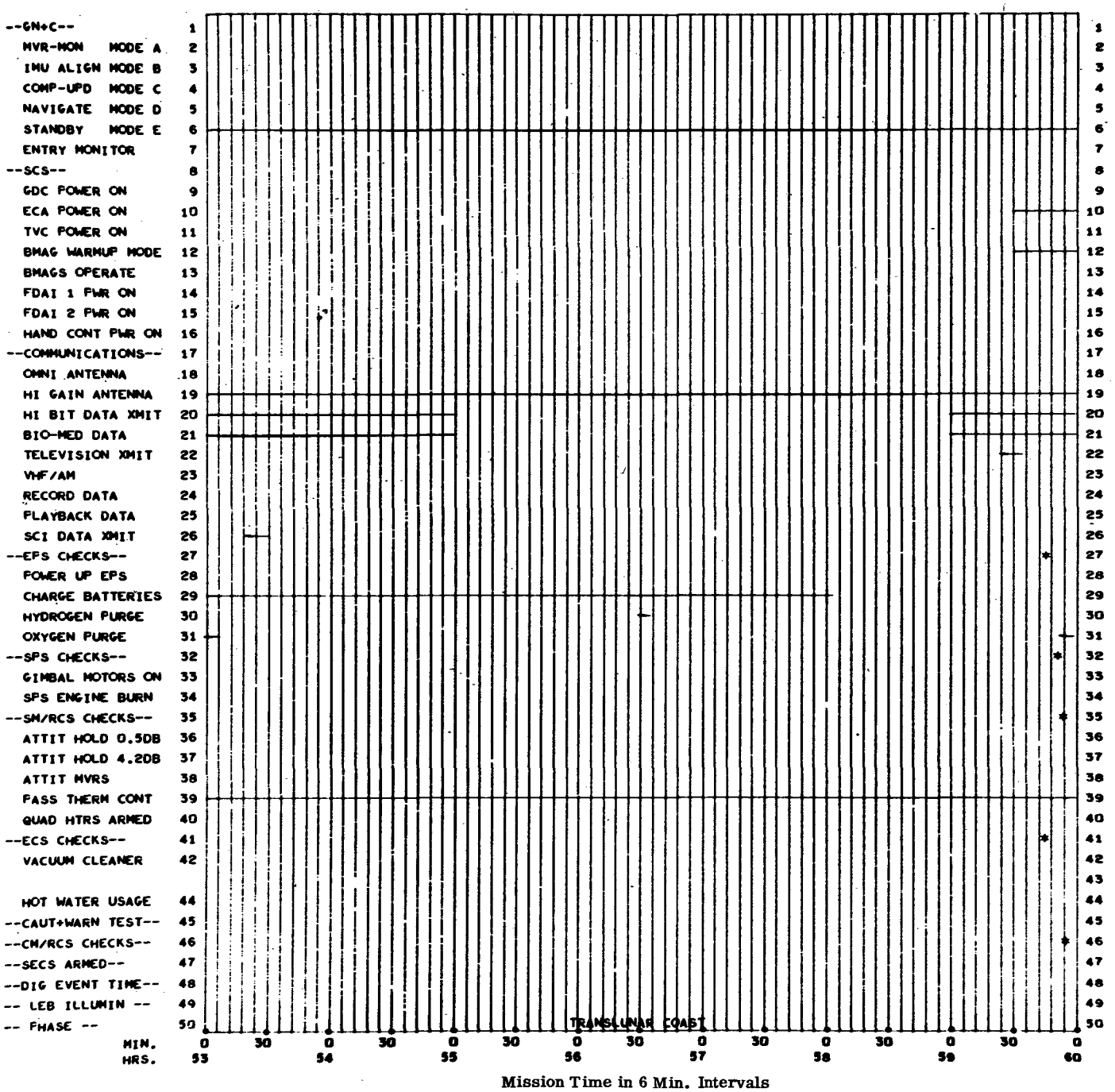
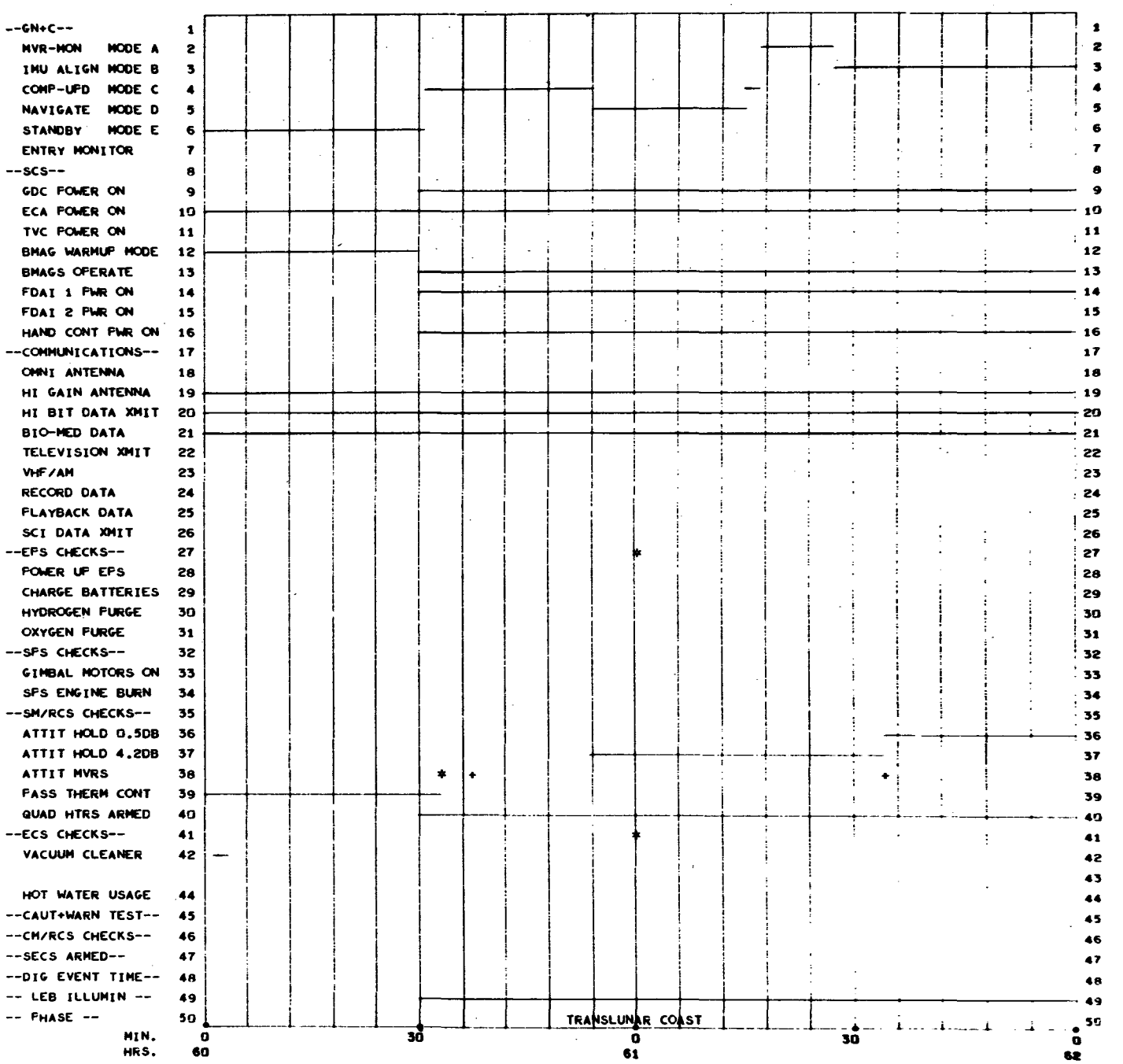


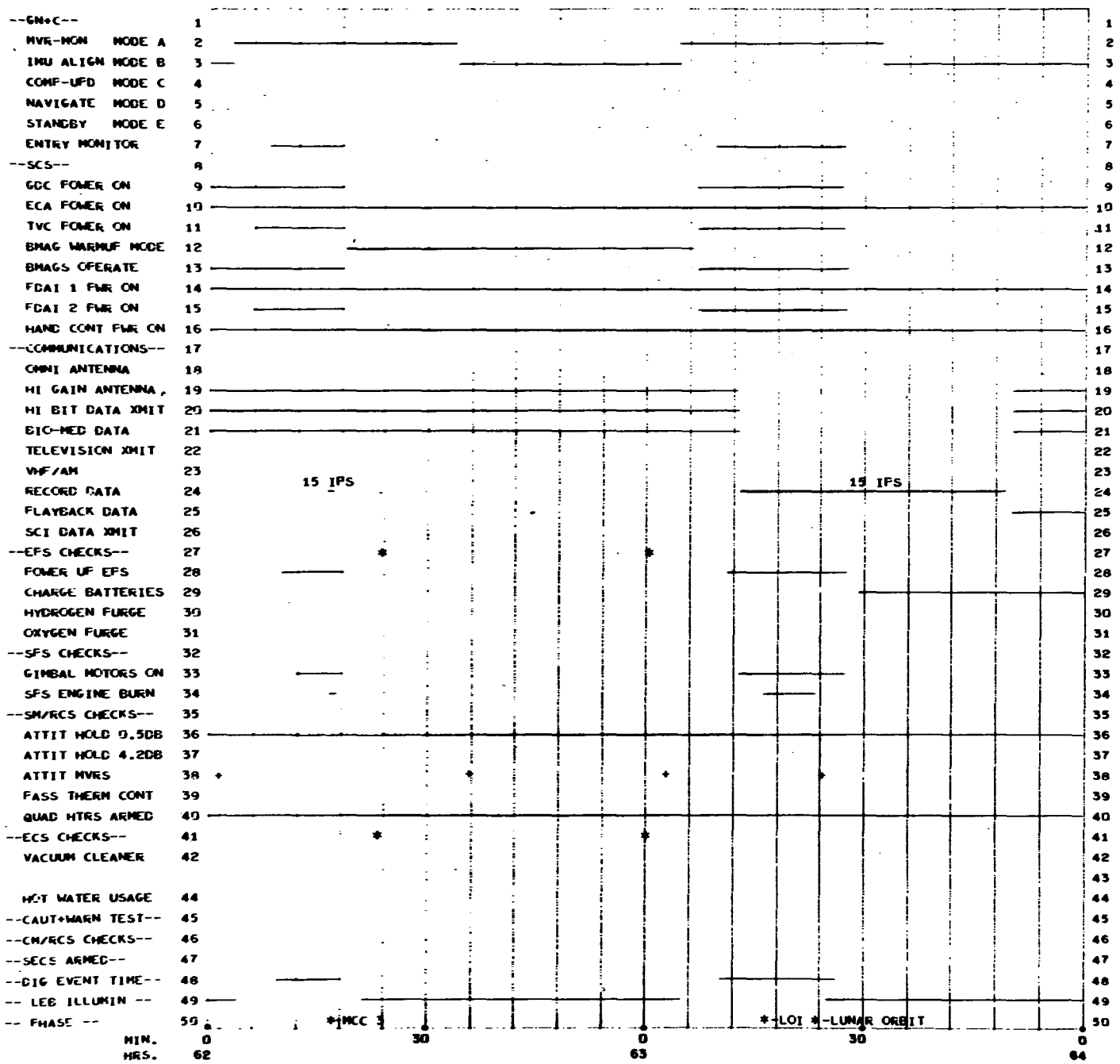
Mission Time in 6 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



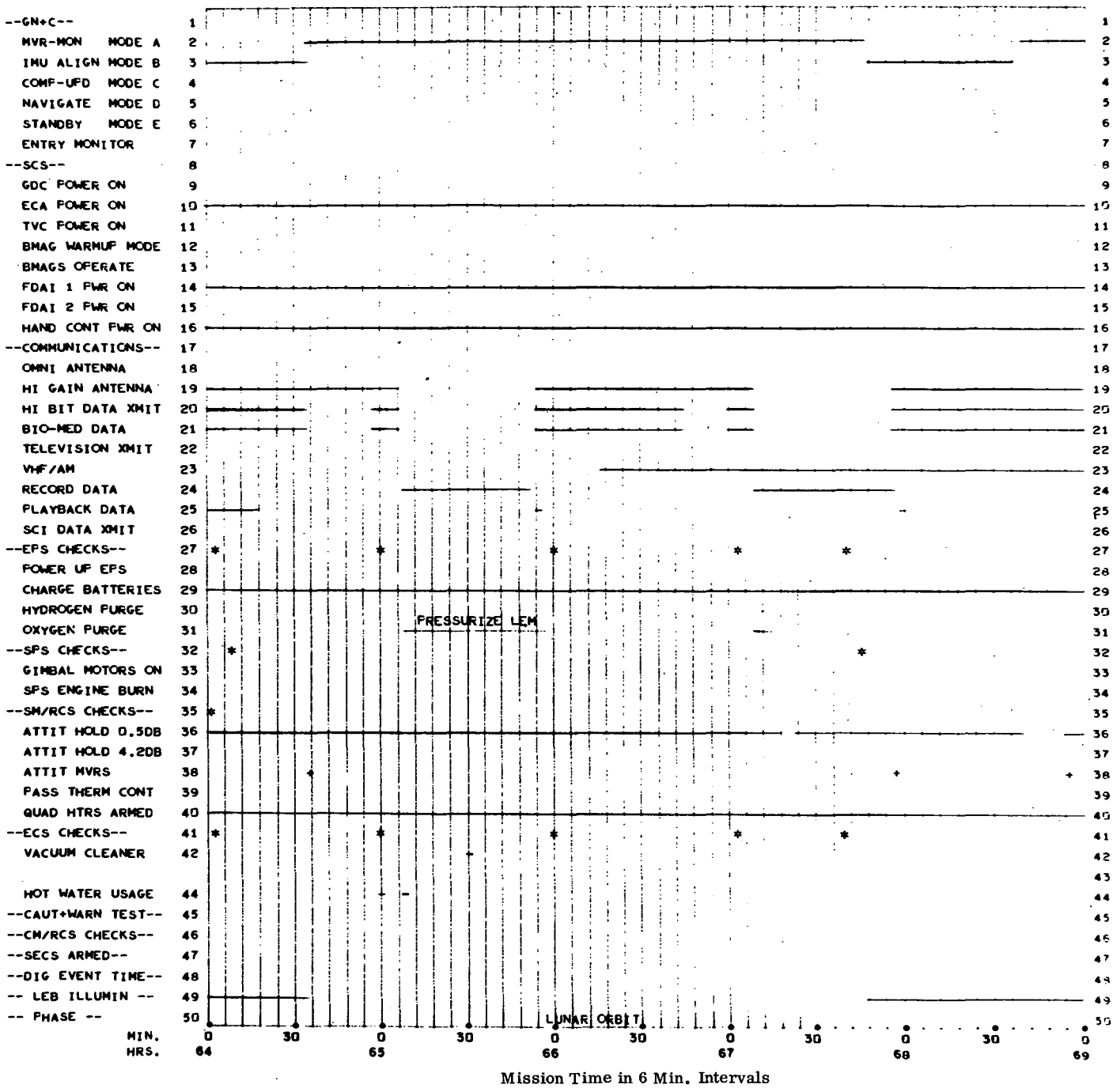
Mission Time in 6 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



Mission Time in 6 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



Mission Time in 6 Min. Intervals

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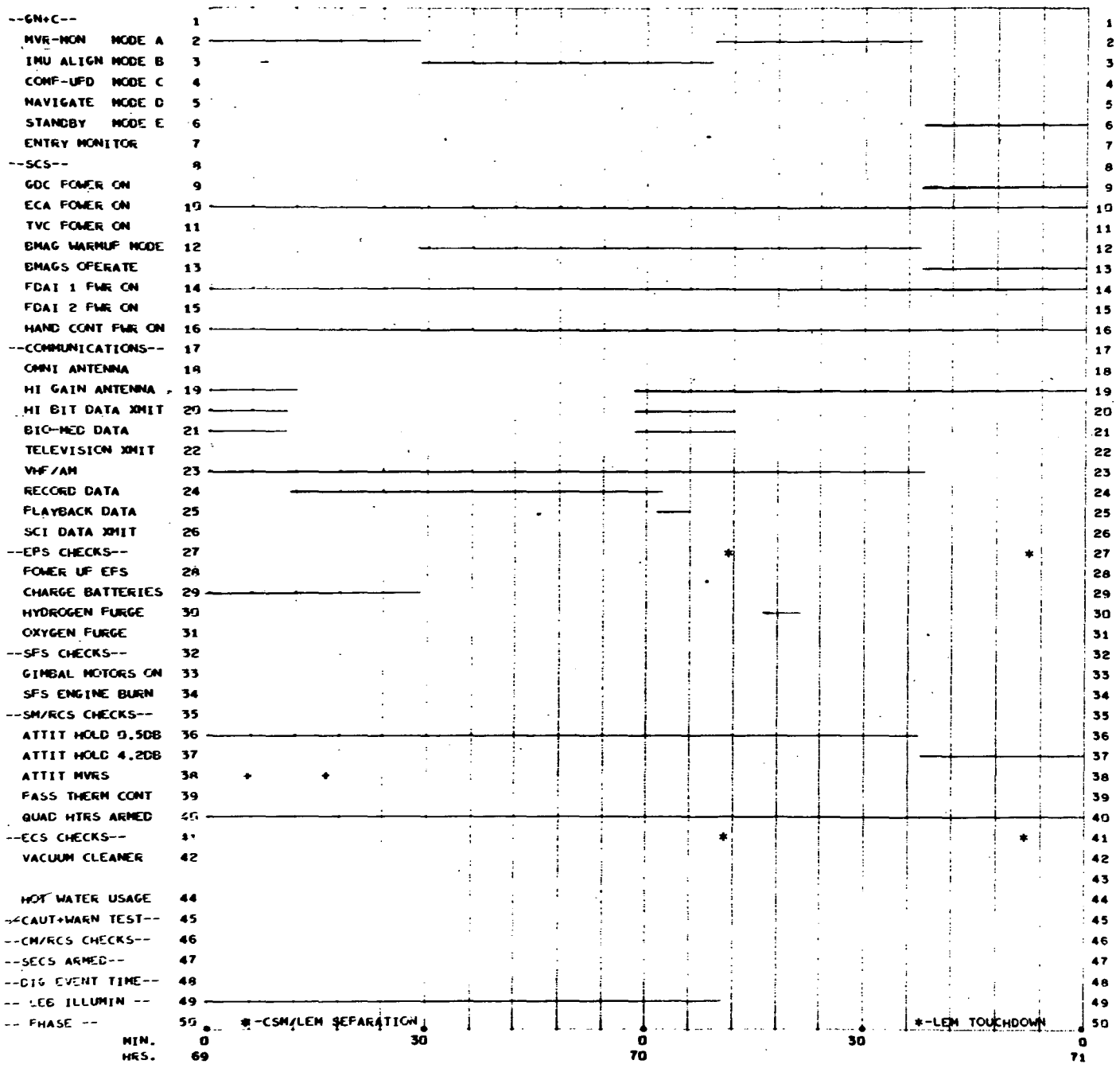

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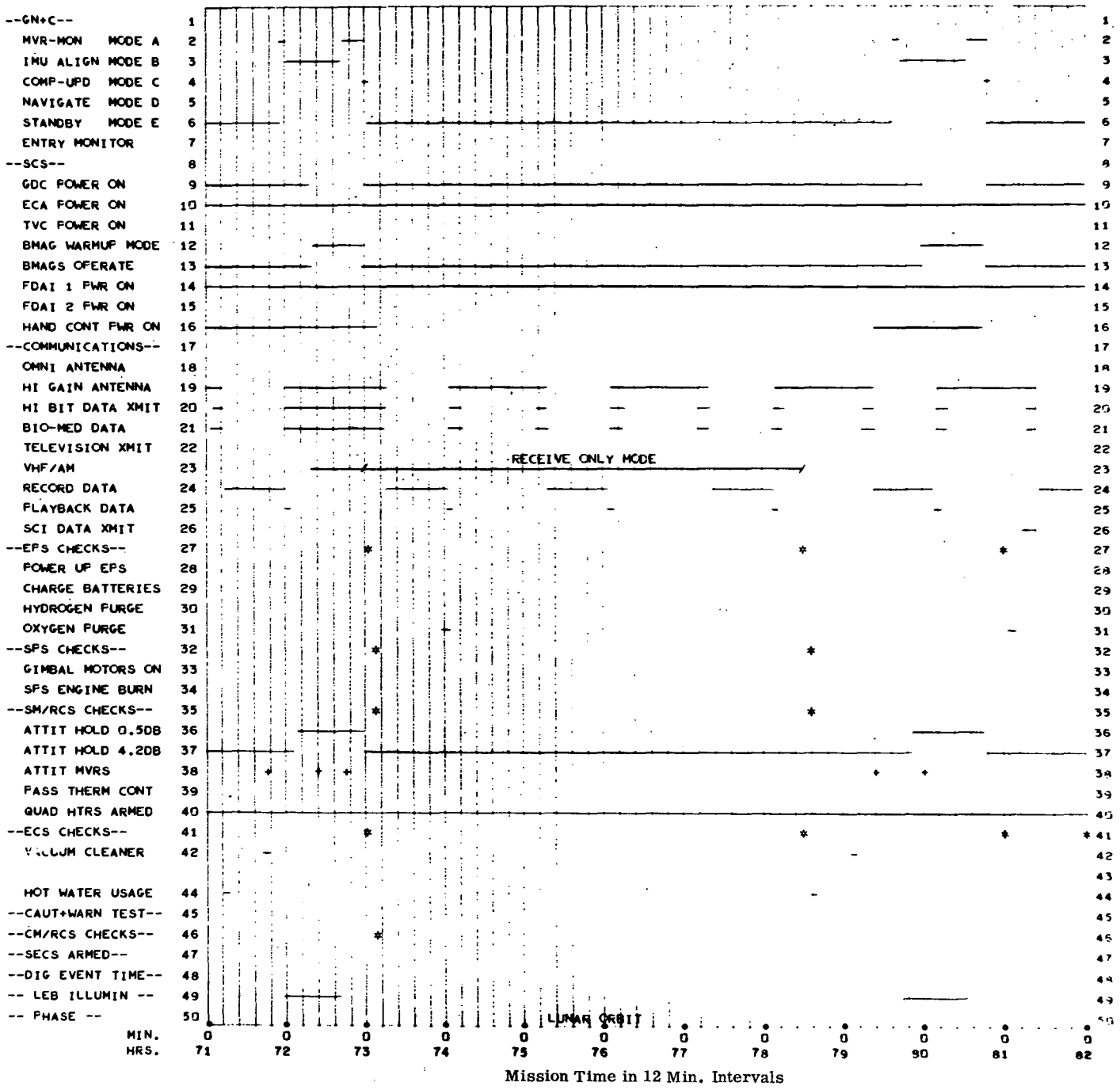

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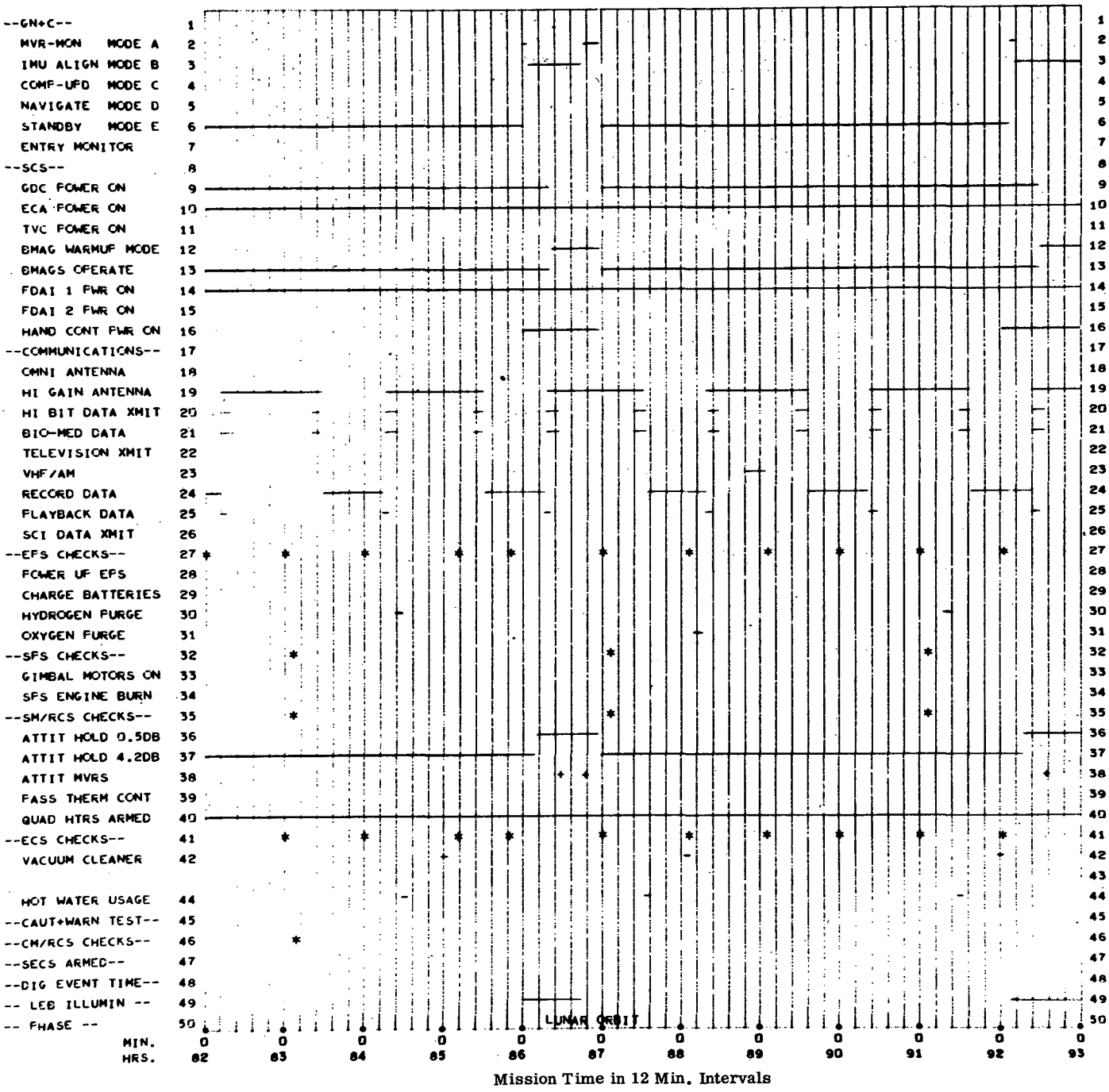


Mission Time in 12 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)

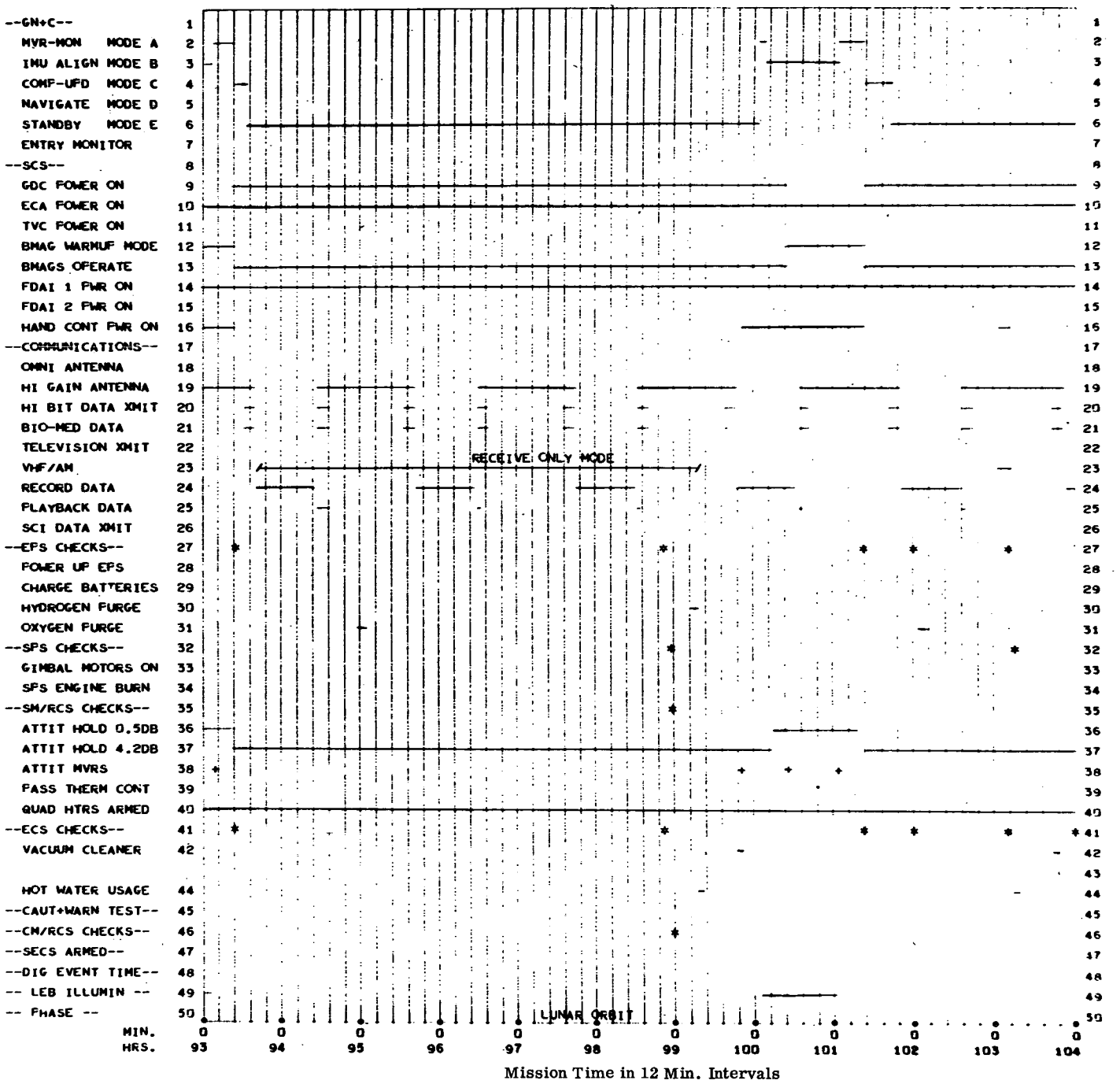


Figure E-1 CSM Duty Cycles (Continued)

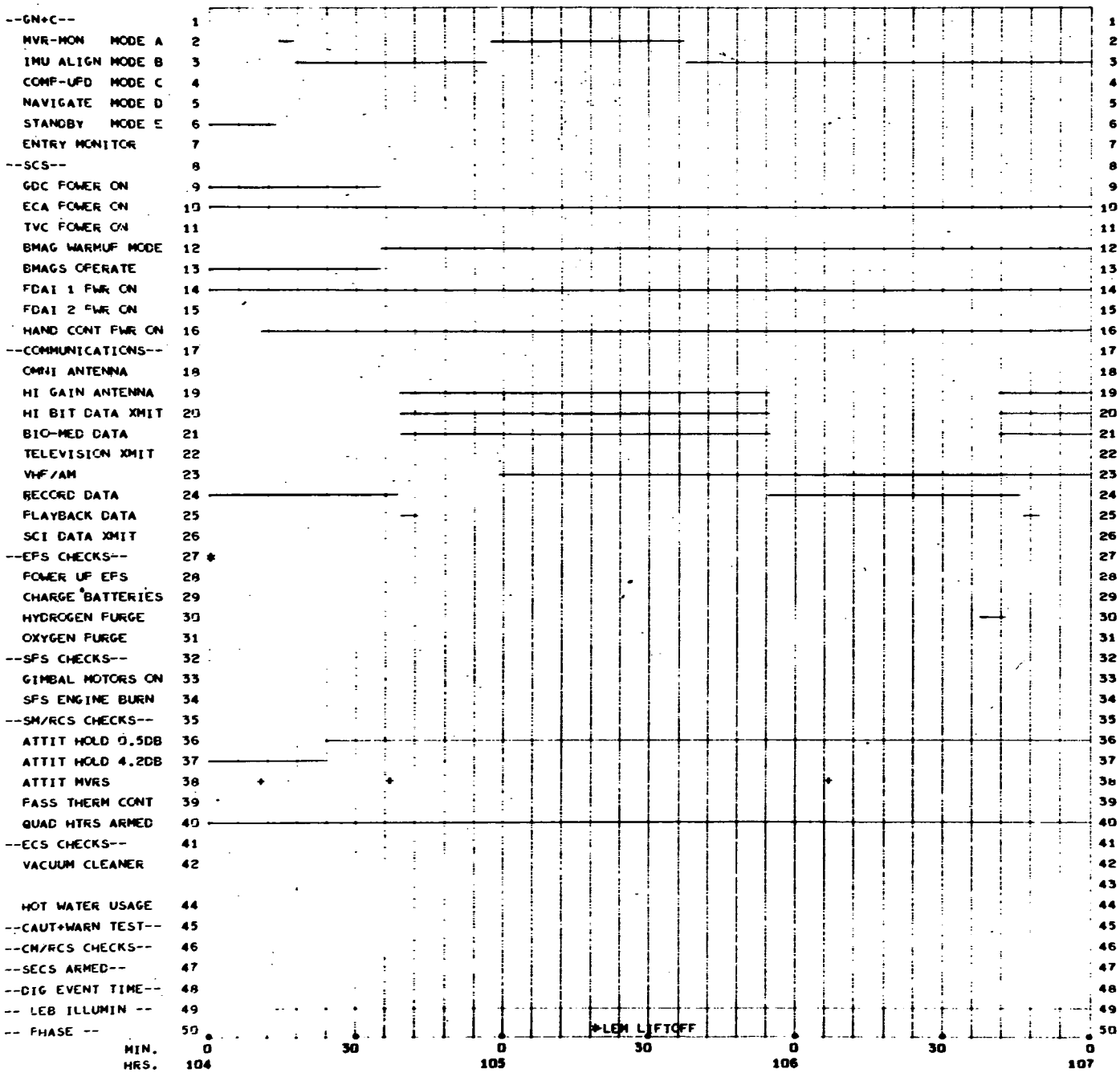
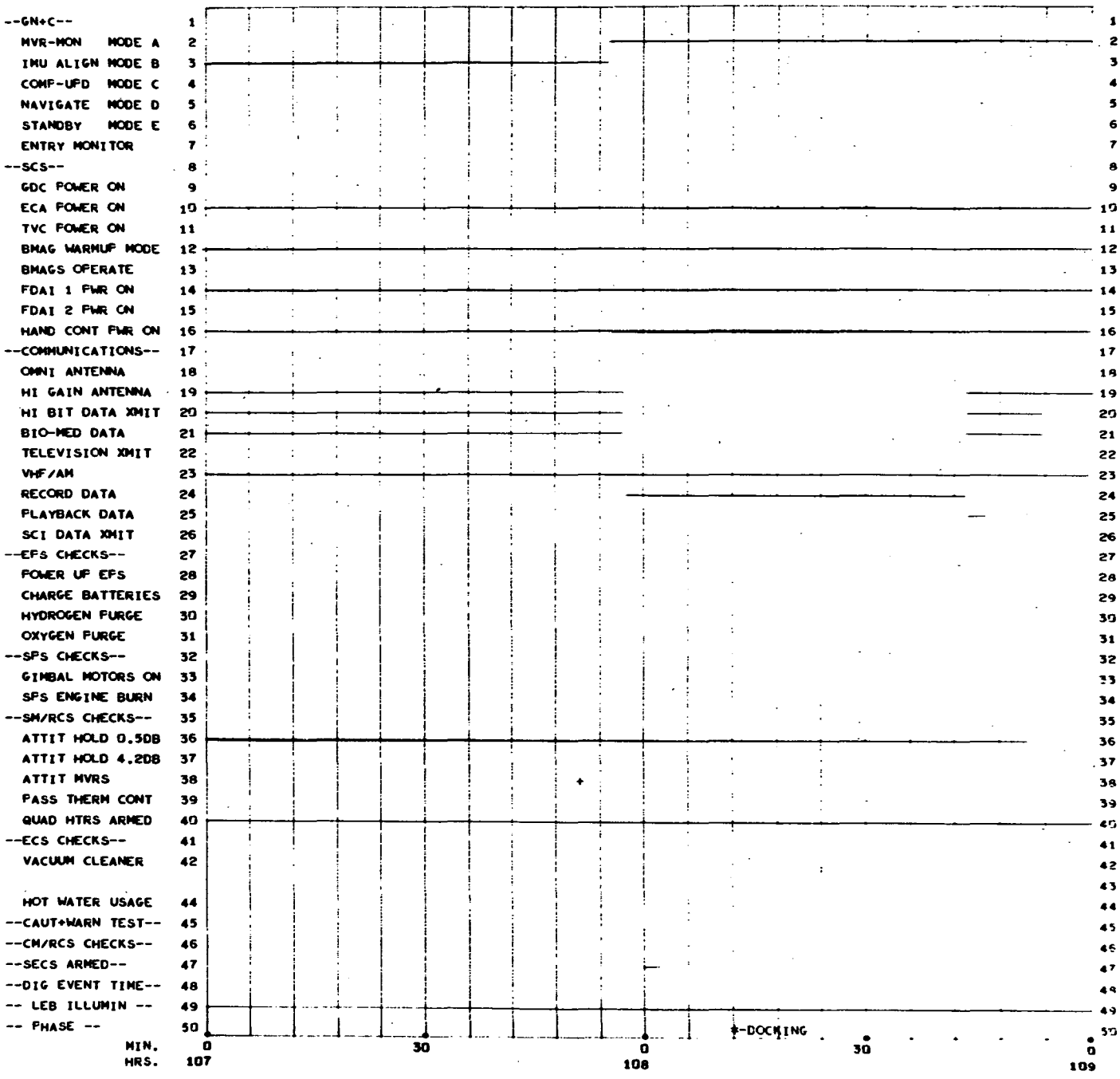
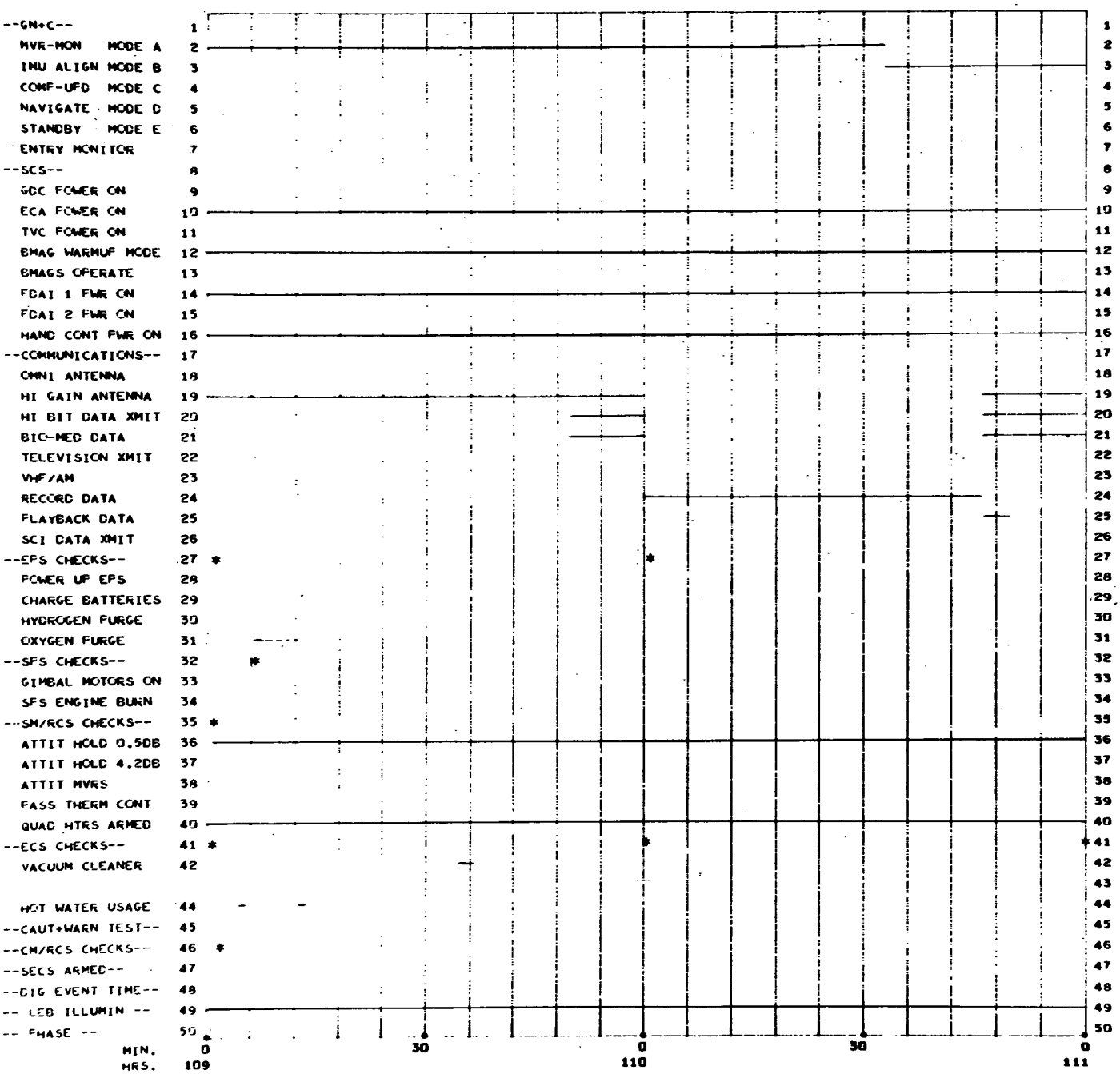


Figure E-1 CSM Duty Cycles (Continued)



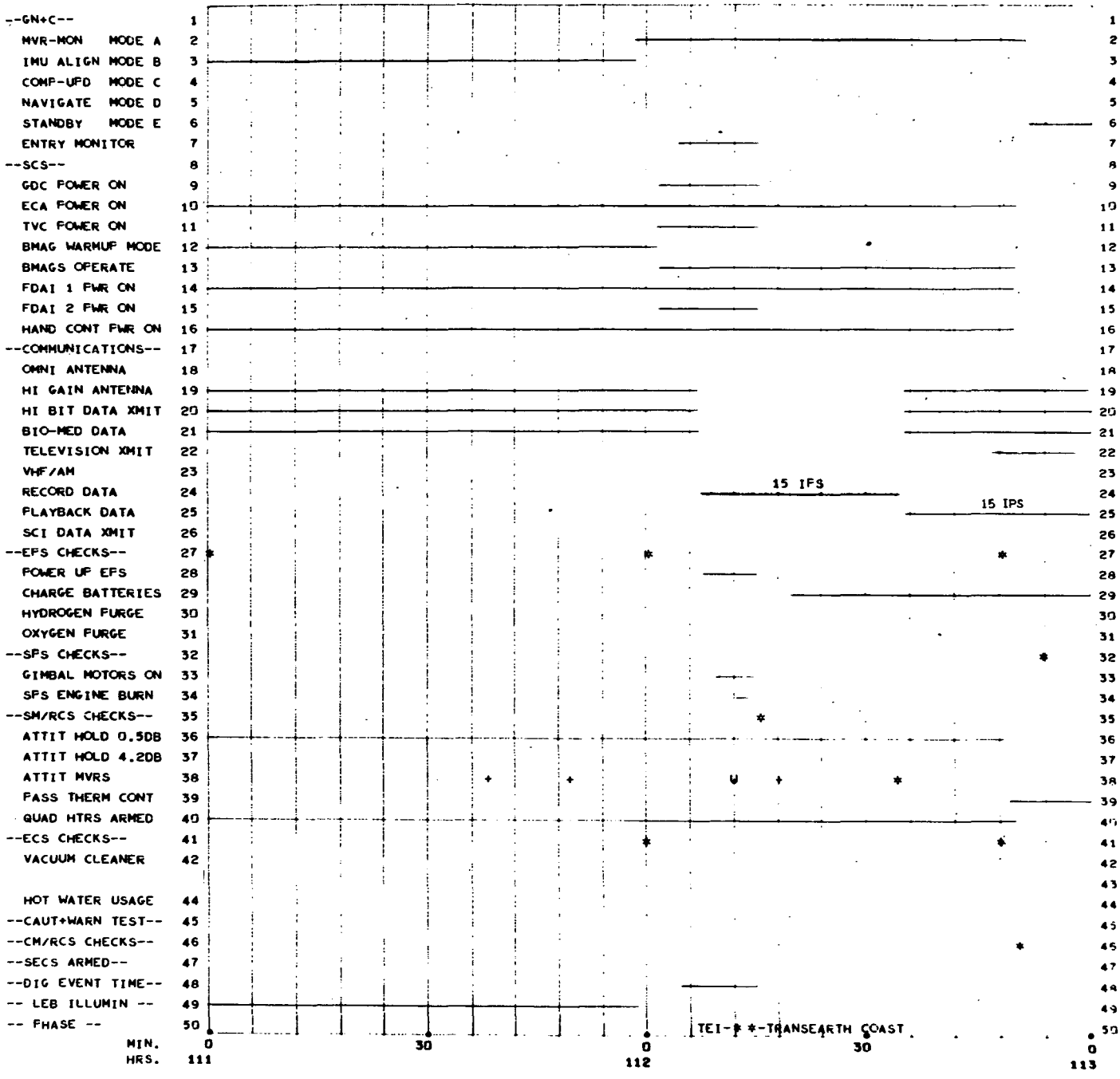
Mission Time in 6 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



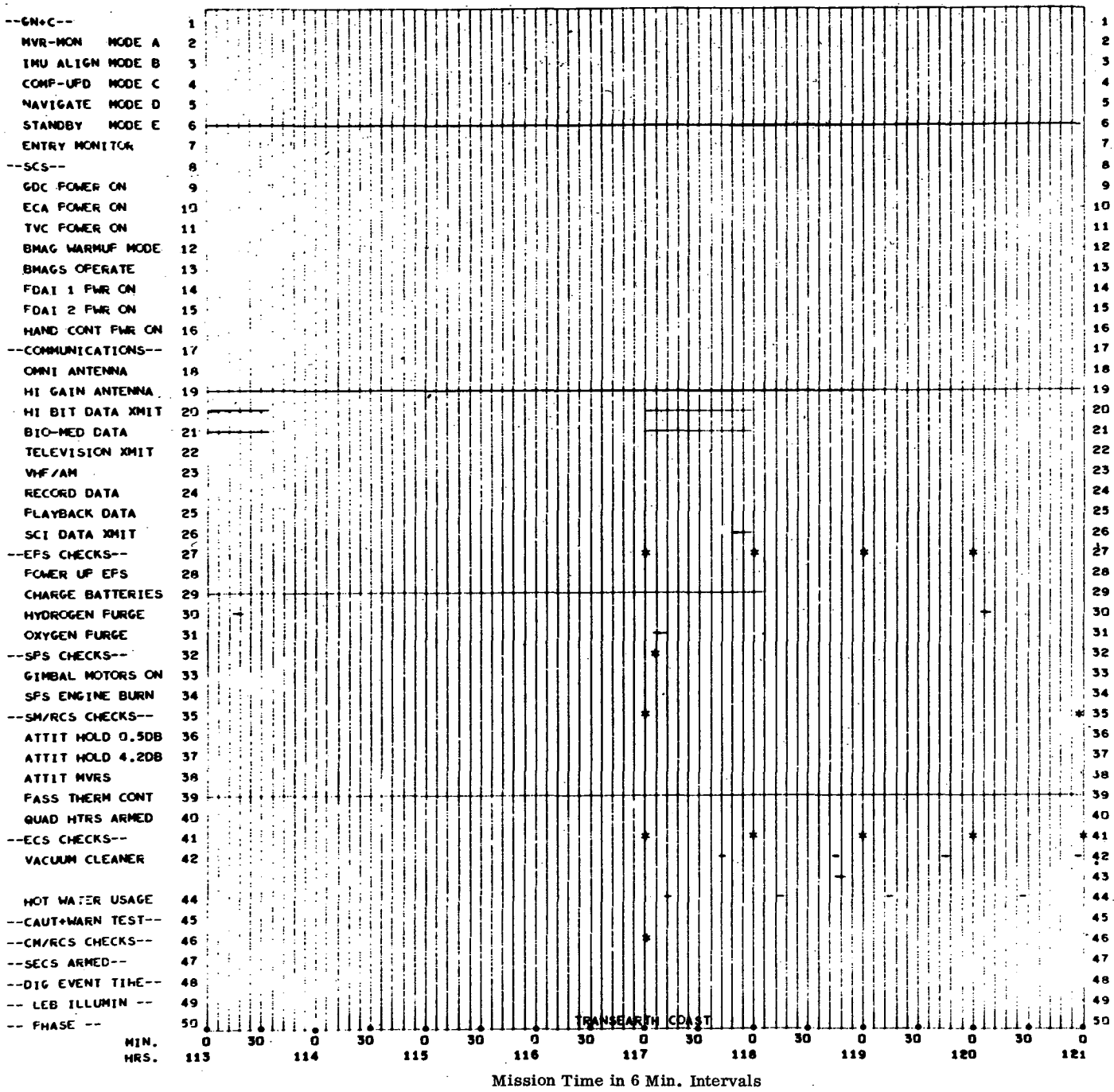
Mission Time in 6 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



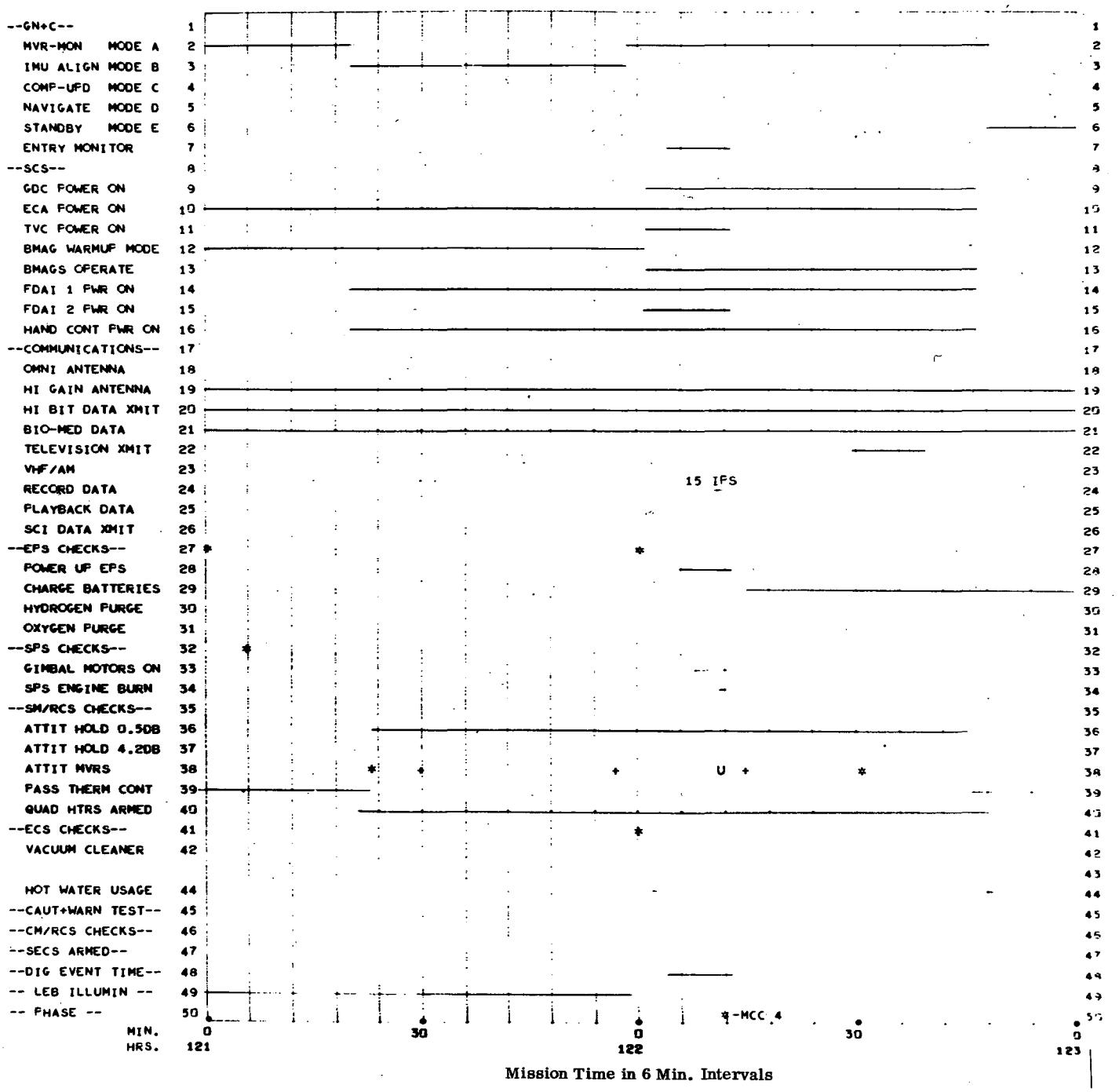
Mission Time in 6 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



Mission Time in 6 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



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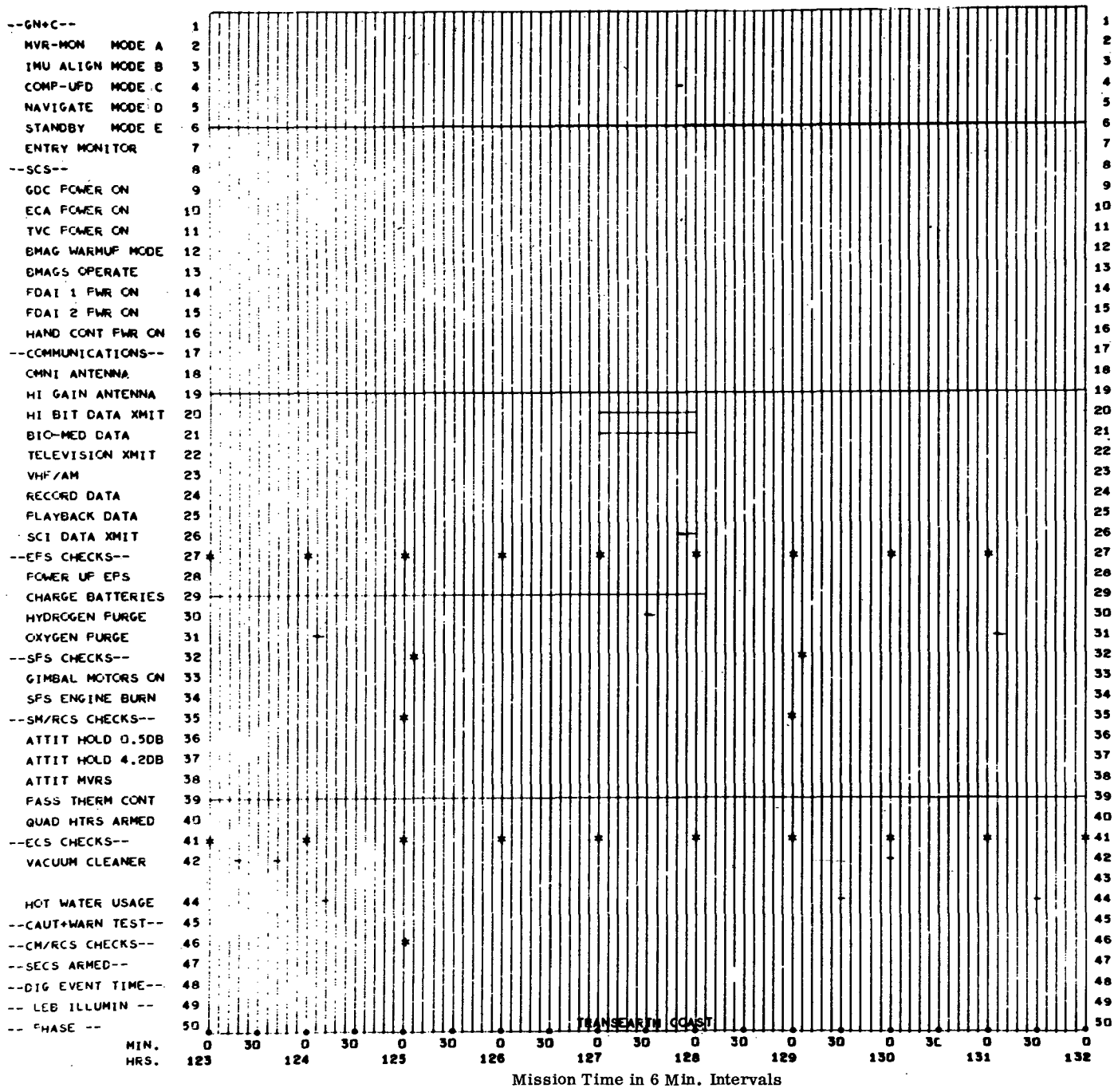

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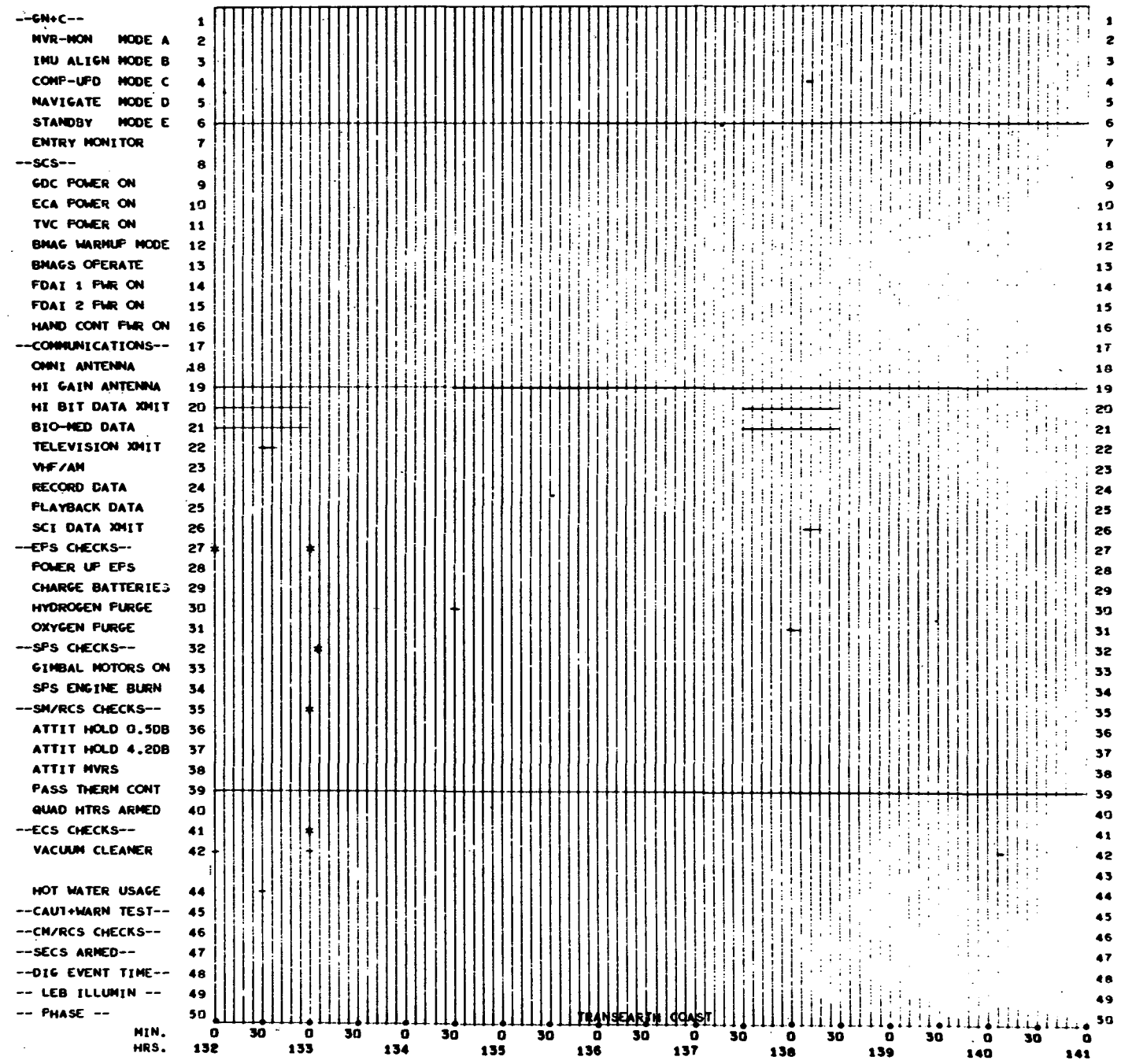
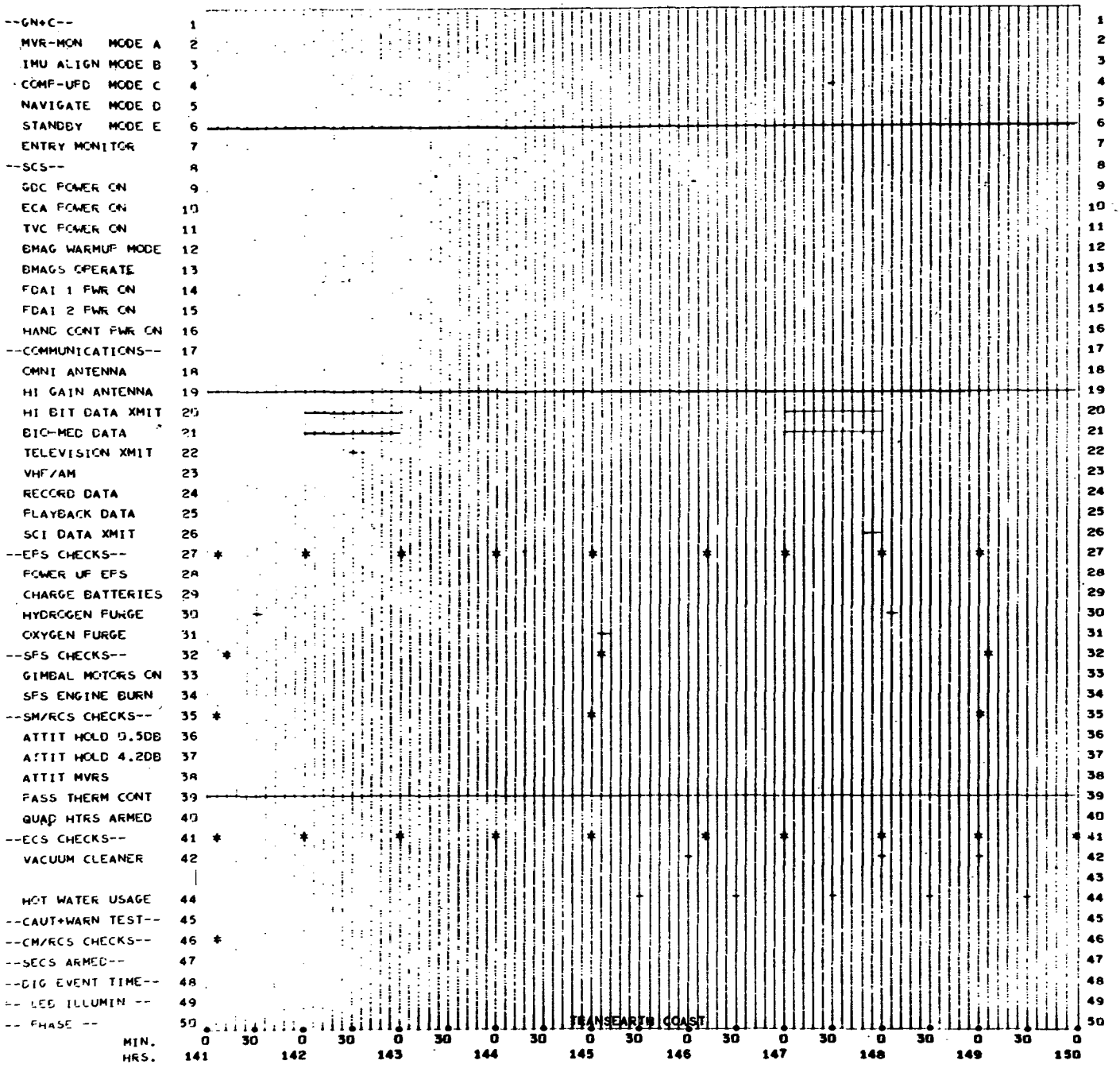


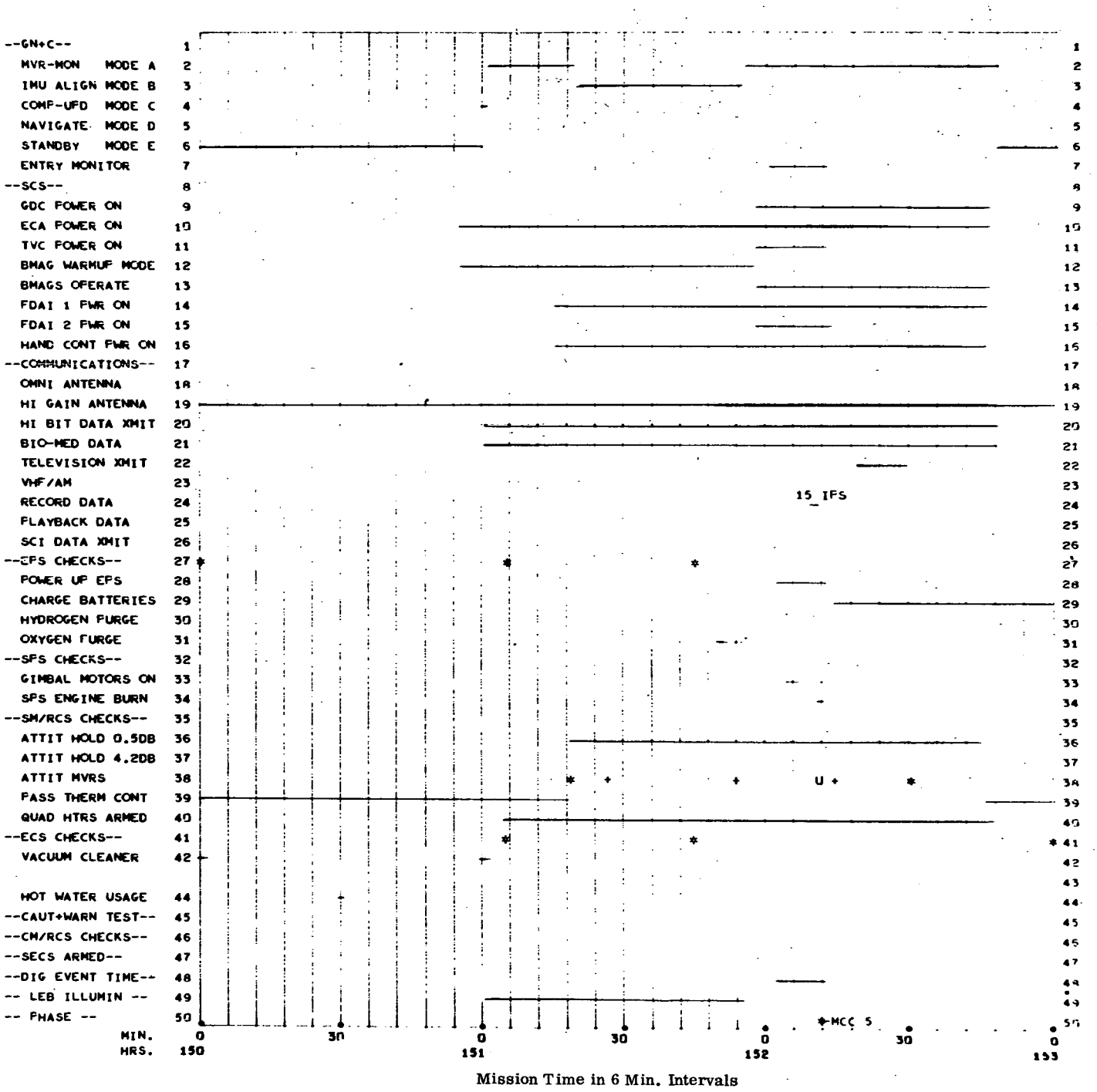
Mission Time in 6 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



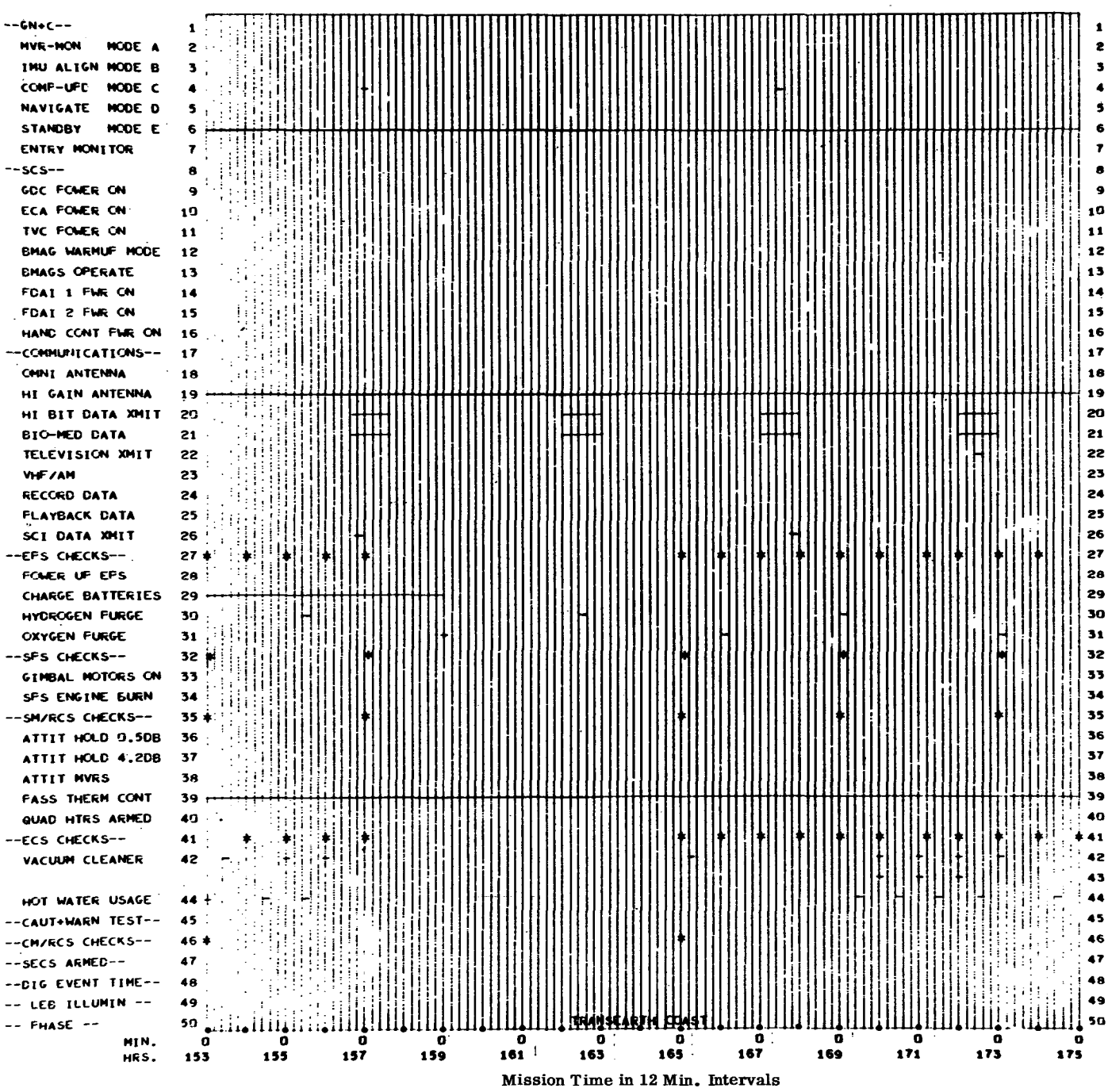
Mission Time in 6 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



Mission Time in 6 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



Mission Time in 12 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)

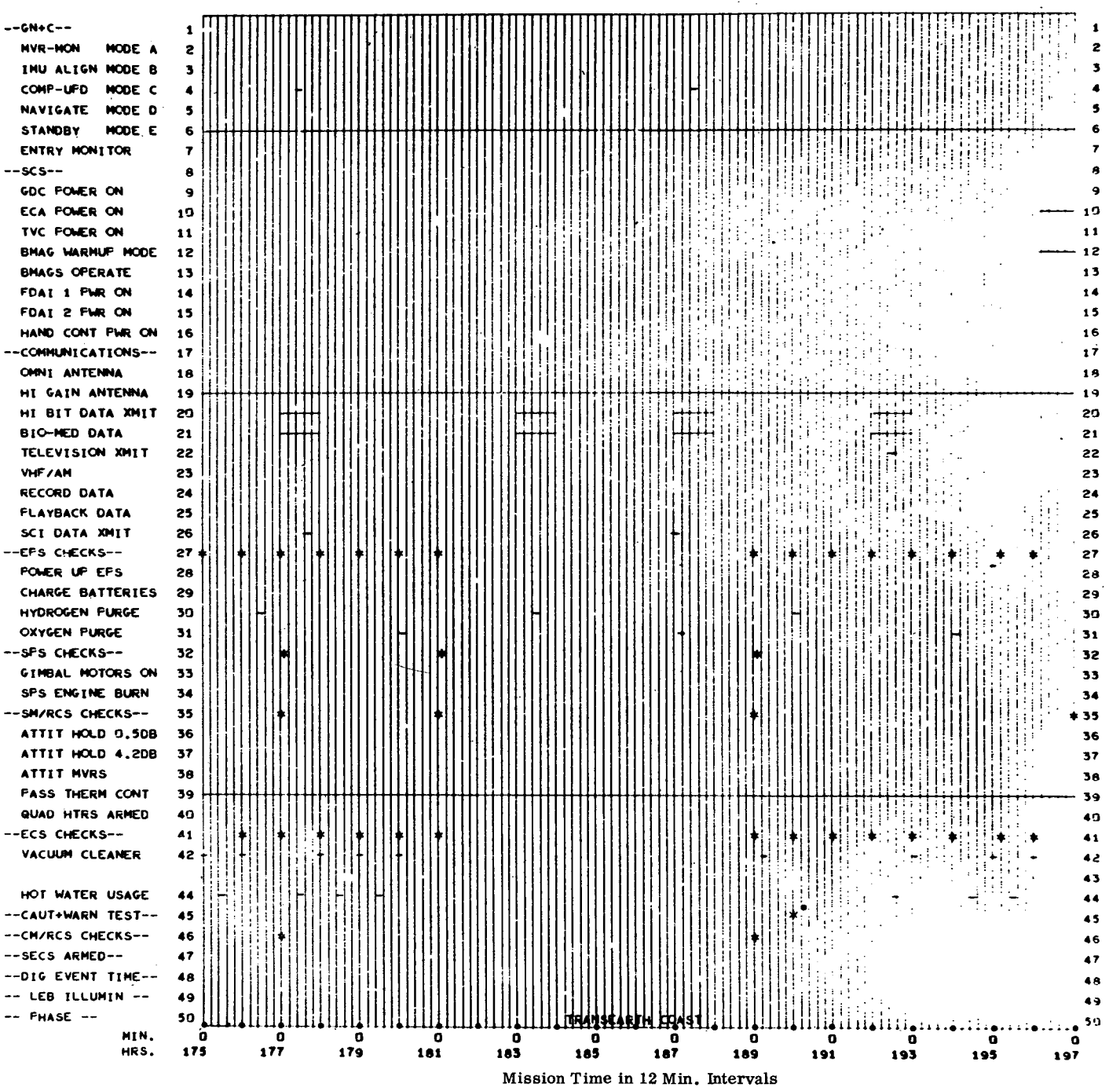
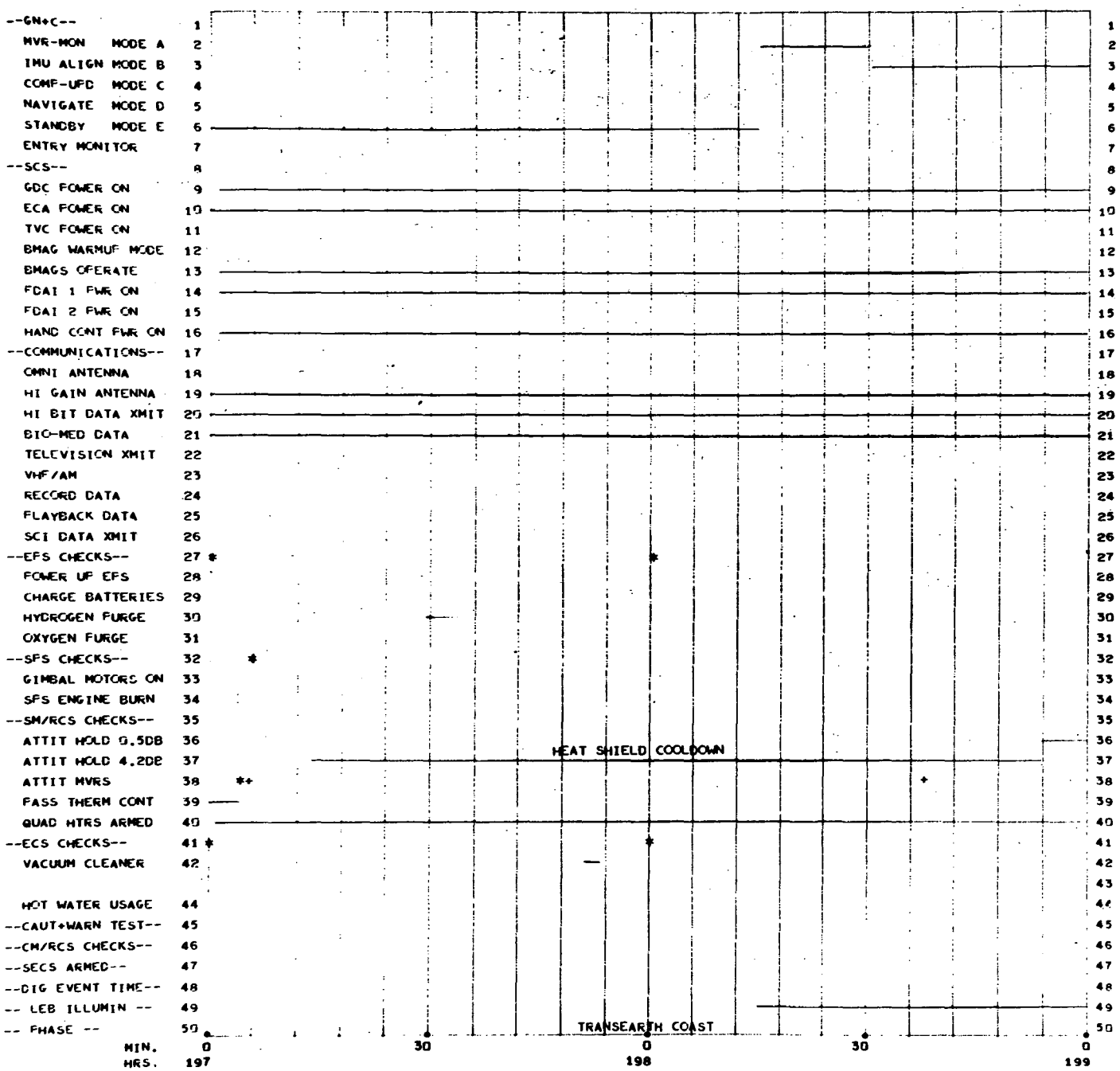
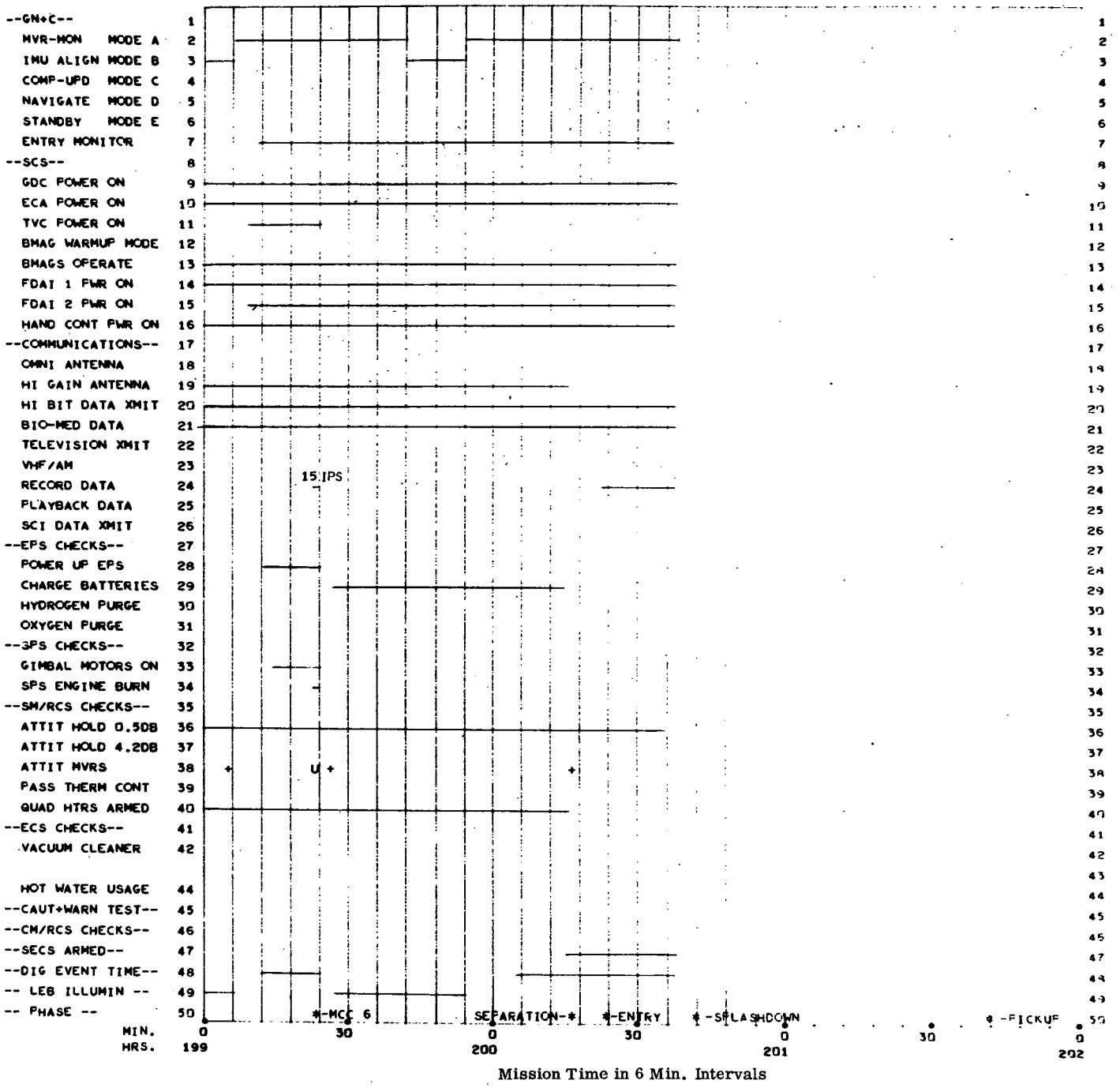


Figure E-1 CSM Duty Cycles (Continued)



Mission Time in 6 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)



Mission Time in 6 Min. Intervals

Figure E-1 CSM Duty Cycles (Continued)

```
--GN+C--
  MVR-MON    MODE A      2 WAS DRAWN  35 TIMES FOR    31.969  HOURS WITH   0  PIPS.
  IMU ALIGN  MODE B      3 WAS DRAWN  23 TIMES FOR    17.369  HOURS WITH   0  PIPS.
  COMP-UPD   MODE C      4 WAS DRAWN  19 TIMES FOR     1.199  HOURS WITH  35  PIPS.
  NAVIGATE   MODE D      5 WAS DRAWN   1 TIMES FOR     0.352  HOURS WITH   0  PIPS.
  STANDBY    MODE E      6 WAS DRAWN  23 TIMES FOR   166.499  HOURS WITH   0  PIPS.
  ENTRY MONITOR          7 WAS DRAWN   9 TIMES FOR     3.514  HOURS WITH   0  PIPS.
--SCS--
  GDC POWER ON           9 WAS DRAWN  16 TIMES FOR    40.978  HOURS WITH   0  PIPS.
  ECA POWER ON          10 WAS DRAWN   6 TIMES FOR    69.974  HOURS WITH   0  PIPS.
  TVC POWER ON          11 WAS DRAWN  10 TIMES FOR     2.956  HOURS WITH   0  PIPS.
  BMAG WARMUP MODE      12 WAS DRAWN  16 TIMES FOR    22.403  HOURS WITH   0  PIPS.
  BMAGS OPERATE         13 WAS DRAWN  16 TIMES FOR    41.549  HOURS WITH   0  PIPS.
  FDAI 1 PWR ON         14 WAS DRAWN   6 TIMES FOR    67.045  HOURS WITH   0  PIPS.
  FDAI 2 PWR ON         15 WAS DRAWN  10 TIMES FOR     4.414  HOURS WITH   0  PIPS.
  HAND CONT PWR ON      16 WAS DRAWN  12 TIMES FOR    40.346  HOURS WITH   0  PIPS.
--COMMUNICATIONS--
  OMNI ANTENNA          18 WAS DRAWN   5 TIMES FOR    23.308  HOURS WITH   0  PIPS.
  HI GAIN ANTENNA       19 WAS DRAWN  26 TIMES FOR   179.447  HOURS WITH   0  PIPS.
  HI BIT DATA XMIT      20 WAS DRAWN  77 TIMES FOR    58.845  HOURS WITH   0  PIPS.
  BIO-MED DATA          21 WAS DRAWN  77 TIMES FOR    58.845  HOURS WITH   0  PIPS.
  TELEVISION XMIT       22 WAS DRAWN  12 TIMES FOR     1.999  HOURS WITH  12  PIPS.
  VHF/AM                23 WAS DRAWN   7 TIMES FOR    42.868  HOURS WITH   4  PIPS.
  RECORD DATA           24 WAS DRAWN  37 TIMES FOR    20.191  HOURS WITH   0  PIPS.
  PLAYBACK DATA         25 WAS DRAWN  26 TIMES FOR     2.454  HOURS WITH   0  PIPS.
  SCI DATA XMIT         26 WAS DRAWN  14 TIMES FOR     2.333  HOURS WITH  14  PIPS.
--EPS CHECKS--          27 WAS NEVER DRAWN BUT WAS PIPPED   136  TIMES.
  POWER UP EPS          28 WAS DRAWN  10 TIMES FOR     2.307  HOURS WITH   0  PIPS.
  CHARGE BATTERIES      29 WAS DRAWN   9 TIMES FOR    41.696  HOURS WITH   0  PIPS.
  HYDROGEN PURGE        30 WAS DRAWN  28 TIMES FOR     2.216  HOURS WITH  28  PIPS.
  OXYGEN PURGE          31 WAS DRAWN  29 TIMES FOR     3.749  HOURS WITH  29  PIPS.
--SPS CHECKS--          32 WAS NEVER DRAWN BUT WAS PIPPED    41  TIMES.
  GIMBAL MOTORS ON      33 WAS DRAWN  10 TIMES FOR     1.686  HOURS WITH   0  PIPS.
  SPS ENGINE BURN       34 WAS DRAWN   8 TIMES FOR     0.151  HOURS WITH   6  PIPS.
--SM/RCS CHECKS--       35 WAS NEVER DRAWN BUT WAS PIPPED    39  TIMES.
  ATTIT HOLD 0.5DB      36 WAS DRAWN  15 TIMES FOR    33.123  HOURS WITH   1  PIPS.
  ATTIT HOLD 4.2DB      37 WAS DRAWN   8 TIMES FOR    31.267  HOURS WITH   0  PIPS.
  ATTIT MVRS            38 WAS DRAWN   2 TIMES FOR     0.104  HOURS WITH  71  PIPS.
  PASS THERM CONT       39 WAS DRAWN   5 TIMES FOR   135.207  HOURS WITH   0  PIPS.
  QUAD HTRS ARMED       40 WAS DRAWN   6 TIMES FOR    65.650  HOURS WITH   0  PIPS.
--ECS CHECKS--          41 WAS NEVER DRAWN BUT WAS PIPPED   136  TIMES.
  VACUUM CLEANER        42 WAS DRAWN  63 TIMES FOR     2.099  HOURS WITH  63  PIPS.

  HOT WATER USAGE       44 WAS NEVER DRAWN BUT WAS PIPPED    61  TIMES.
--CAUT+WARN TEST--
--CM/RCS CHECKS--       46 WAS NEVER DRAWN BUT WAS PIPPED    18  TIMES.
--SECS ARMED--          47 WAS DRAWN   7 TIMES FOR     2.366  HOURS WITH   0  PIPS.
--DIG EVENT TIME--      48 WAS DRAWN  11 TIMES FOR     3.541  HOURS WITH   0  PIPS.
-- LEB ILLUMIN --       49 WAS DRAWN  17 TIMES FOR    23.180  HOURS WITH   0  PIPS.
-- PHASE --             50 WAS NEVER DRAWN BUT WAS PIPPED    24  TIMES.
```

Figure E-1 CSM Duty Cycles (Continued)

E.2.2 LM DESCRIPTION

E.2.2.1 Electronic Explosive Devices

The EED consists of a control panel, relays, two separate batteries, and explosive devices. The timeline indicates when EED are available. The EED is turned off when the last explosive device is fired.

The explosive devices and the times they are fired are as follows:

- LM/S-IVB Separation 002:41:40
- RCS He Pressure 067:14:17
- Landing Gear Deploy 068:29:42
- Descent Prop. He Pressure 069:28:31
- Ascent Prop. He Pressure 105:03:24
- Ascent/Descent Separation 105:18:14

The Ascent/Descent Separation includes three functions:

- Interstage structural connectors
- Cable cutters
- Deadfacing relays.

E.2.2.2 Communications

The communications subsystem consists of receivers and transmitters, signal processing assembly, antennas, and antenna heaters. Equipment is shown as being utilized when the equipment is switched "on". However, transmitter equipment operates only when keyed. A 50% duty cycle is assumed for VHF voice transmission. The exact transmission times are not specified. S-band antenna equipment includes the steerable antenna, erectable antenna, and the omni-antenna.

The operations of the omni-antenna and the erectable antenna are included with that of the steerable antenna. The omni-antenna and the erectable antenna are used in place of the steerable antenna during the following time intervals:

Omni-Antenna - 067:55:42 - 068:46:38

Lunar Antenna - 073:09:30 - 104:54:54

Variable power requirements for the steerable antenna depend on the amount of slewing and are not included. Heaters are required for the steerable antenna during the translunar

coast phase, while the equipment is off. The utilization periods indicate a typical thermal cycle. A thermostat controls the activation of the S-band antenna heater at approximately -40°F. Since the temperature at KSC is never -40°F the heater is not activated during prelaunch.

E.2.2.3 Crew Provisions

The waste management entry indicates the urination cycle. The entry for the space suit indicates a 100% utilization.

The EVA garments entry includes the PLSS units. The utilization period represents the time from when the first man puts garments on until the time the last man takes them off. The "Recharge of PLSS" entry covers the period from the start of recharge of first PLSS and the completion of recharge of last PLSS. The crew restraints utilization time represents the time the crew is attached to constraints.

The sequence camera is attached to a bracket near the left window and is operated automatically when turned on. It is removed from the bracket during lunar stay when it is positioned by the Systems Engineer. There are two magazines for the sequence camera. Each magazine is capable of holding enough film for 80 minutes coverage.

The item "El Light and Dim" includes two ceiling flood lights and two map lights, as well as all electroluminescent panel and instrument lighting. The dimmer controls for the electroluminescent lighting, normally carried as part of the EPS, is also included.

E.2.2.4 Display and Controls

Circuit breakers, although located on control panels, are included with the systems they control.

The following are included in "Flight Instruments":

- FDAI
- Cross Pointer Meter
- Range/range rate, altitude/altitude rate
- DSKY (LGC input and output)
- DEDA (AGS input and output)

The SCS control panels include select switches to control the operations of the G N & C. The duty cycles for these controls are included with those equipments they control.

The following are part of the "Caution and Warning" and are described in the Instrumentation Subsystem:

- Warning Flags
- Master Alarm
- Annunciator Lights

E.2.2.5 Electrical Power

The DC Power Utilization duty cycle includes the operation of batteries, ECA's, and Power Distribution Control Circuits. The distribution losses are proportional to the power used and also depend on the number and type of power distribution units.

The Electrical Power Utilization is separated into four parts, each of which includes the pertinent items of equipment.

- Ascent Power (D.C.)
- Descent Power (D.C.)
- Inverter (A.C.)
- Space Suit Umbilical

E.2.2.6 Environmental Control

The following are on as long as the systems are pressurized:

- Primary Heat Transport
- Secondary Heat Transport
- Ascent Oxygen Tank
- Descent Oxygen Tank
- Descent Water Storage
- Ascent Water Storage

The glycol pump utilization indicates when primary heat transport is operating. The water management utilization indicates period during which water is used. The oxygen management utilization indicates period during which oxygen is used. The cabin ARS and suit ARS utilization includes that of cabin and suit fans.

During the cabin ARS utilization, the cabin oxygen repressurization recharge is as follows:

From 075:25:15 to 075:26:06
087:40:15 to 087:41:26
093:20:15 to 093:22:00
103:33:15 to 103:37:27

During these periods and also periods of cabin depressurization, the ECS relay box is activated.

The ECS Relay Box, which controls cabin pressurization, is in operation at the beginning and at the end of each cabin ARS. The numbers above the start times and the end of the times of the cabin ARS entry, line 14, indicate the duration the ECS Relay Box is in operation.

The ECS Relay Box timeline is as follows:

72:11:00 to 72:20:00 (9 min.)
75:25:15 to 75:26:35 (1 min. 20 sec.)
84:28:15 to 84:37:15 (9 min.)
87:40:15 to 87:41:35 (1 min. 20 sec.)
90:08:15 to 90:17:15 (9 min.)
93:20:15 to 93:23:15 (3 min.)
100:23:15 to 100:32:15 (9 min.)
103:33:15 to 103:39:15 (6 min.)

The suit ARS utilization includes suit fans. The space suit umbilical utilization represents the time the astronaut is hooked into space suit.

E.2.2.7 Instrumentation

The instrumentation subsystem includes telemetry, C&W and scientific equipment. The sensors and signal conditioning unit are used by both the telemetry (PCMTEA) and the C&W.

The caution and warning includes the caution and warning electronics (CWEA) as well as individual warning flaps, master alarm light and annunciator light.

The scientific equipment includes sample containers and cameras carried in the CM and in the LM ascent stage, and an Apollo Lunar Scientific Equipment Package (ALSEP) carried in the descent stage. The ALSEP includes equipment for use in establishing a scientific

station to be left on the moon for use of long periods (approximately 6 months) after the end of the LM mission. It uses its own antenna and the Radioisotope Thermoelectric Generator. The exact composition of the ALSEP and lunar scientific experiments have not been determined, but specified experiments were assumed in the operational timeline.

Voice recording equipment is included as part of the Communications Subsystem.

E.2.2.8 Propulsion

The propulsion subsystem includes both the descent stage and ascent stage main propulsion subsystems. Helium and propellant tanks are considered operating from the time of filling before earth launch to completion of the utilization of the propulsion. Status sensors are included as part of the tanks.

The pressurization sections include pressure regulators, valves and plumbing, and are considered in use from the time of pressurization to the completion of subsystem use. The descent propulsion is vented during the early part of Phase 11.1.

The following valves are part of the propulsion subsystem:

- Ascent pressurization solenoid valves
- Descent pressurization solenoid valves
- Ascent engine shutoff valves
- Ascent engine pilot pre-valves
- Descent engine shutoff valves
- Descent engine pilot pre-valves
- Descent engine throttle valves

The descent engine amplifier operates for the same period as the descent engine. The descent and ascent stage also has a pressure-volume-temperature Gaging System which is used during engine operation.

E.2.2.9 Reaction Control System

The helium and propellant tasks with sensors are considered in operation from time of descent through the end of the LM activities. The helium assembly includes pressure regulators, and plumbing and is in use after pressurization of the propellant tanks.

Separate entries are made for ascent interconnect valve, RCS propellant shutoff valves, crossfeed valves, and cluster isolation valves; and the assumed times of operation are given. The time represents valve open for ascent interconnect valve and valve closed for the main shutoff valves.

The thrust chamber assembly is shown as operating when the RCS is controlling attitude or making translation maneuvers. No individual cycling times are shown.

The propellant quantity gauging section (PQGS) is shown on whenever the power is on for this unit.

The cluster heaters are shown on whenever the power is available and are thermostatically controlled.

E.2.2.10 Guidance, Navigation and Control

The PGNCS includes the following:

- LGC, Mode 1, Standby
- LGC, Mode 2, Operate
  (DSKY is included as part of the LGC)
- IMU, Mode 1, Standby
- IMU, Mode 2, Operate
- AOT

The AGS utilization is stated in two modes, representing standby and operating conditions, and includes the ASA, AEA and DEDA.

Radar includes the following:

- Rendezvous Radar
- Rendezvous Radar Heaters utilization in two modes:
  - Mode 1, Standby - Low Temperature (The average duty cycle is stated. The actual on-off times are not given.)
  - Mode 2, Normal - Higher Temperature (The average duty cycle is stated. The actual on-off times are not given.)
- Landing Radar
- Heaters
- Tracking Light

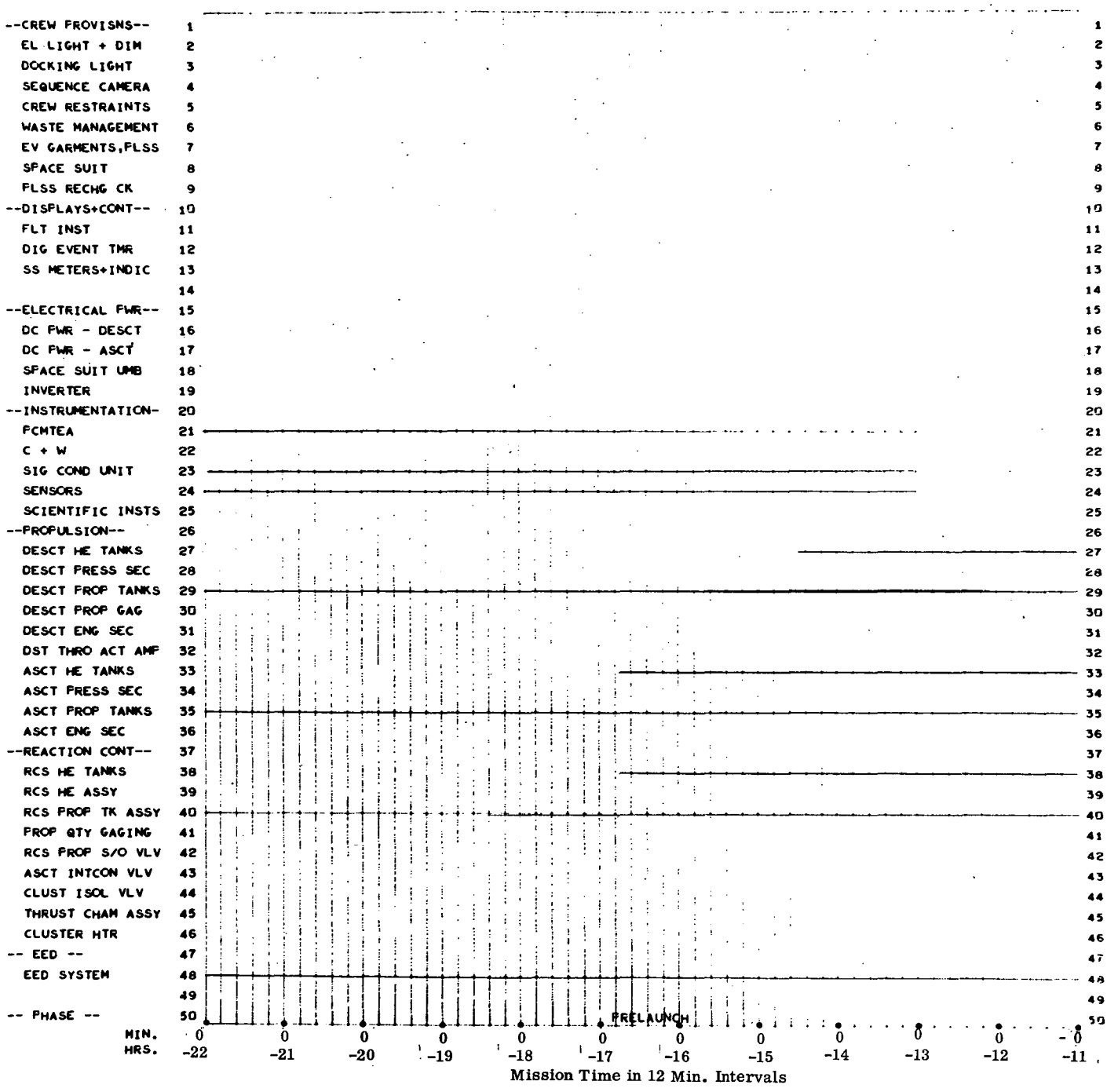
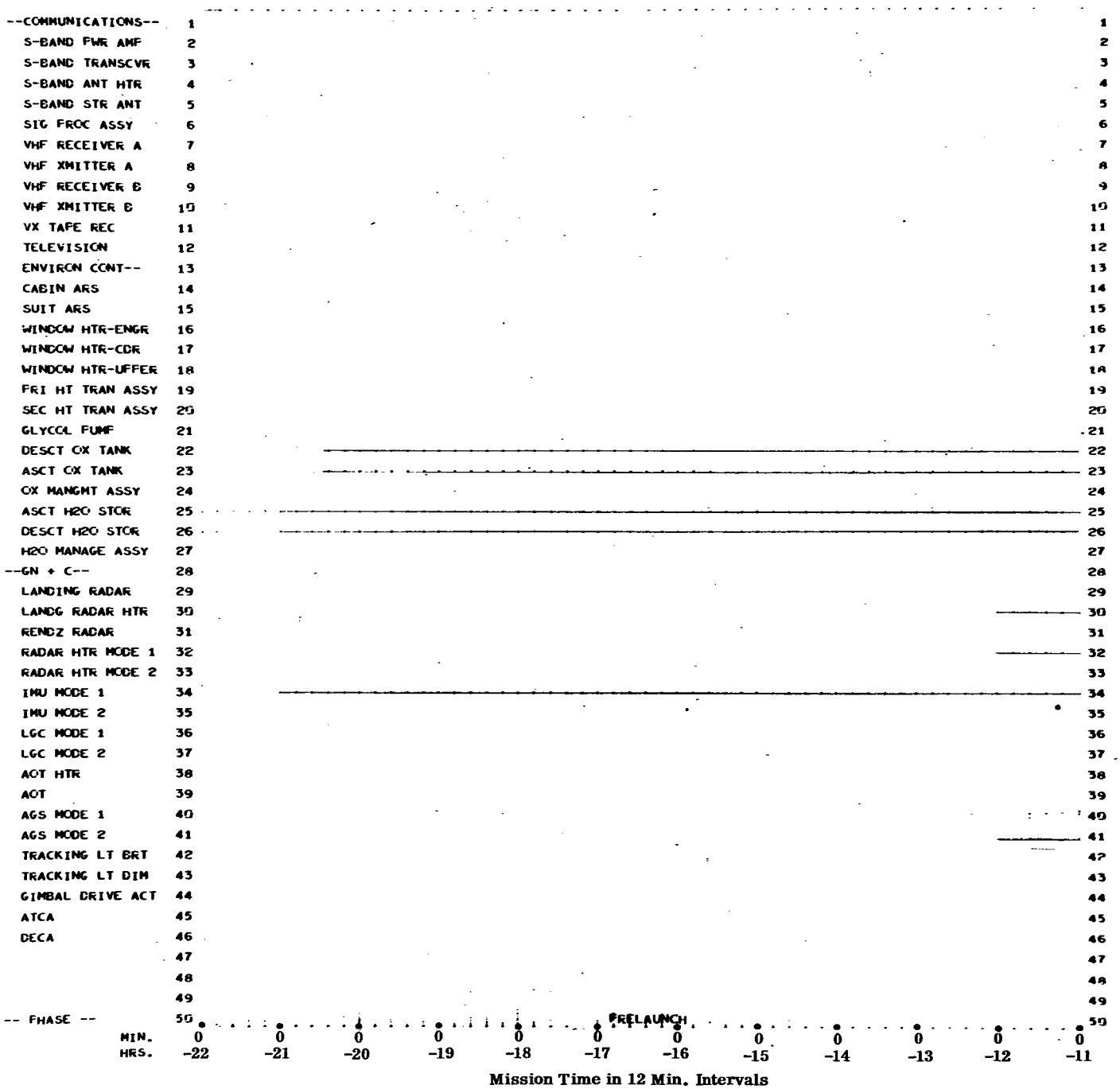


Figure E-2 LM Duty Cycles



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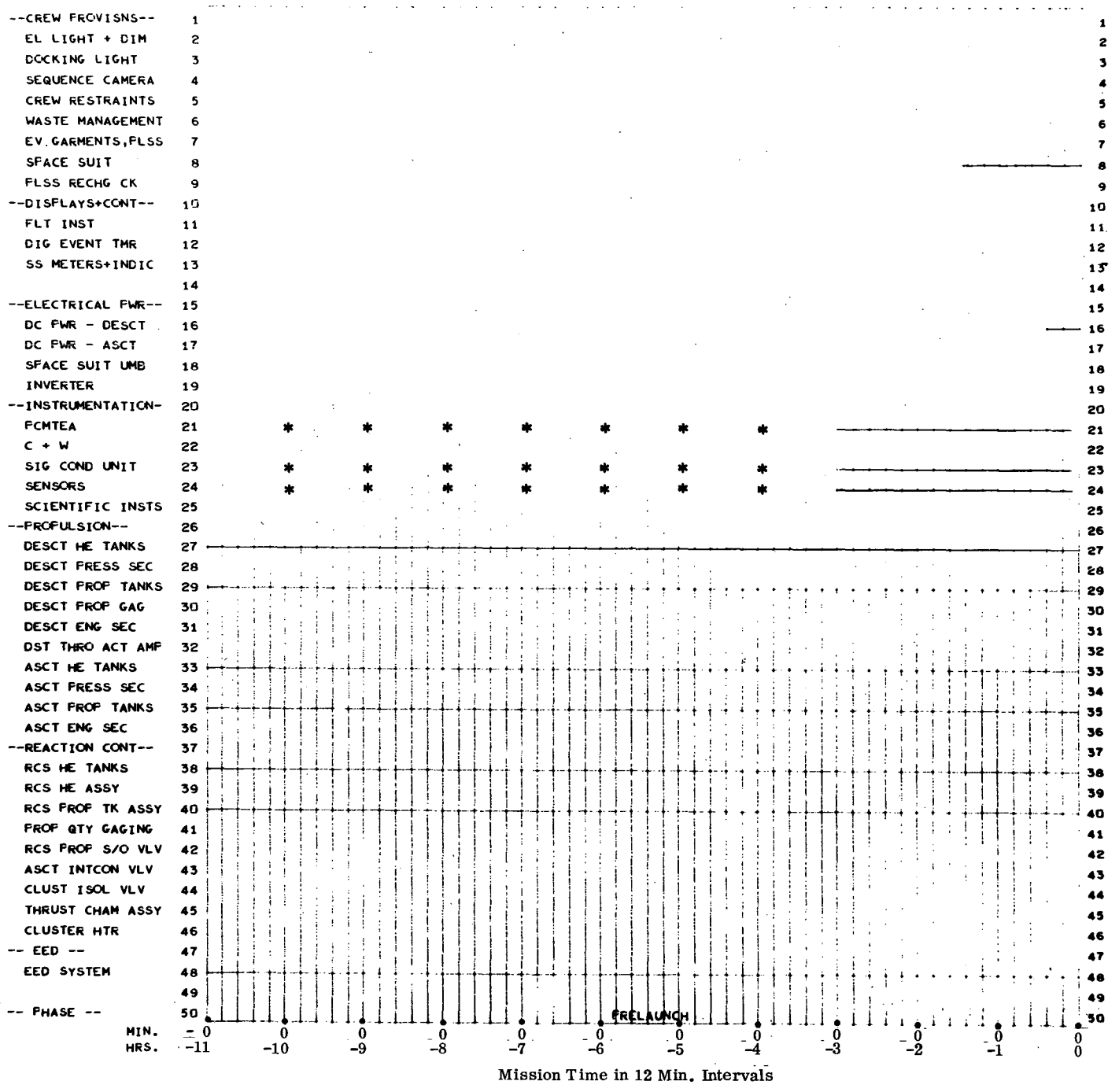

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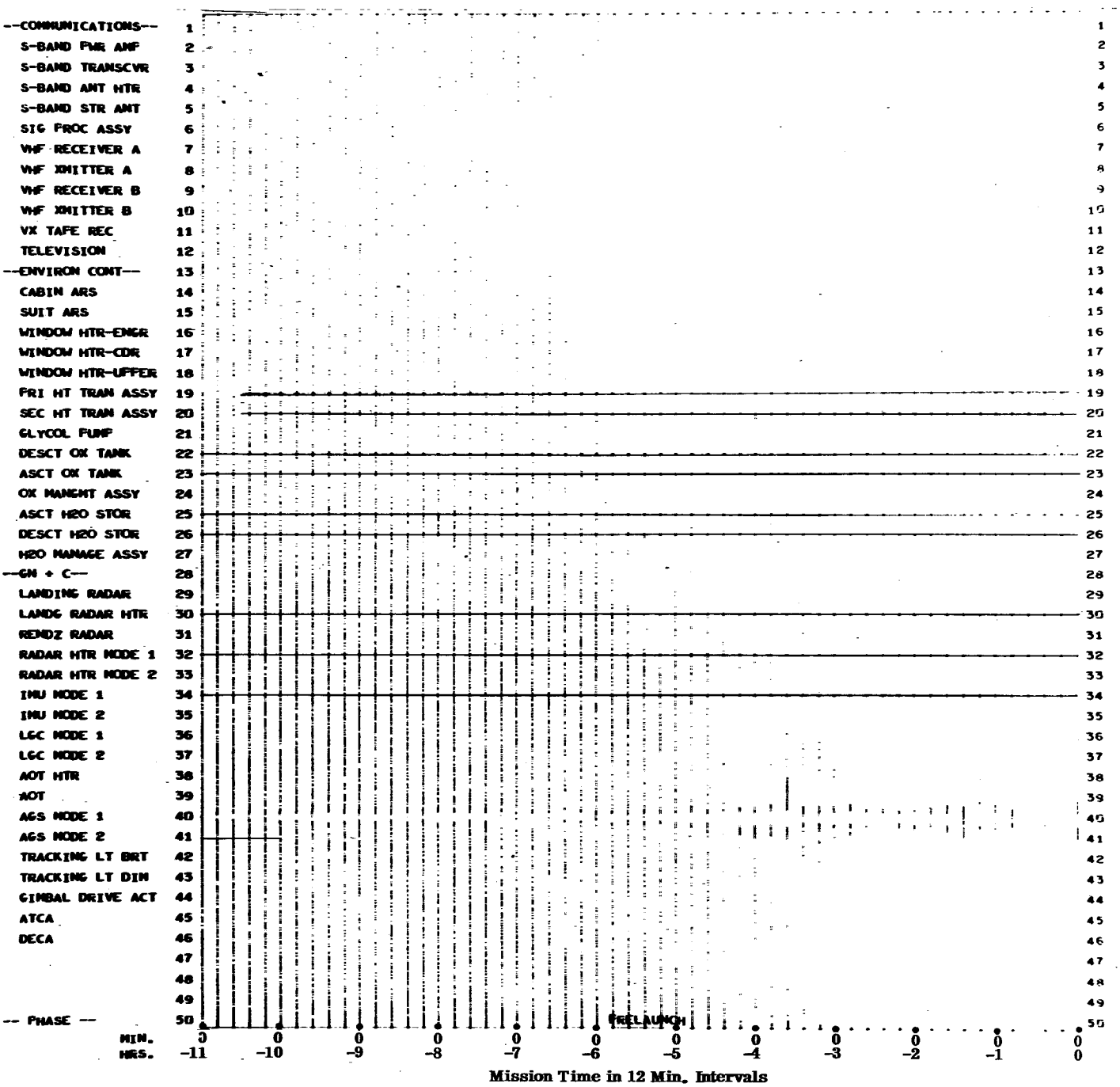

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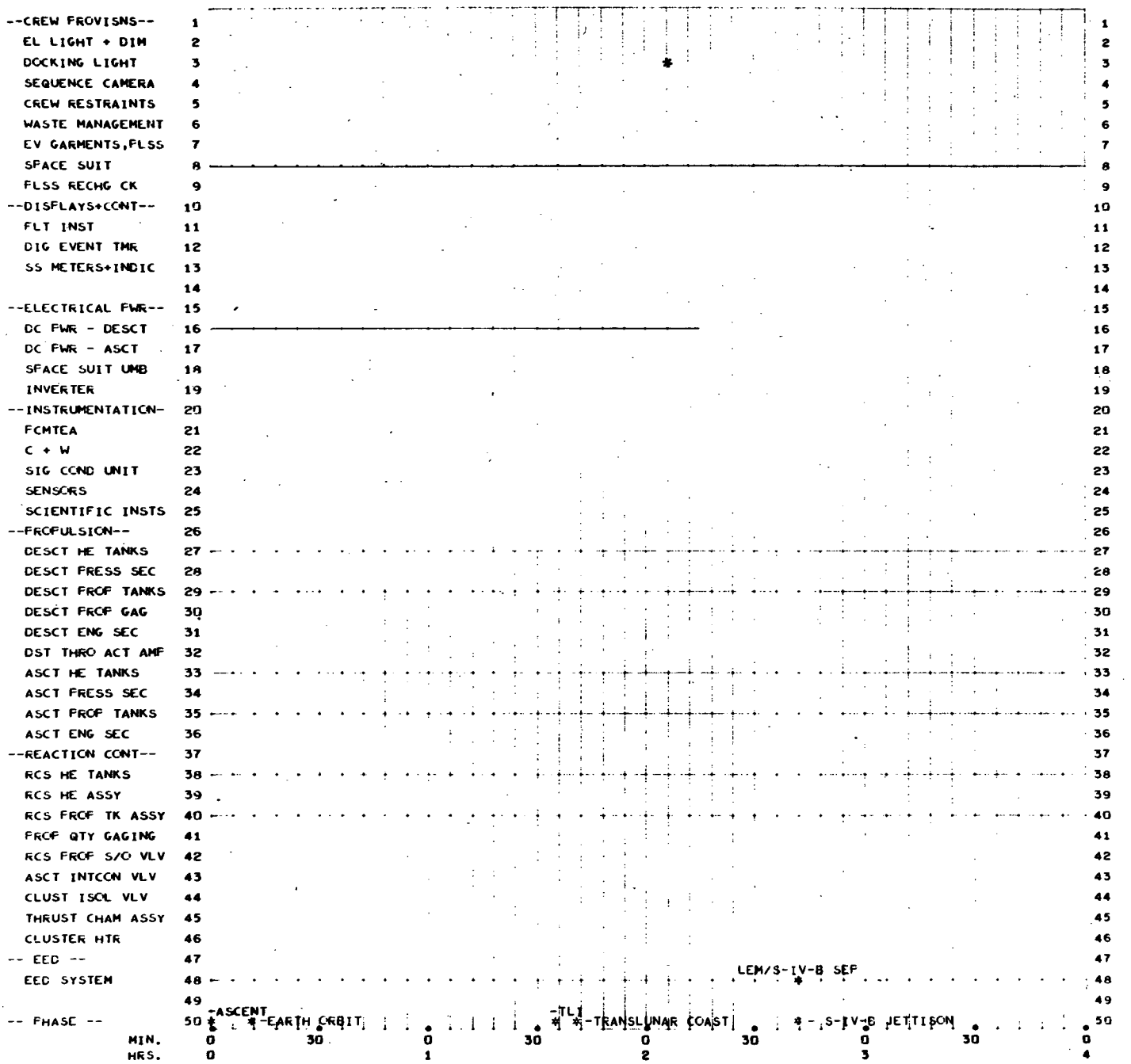

Mission Time in 6 Min. Intervals

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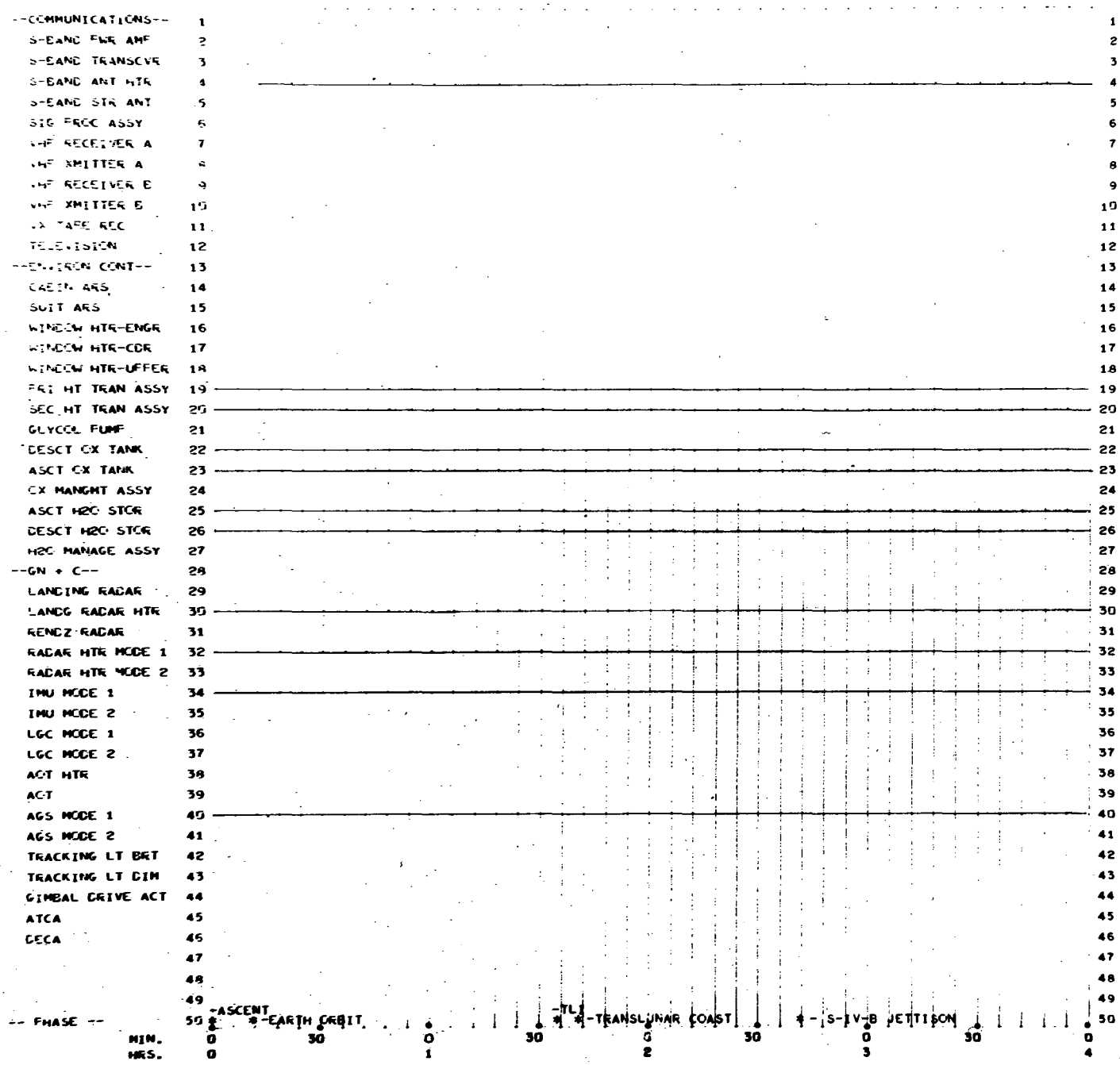

Mission Time in 6 Min. Intervals

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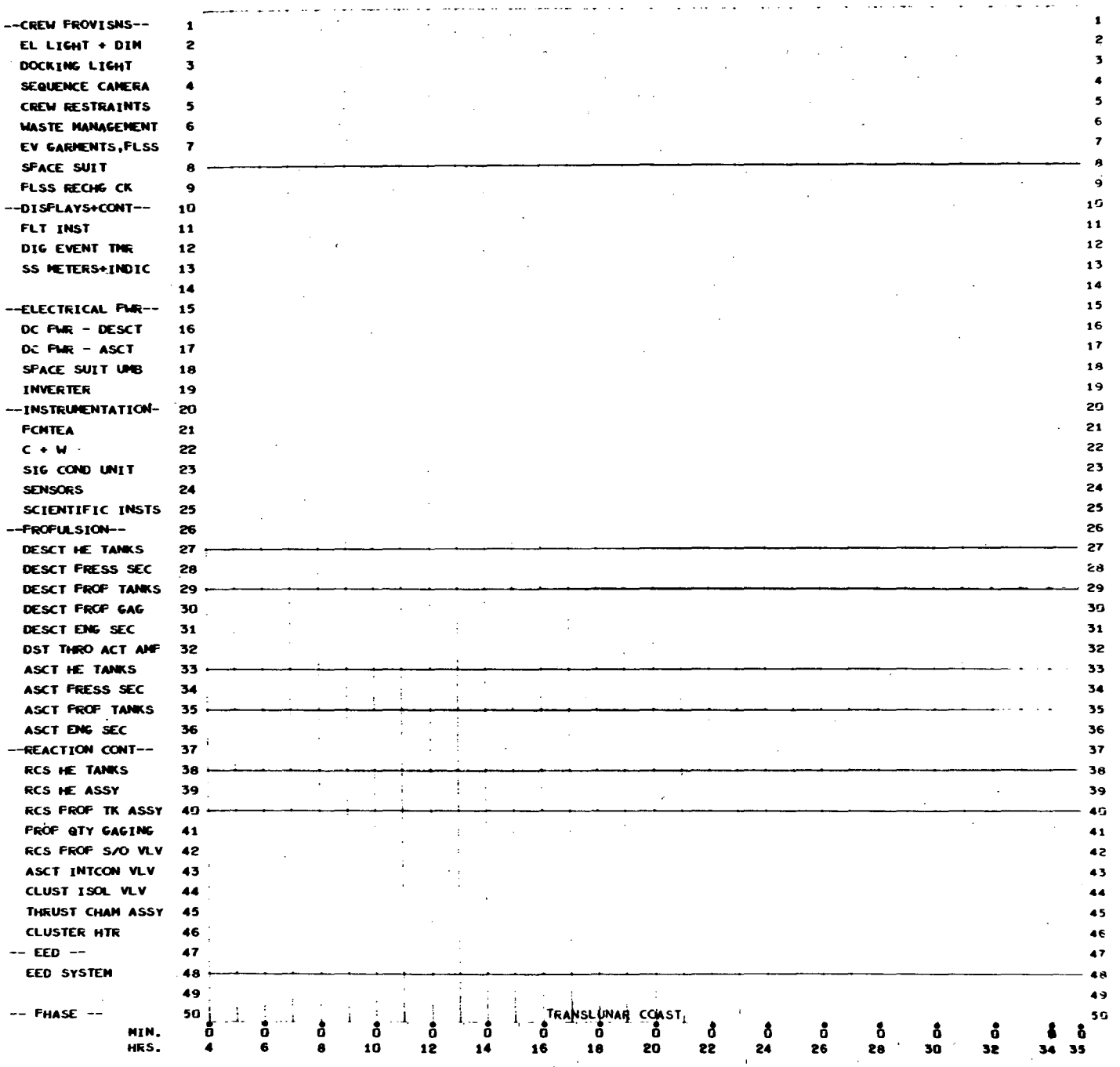

Mission Time in 1 Hour Intervals

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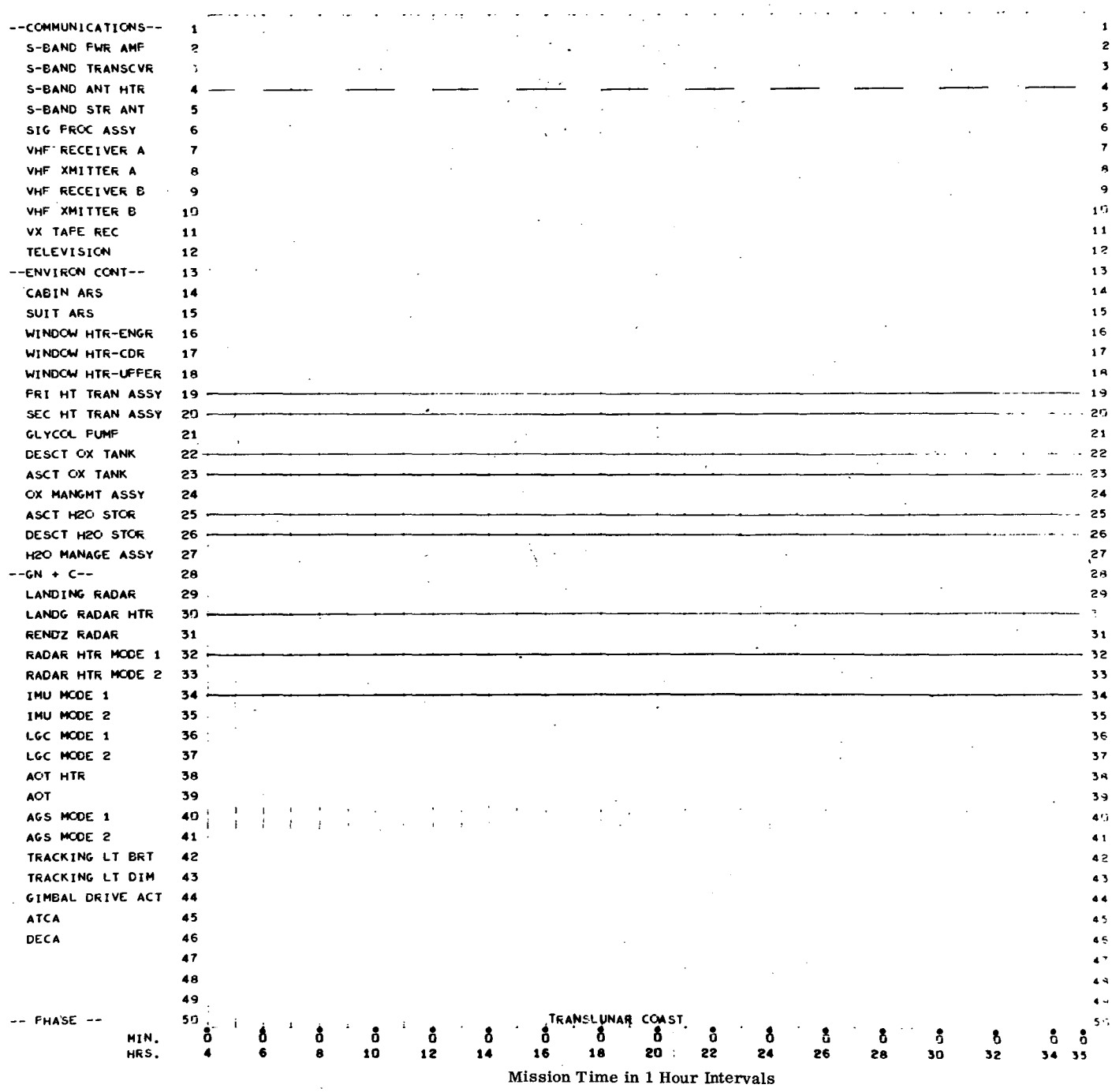

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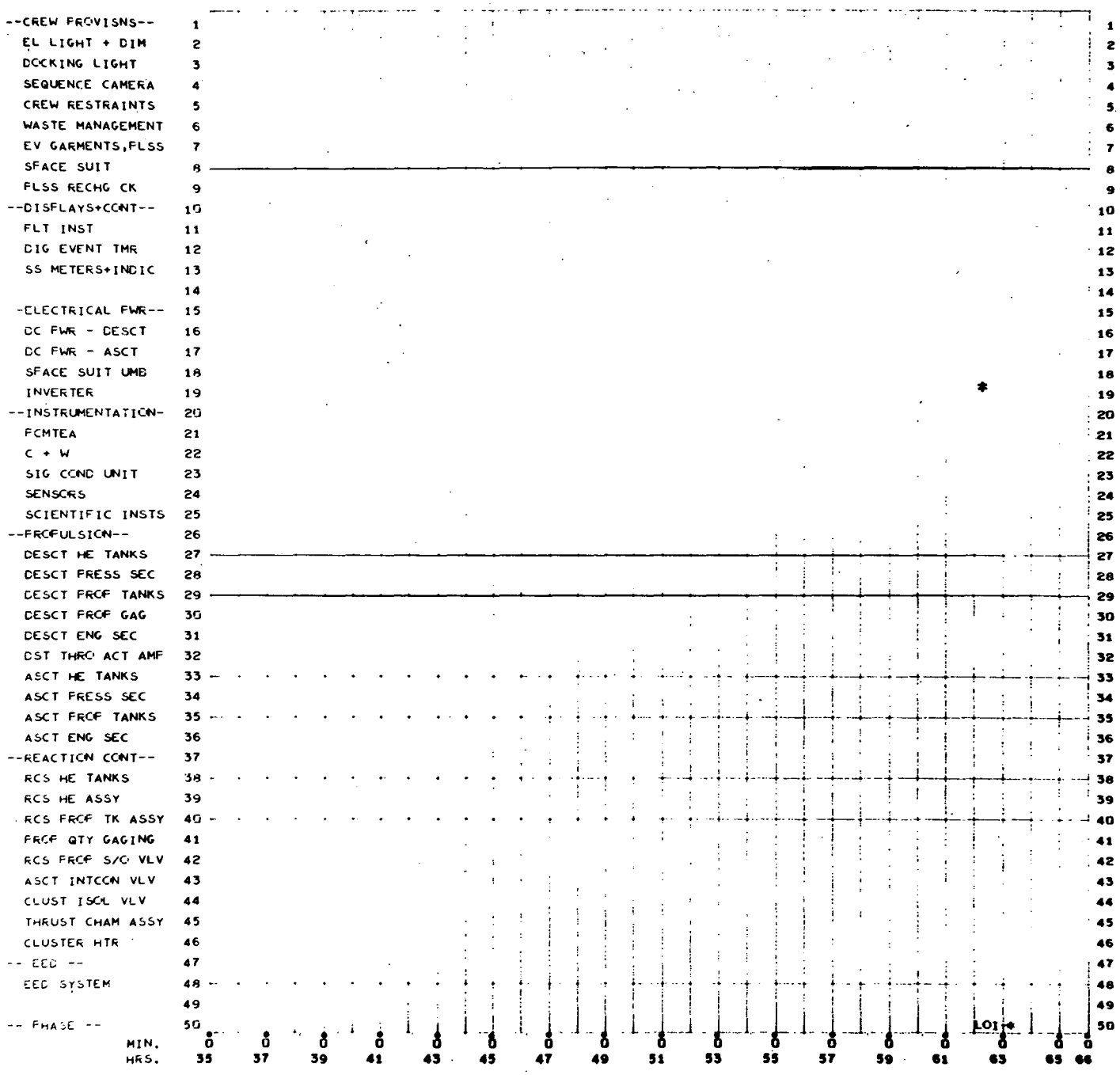

Mission Time in 1 Hour Intervals

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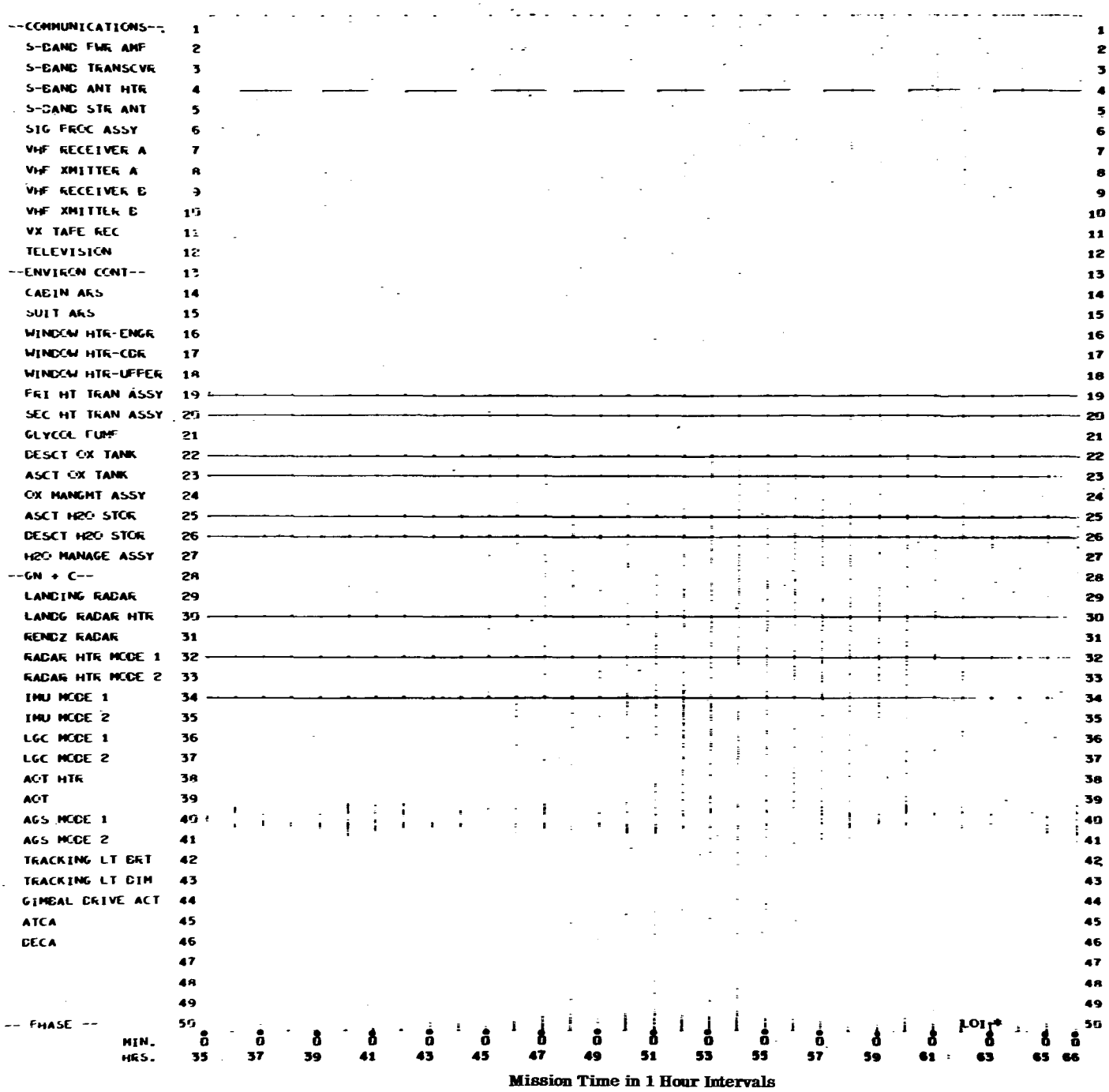

Mission Time in 1 Hour Intervals

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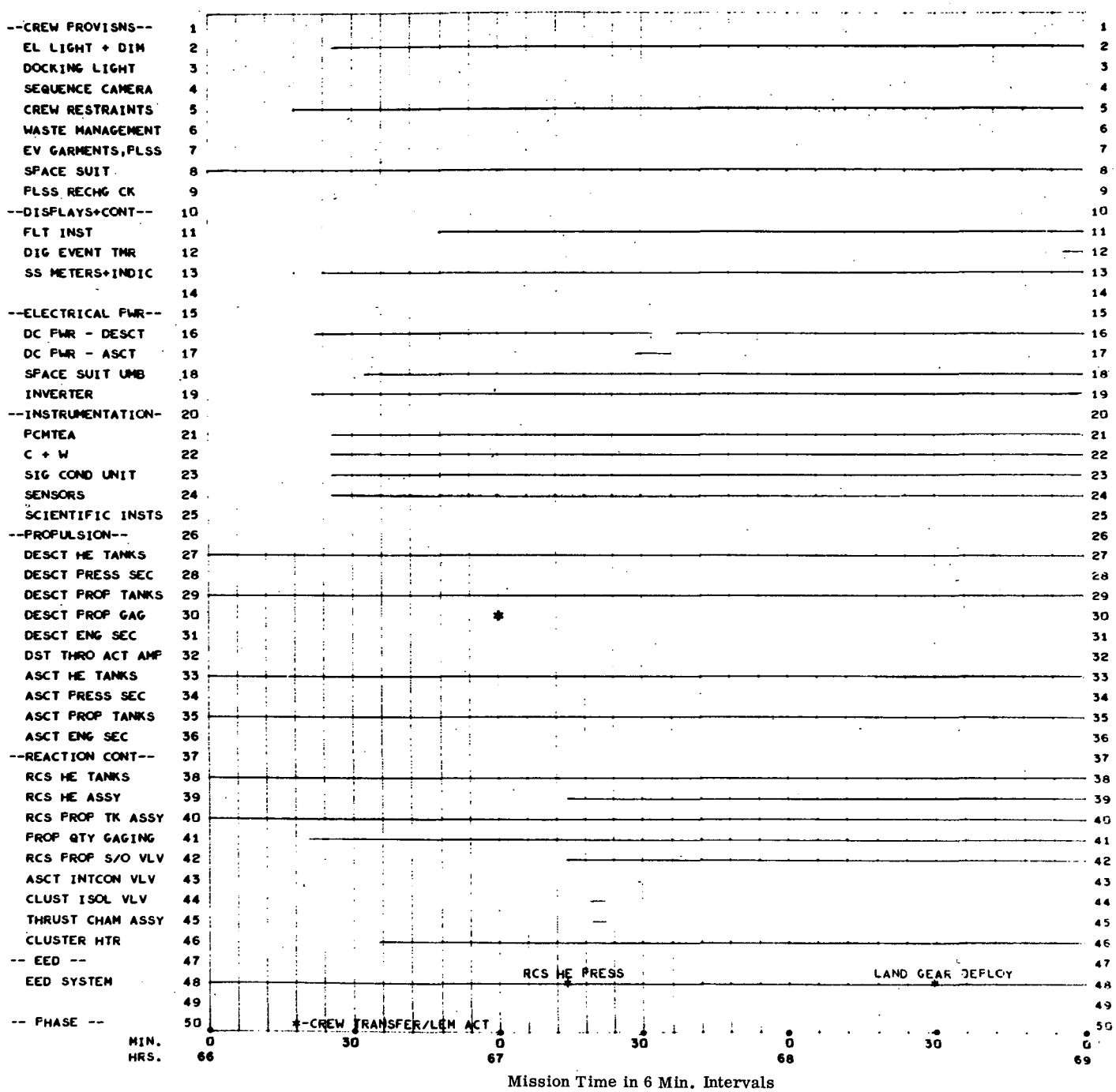
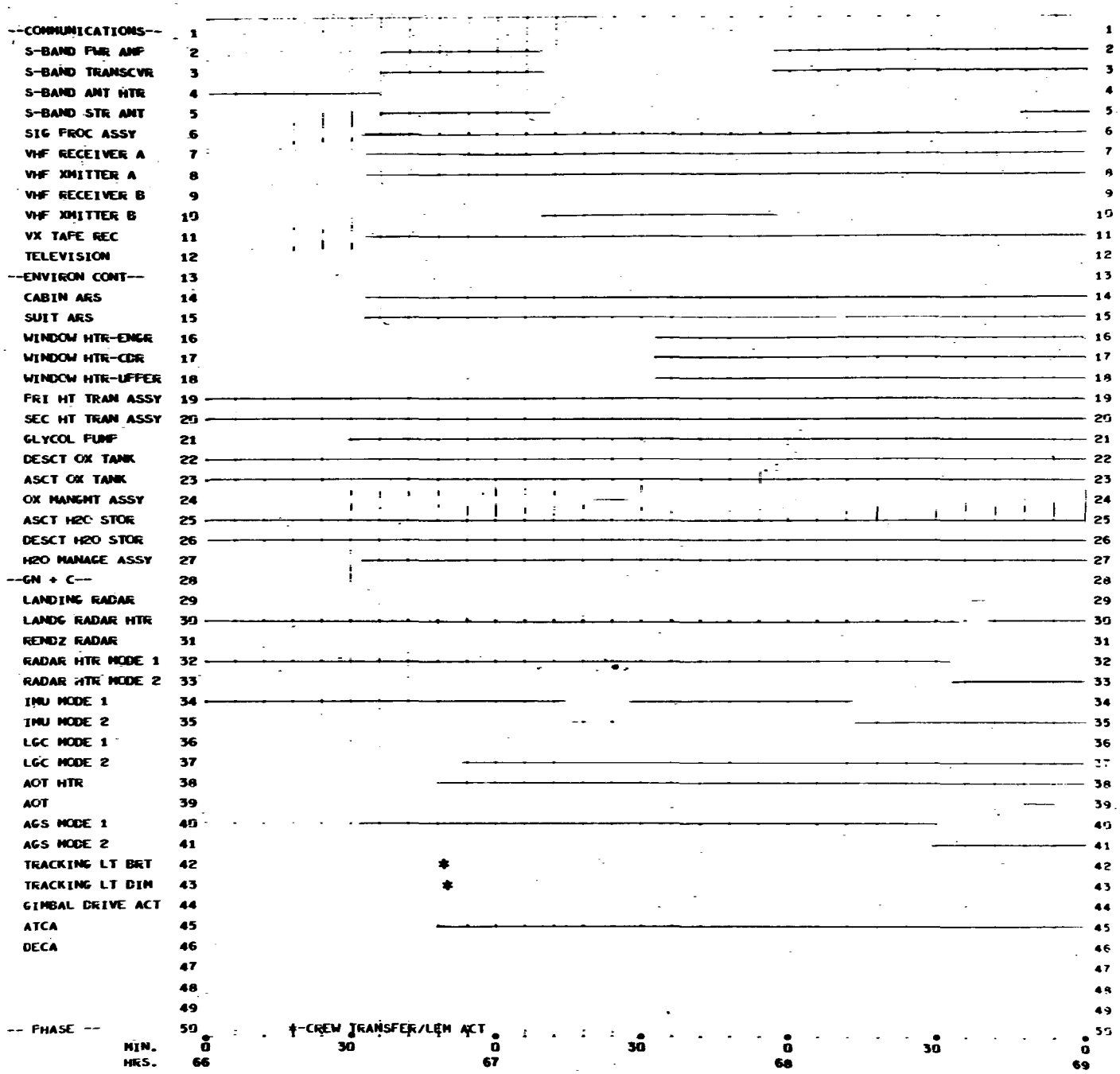


Mission Time in 6 Min. Intervals

Figure E-2 LM Duty Cycles (Continued)



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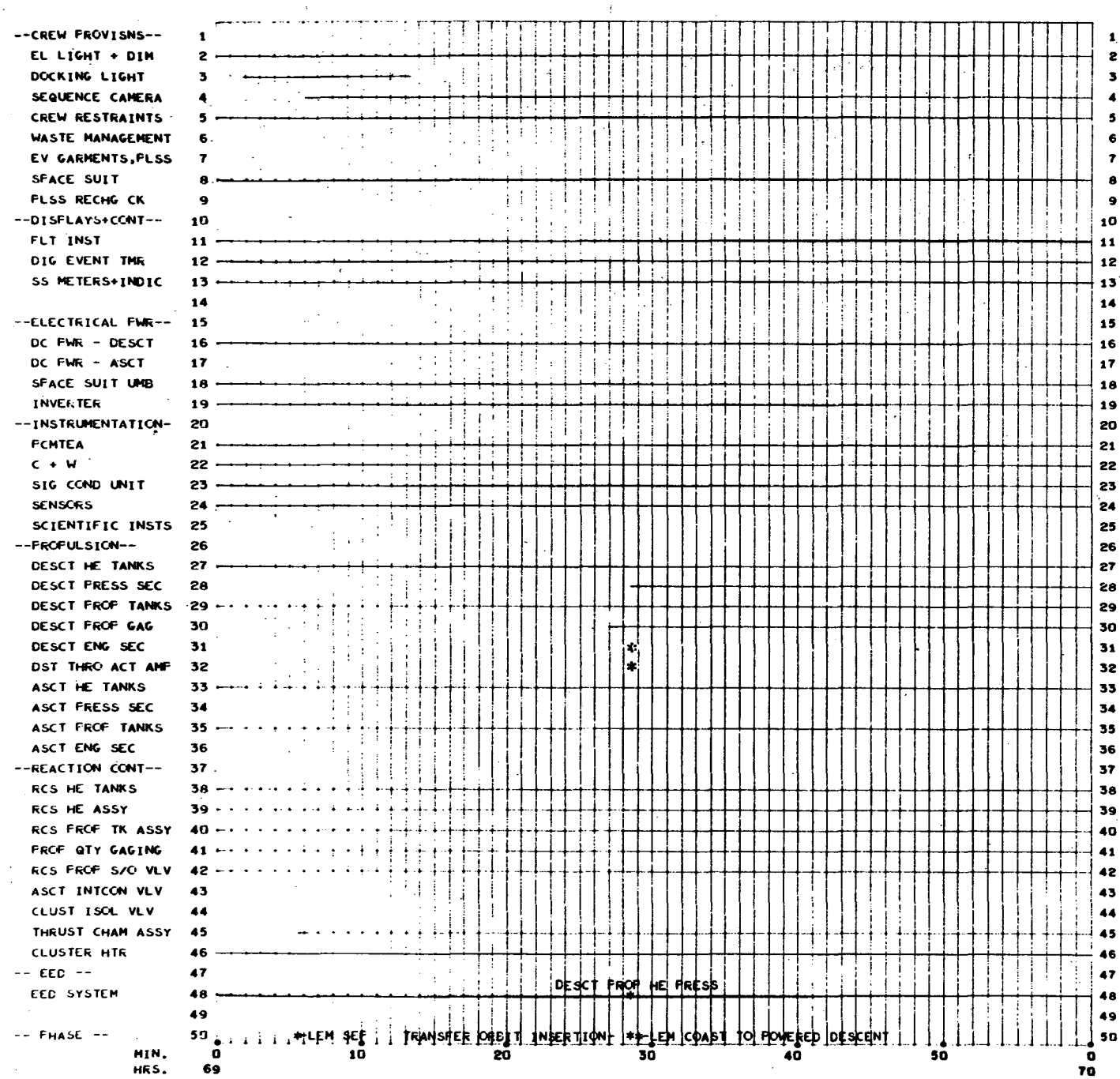

Mission Time in 1 Min. Intervals

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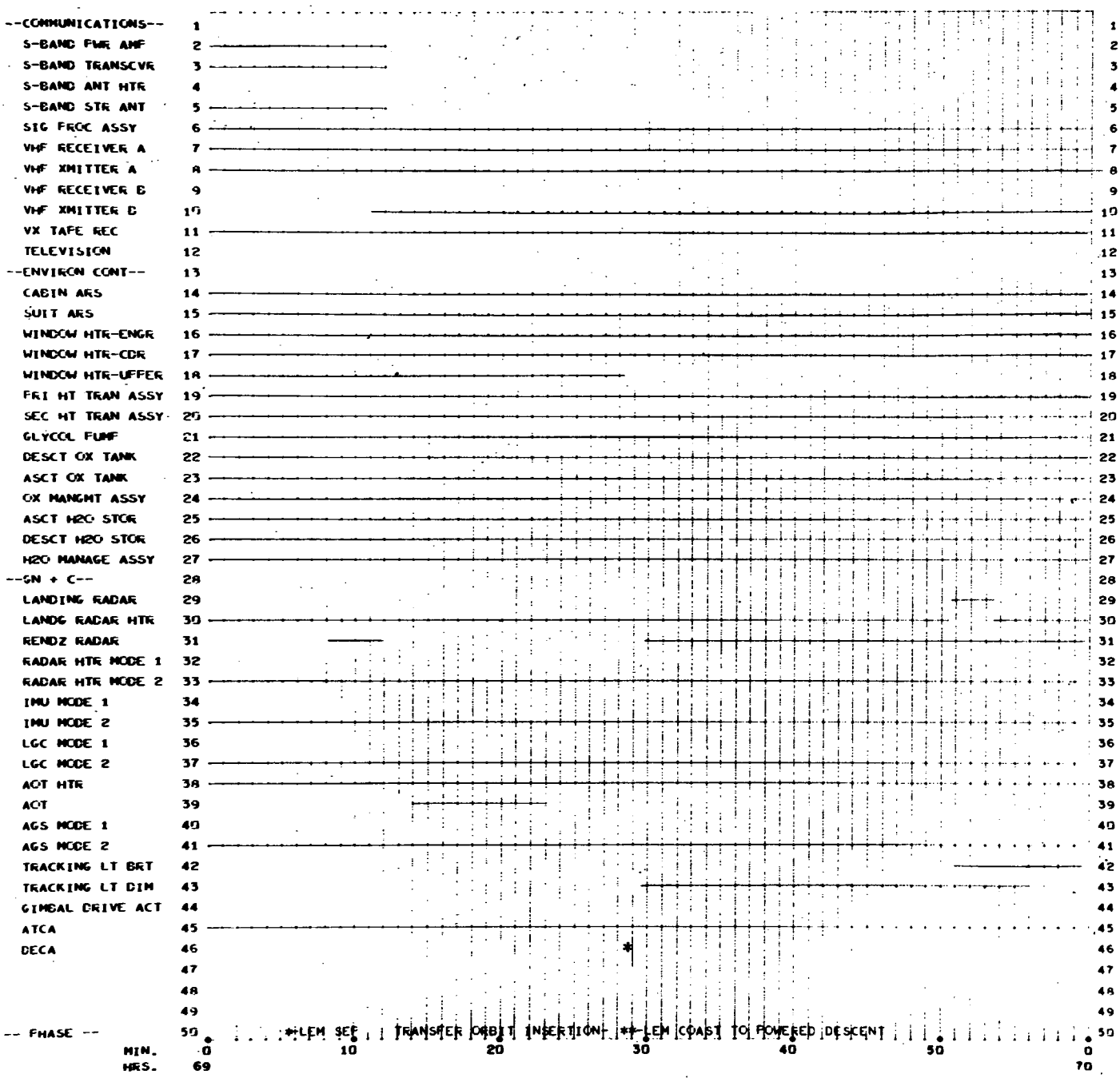

Mission Time in 1 Min. Intervals

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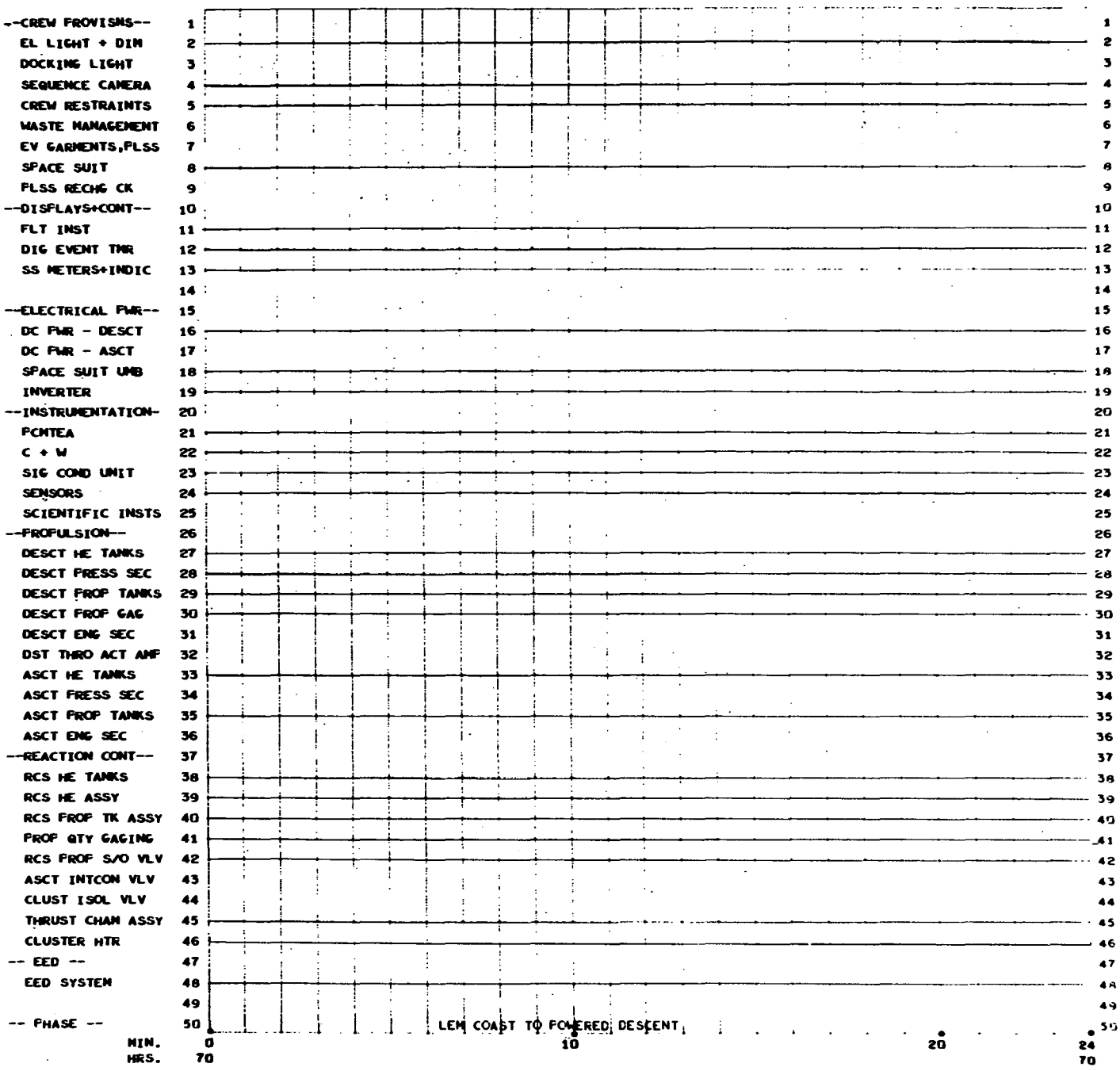
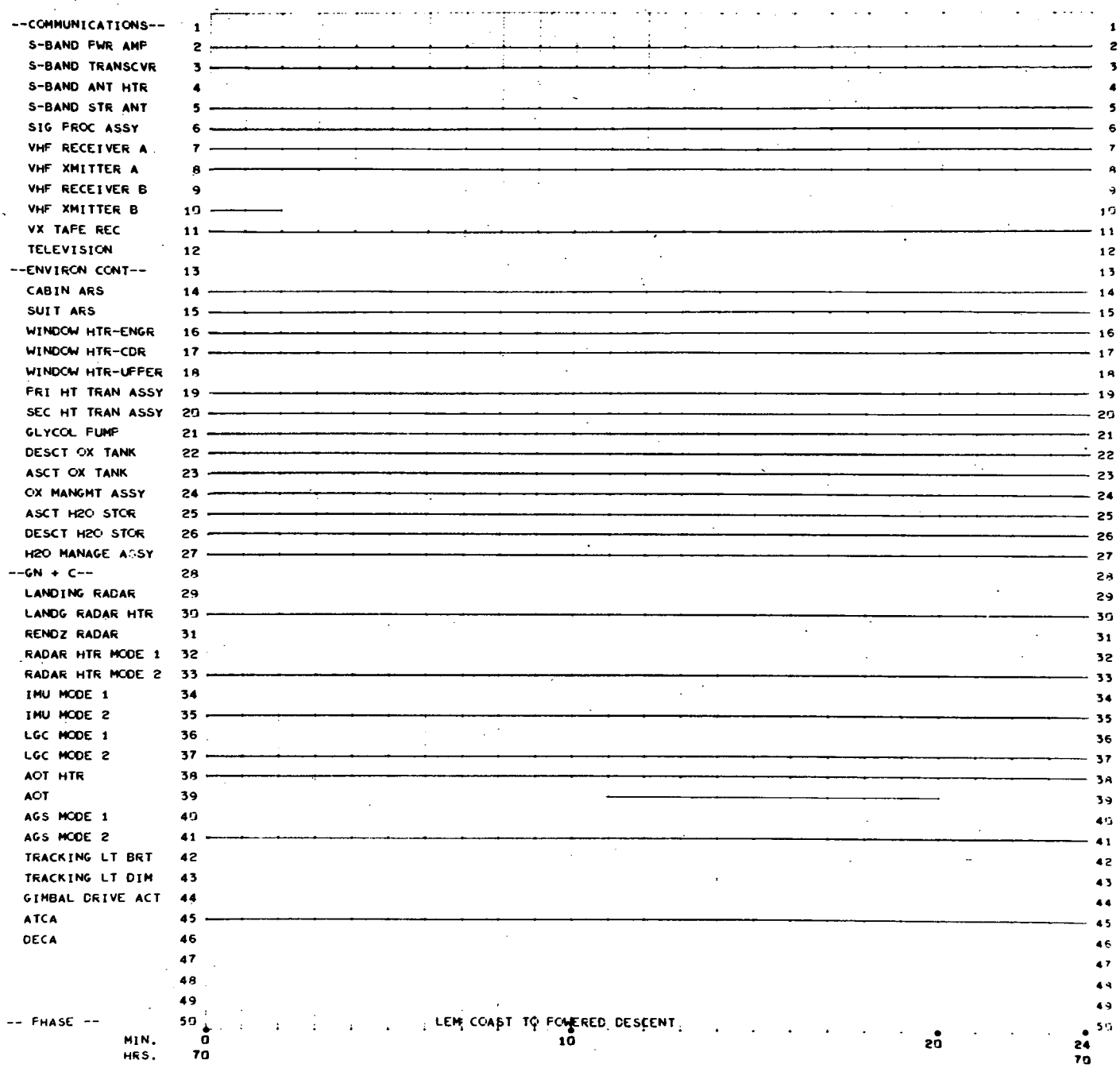


Mission Time in 1 Min. Intervals

Figure E-2 LM Duty Cycles (Continued)



Mission Time in 1 Min. Intervals

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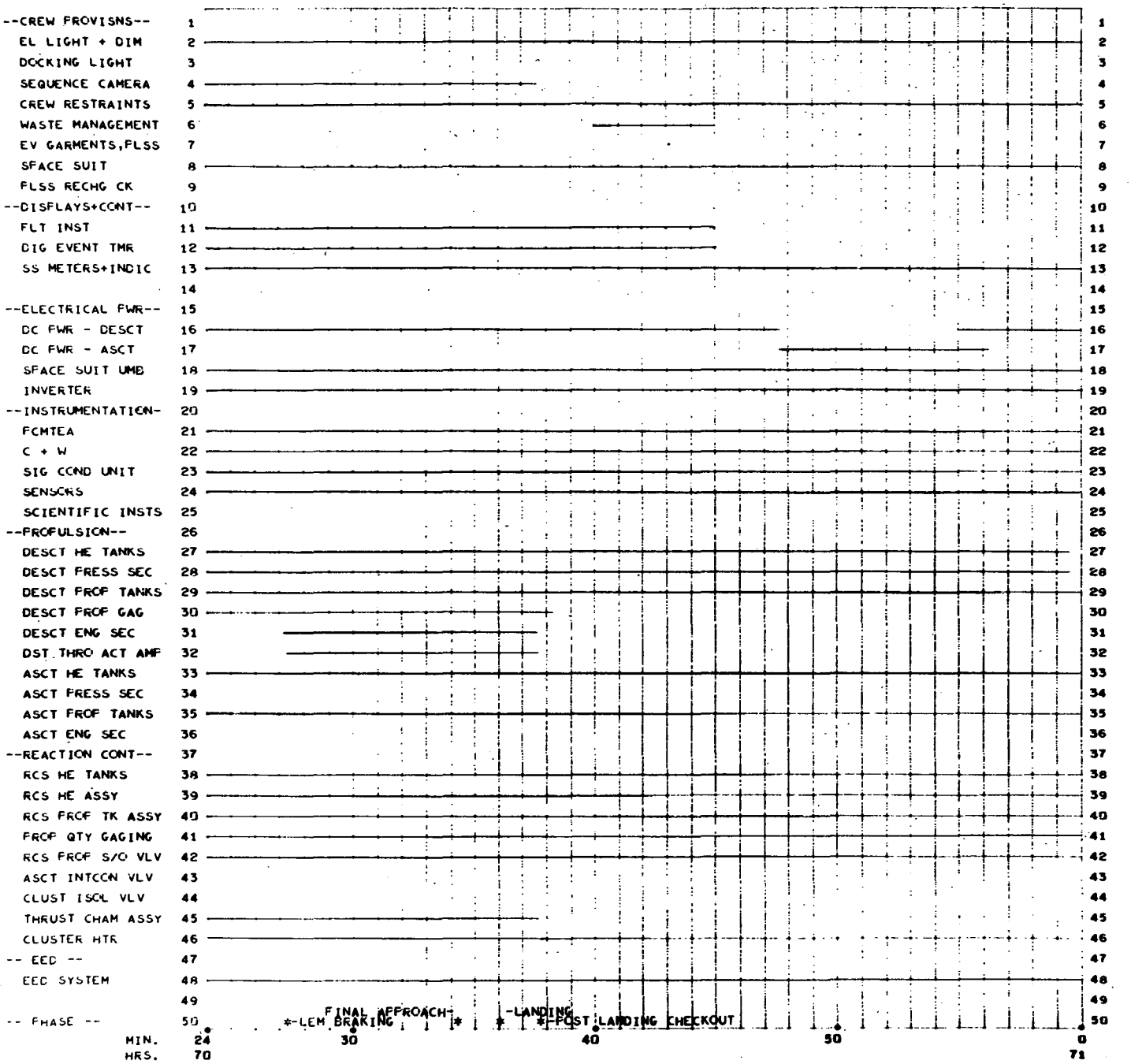

Mission Time in 1 Min. Intervals

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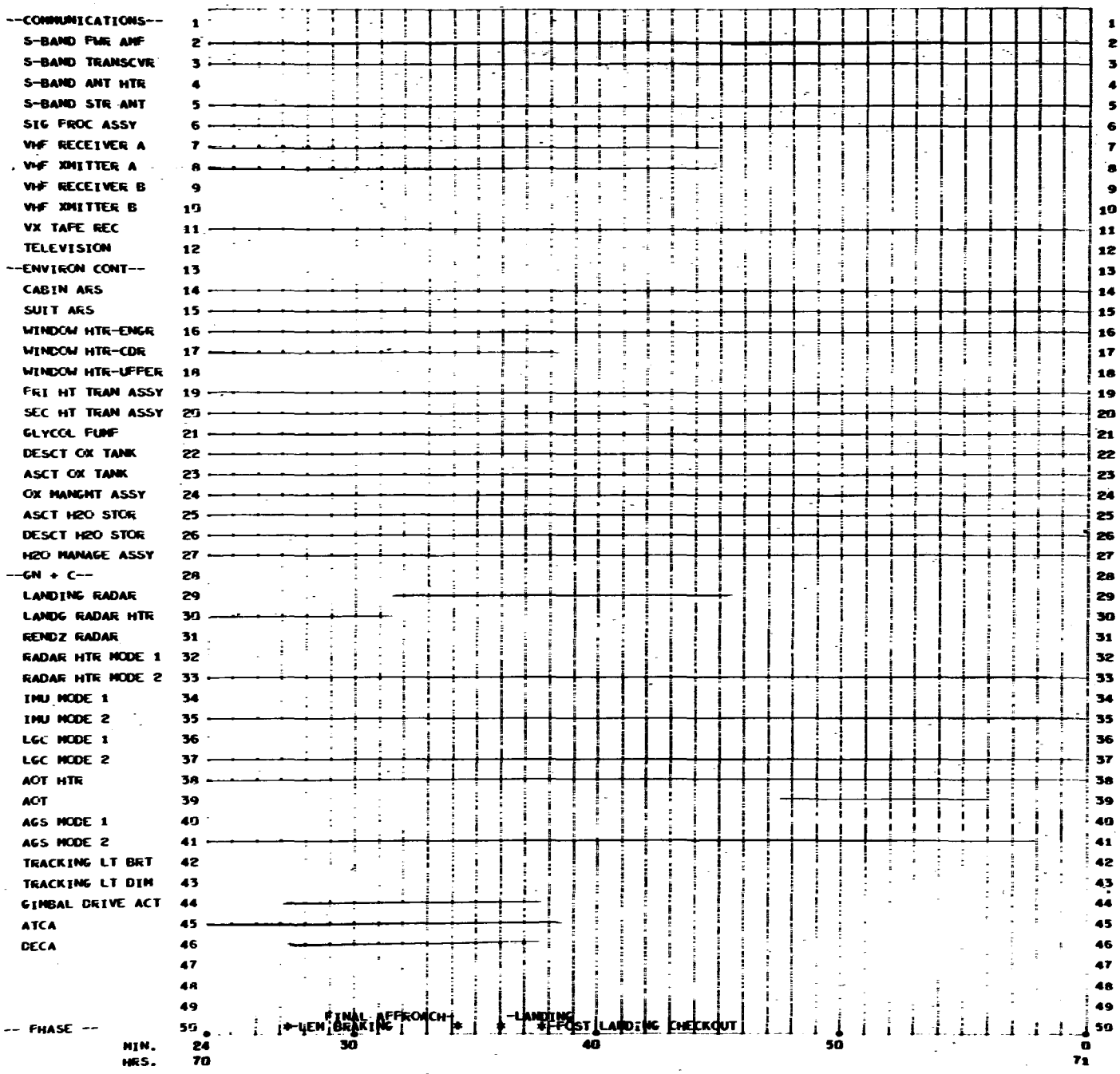
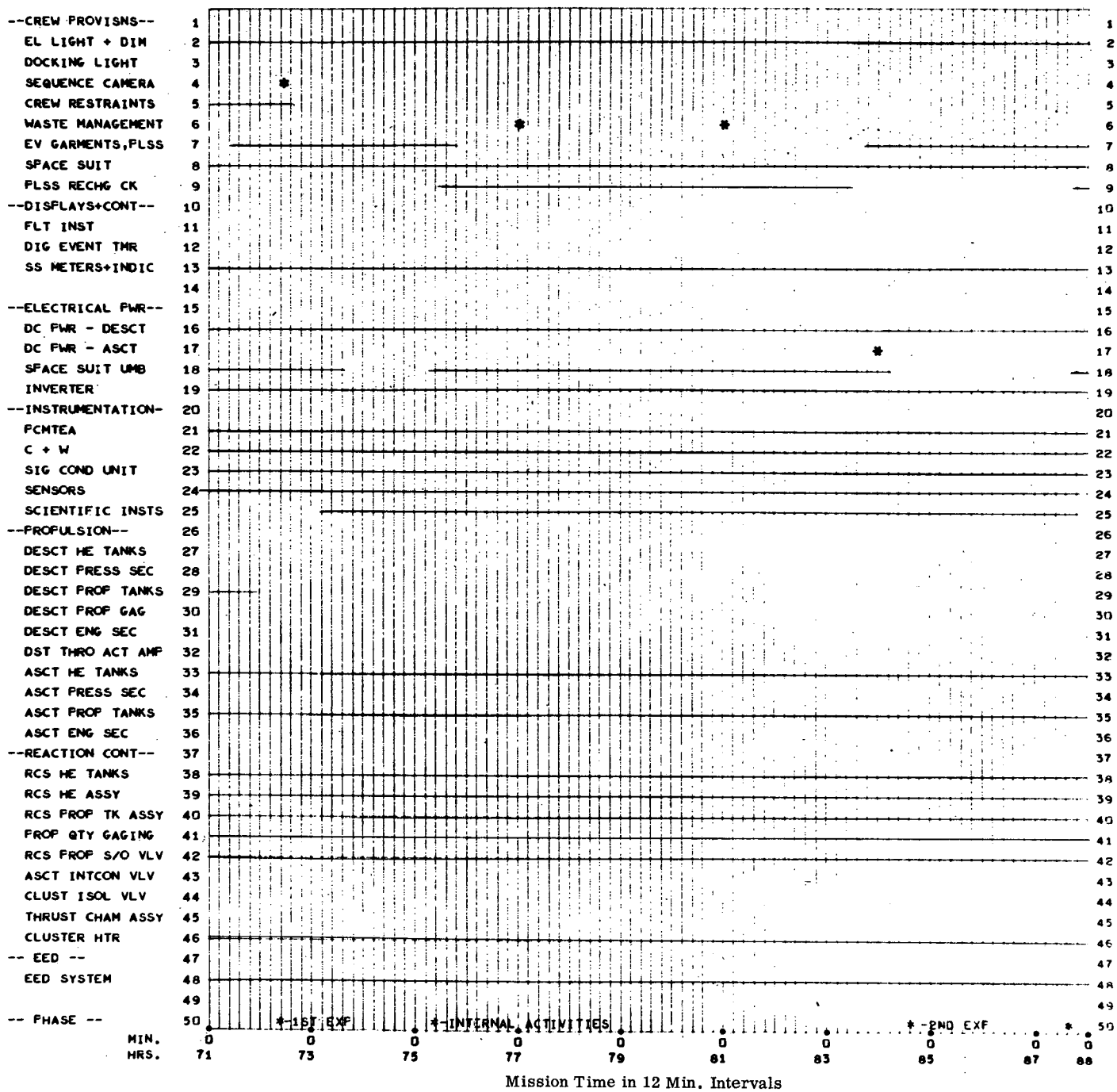


Mission Time in 1 Min. Intervals

Figure E-2 LM Duty Cycles (Continued)



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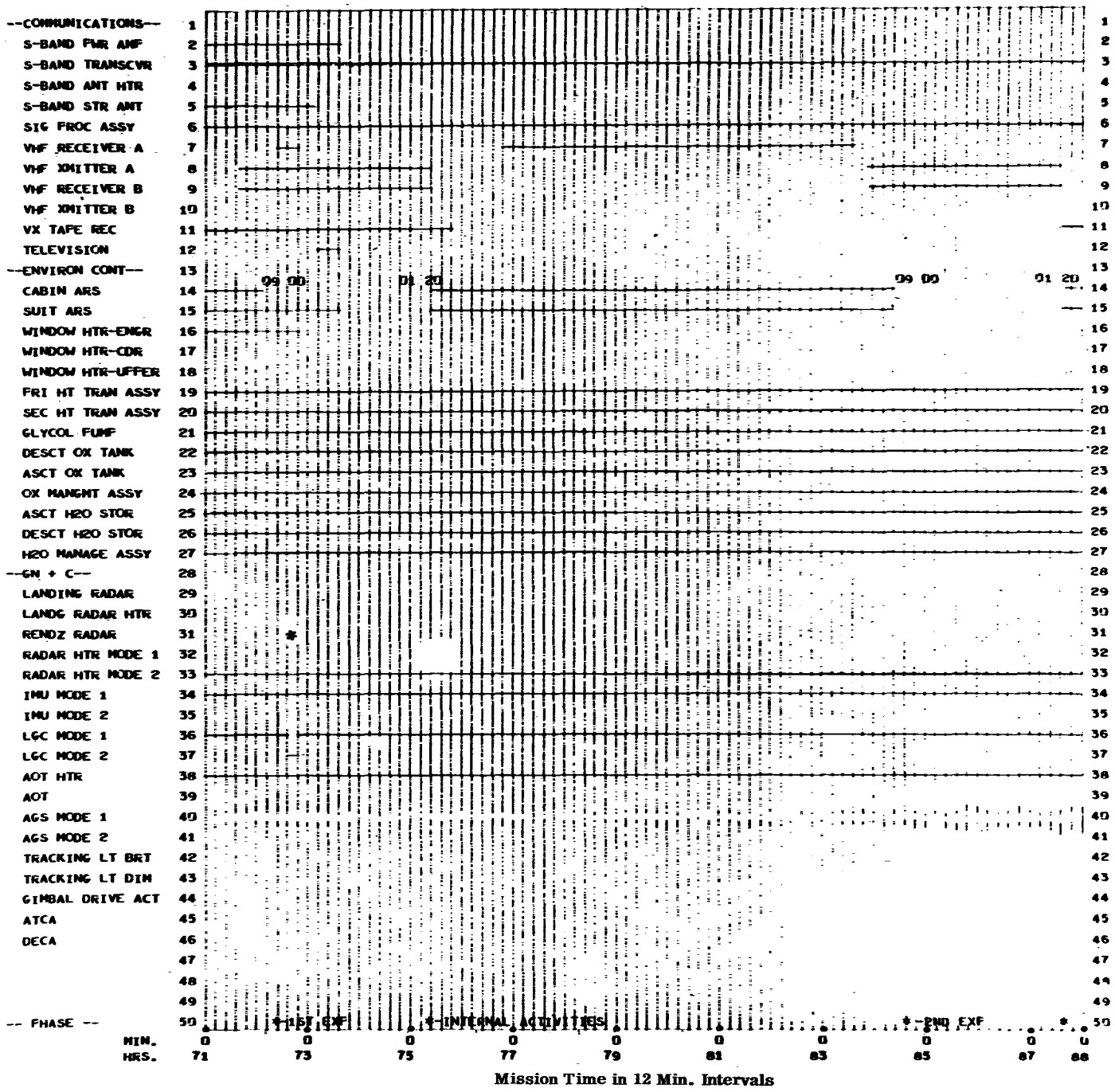

Mission Time in 12 Min. Intervals

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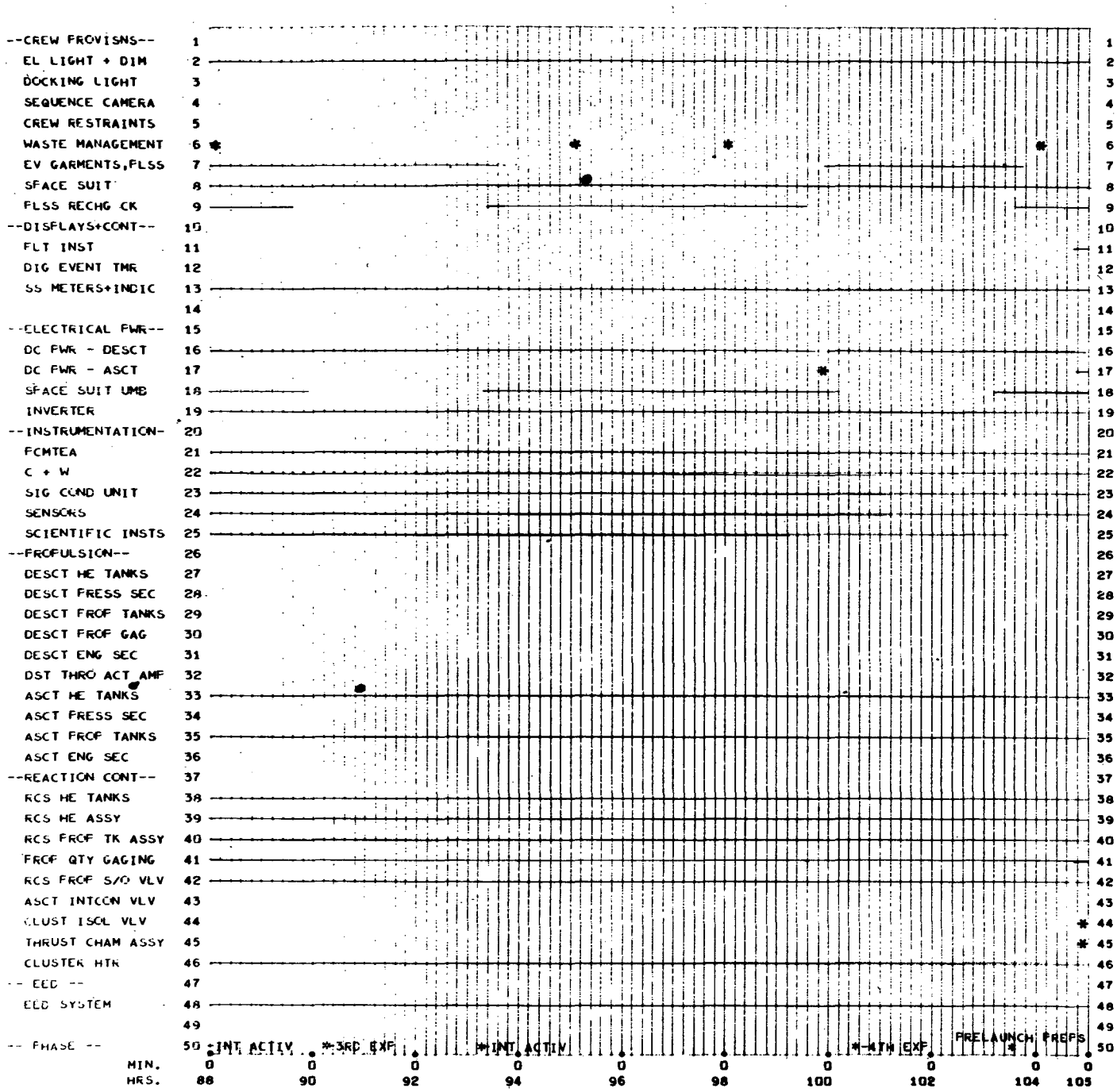

Mission Time in 12 Min. Intervals

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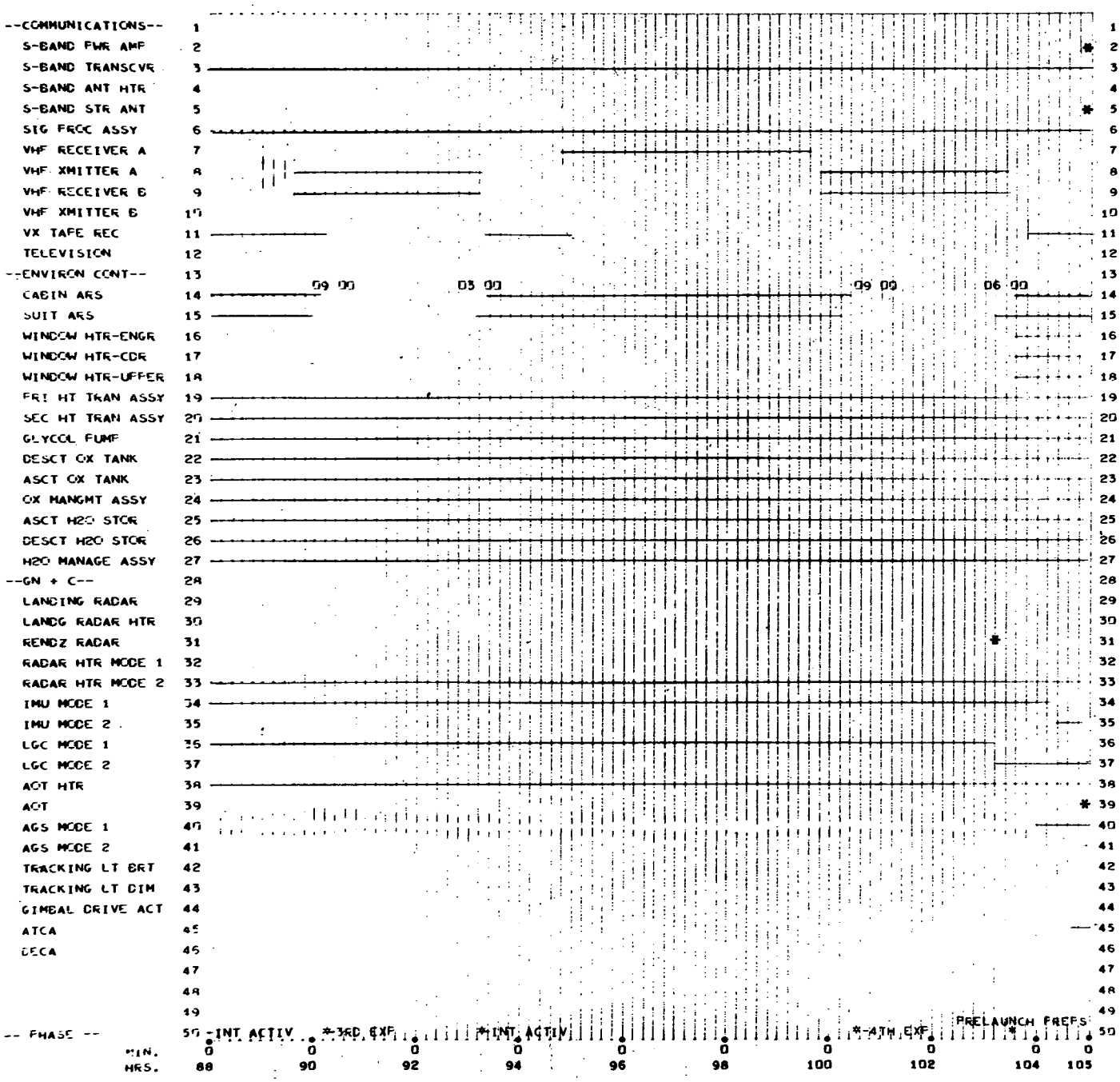
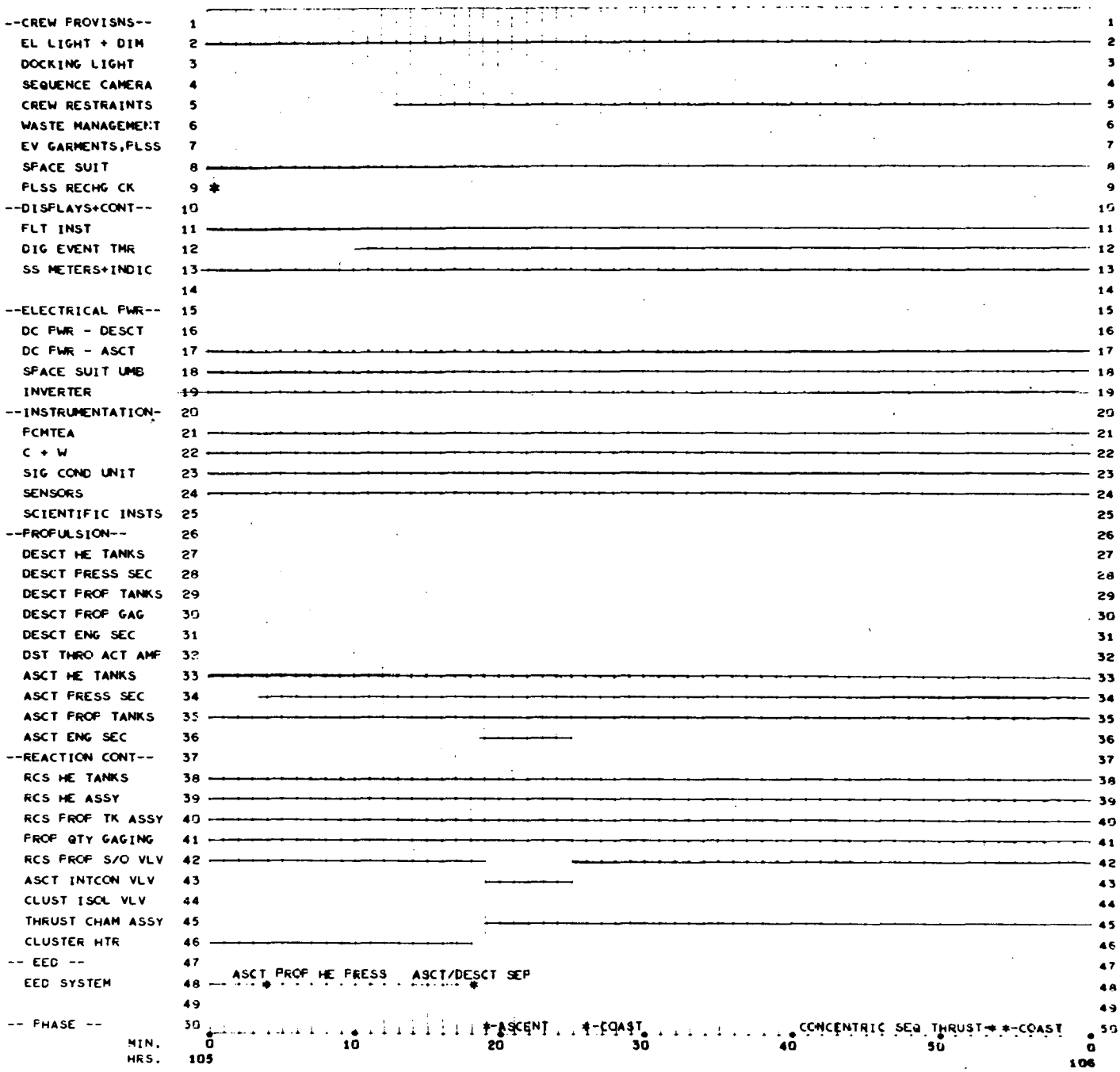


Mission Time in 12 Min. Intervals

Figure E-2 LM Duty Cycles (Continued)



Mission Time in 1 Min. Intervals

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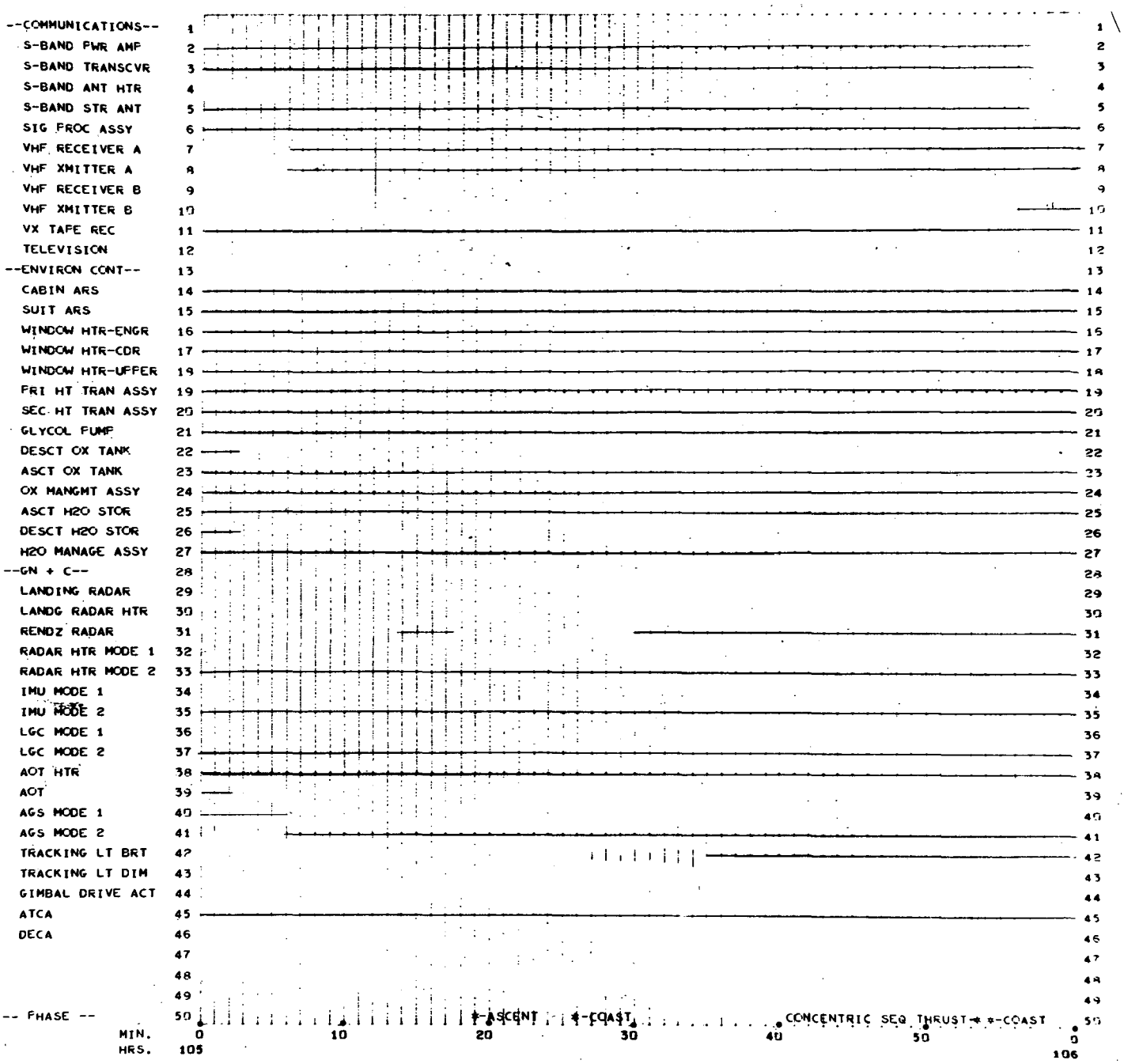

Mission Time in 1 Min. Intervals

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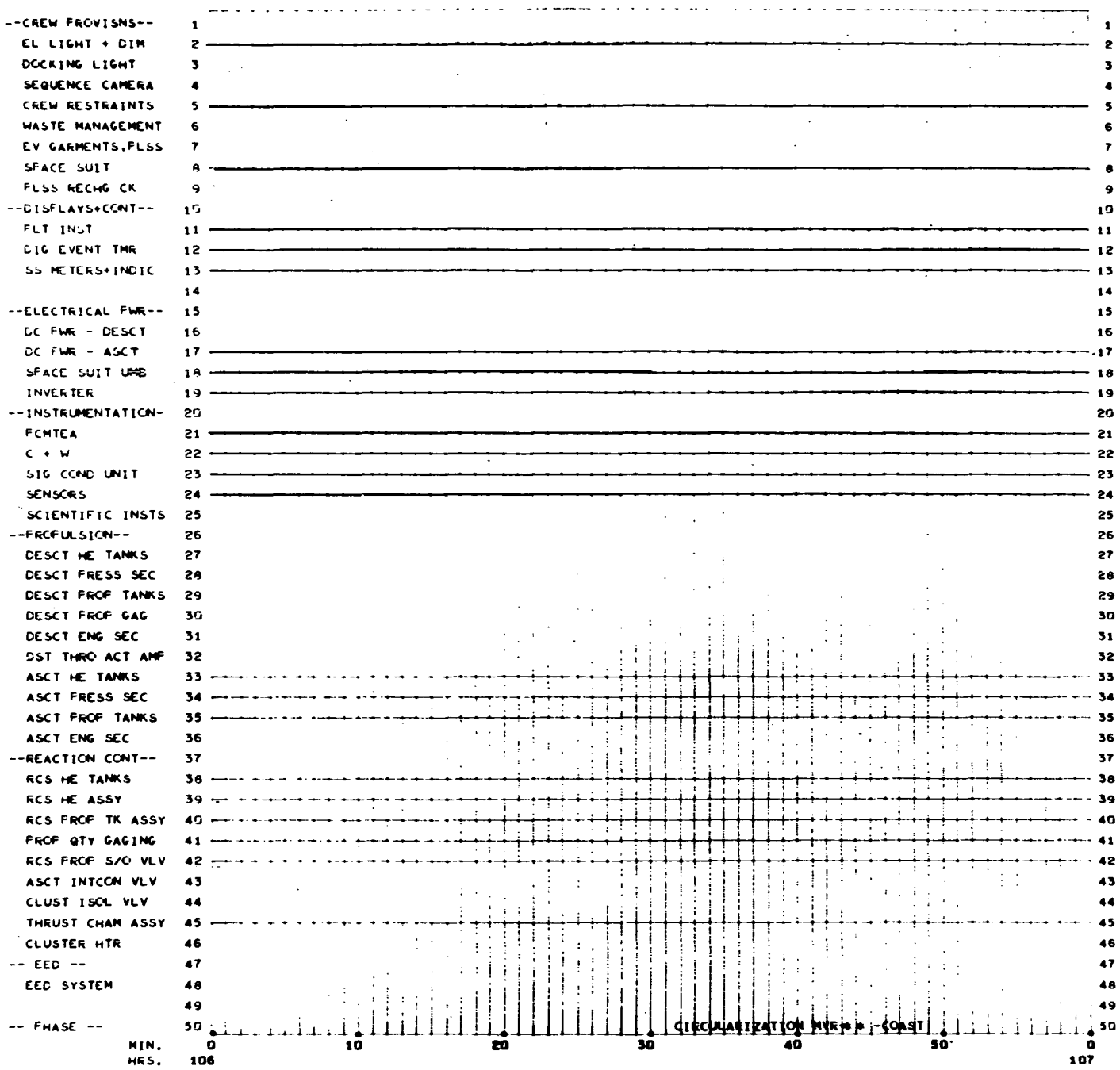

Mission Time in 1 Min. Intervals

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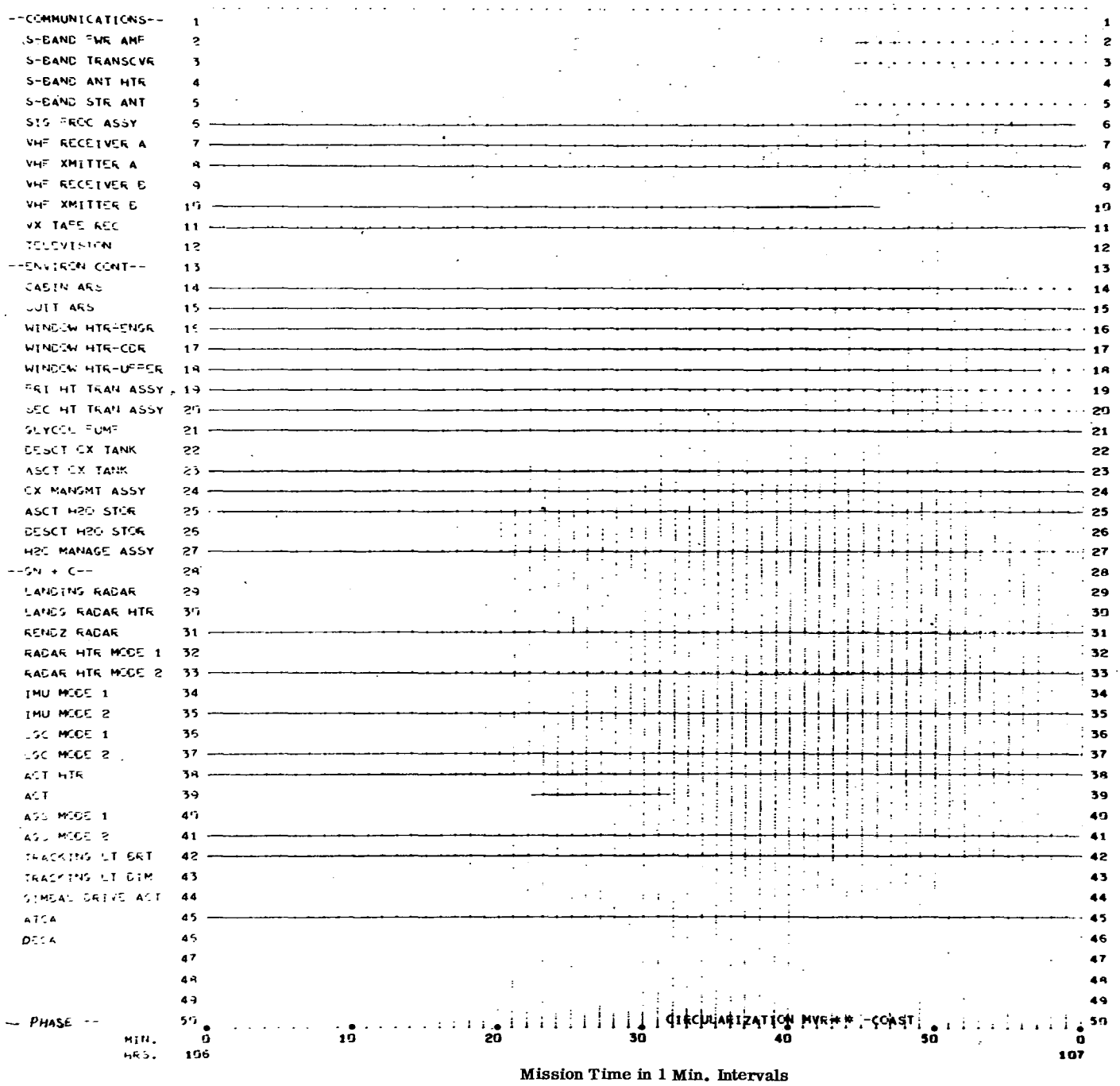

Mission Time in 1 Min. Intervals

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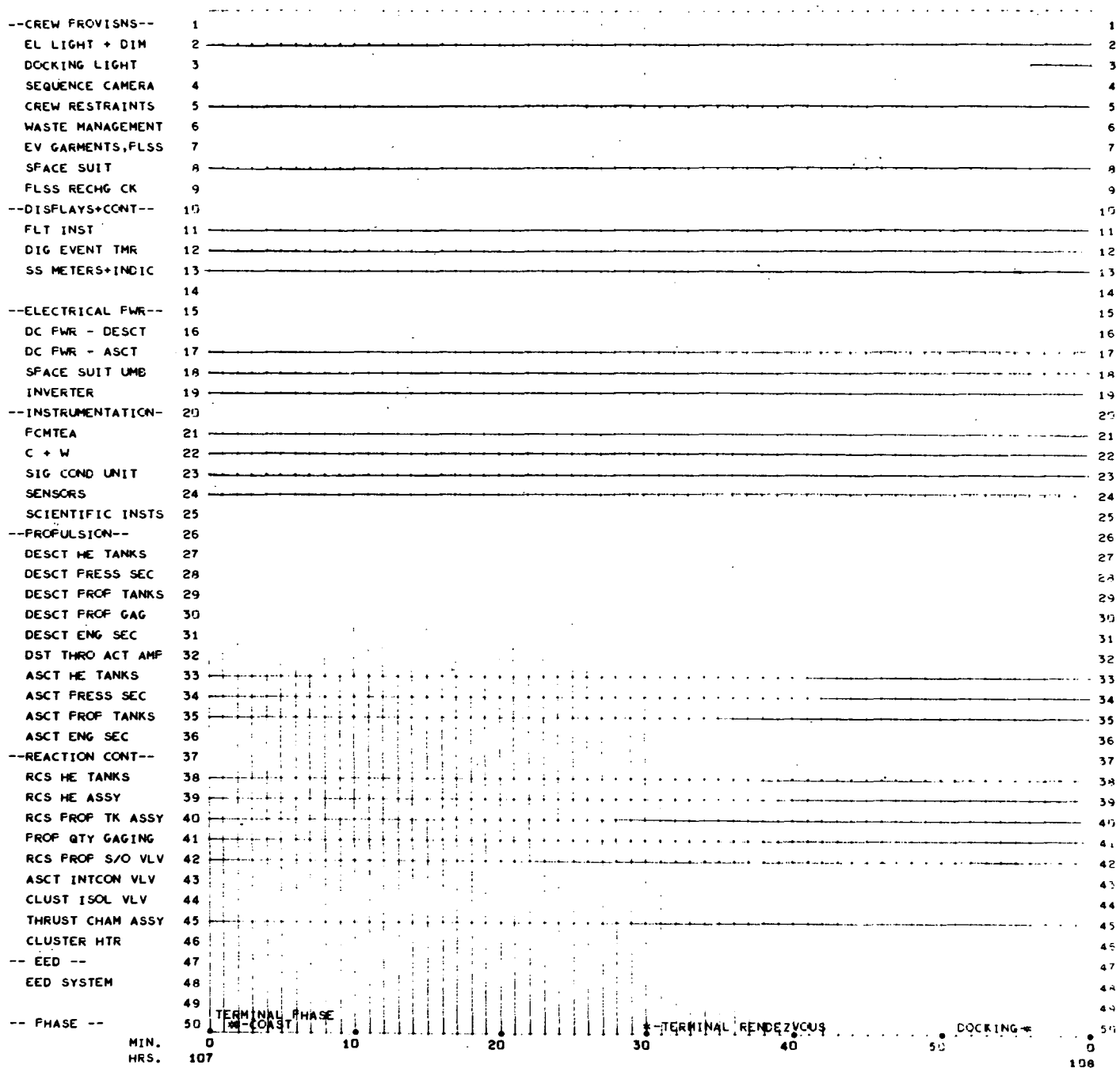

Mission Time in 1 Min. Intervals

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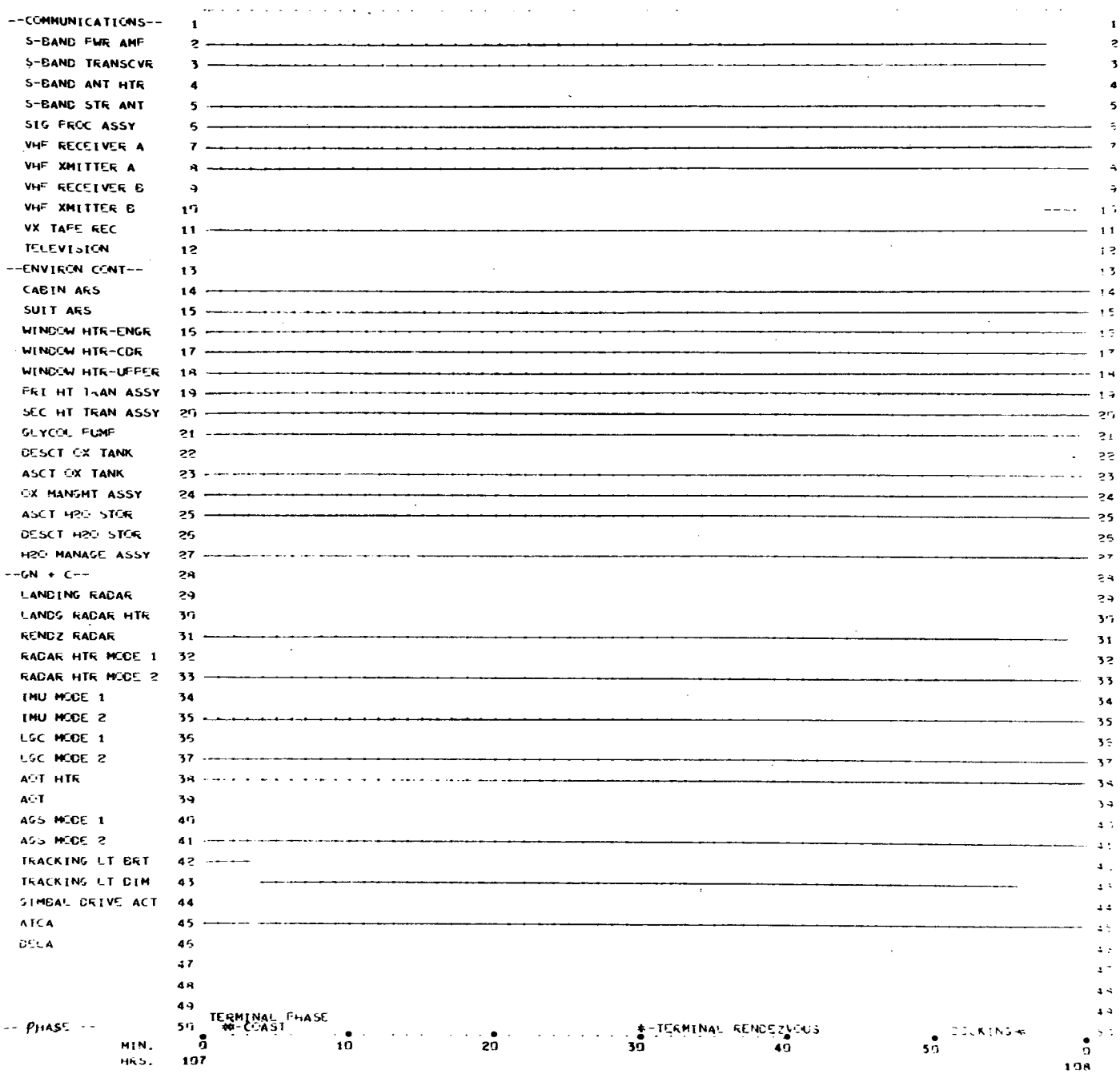
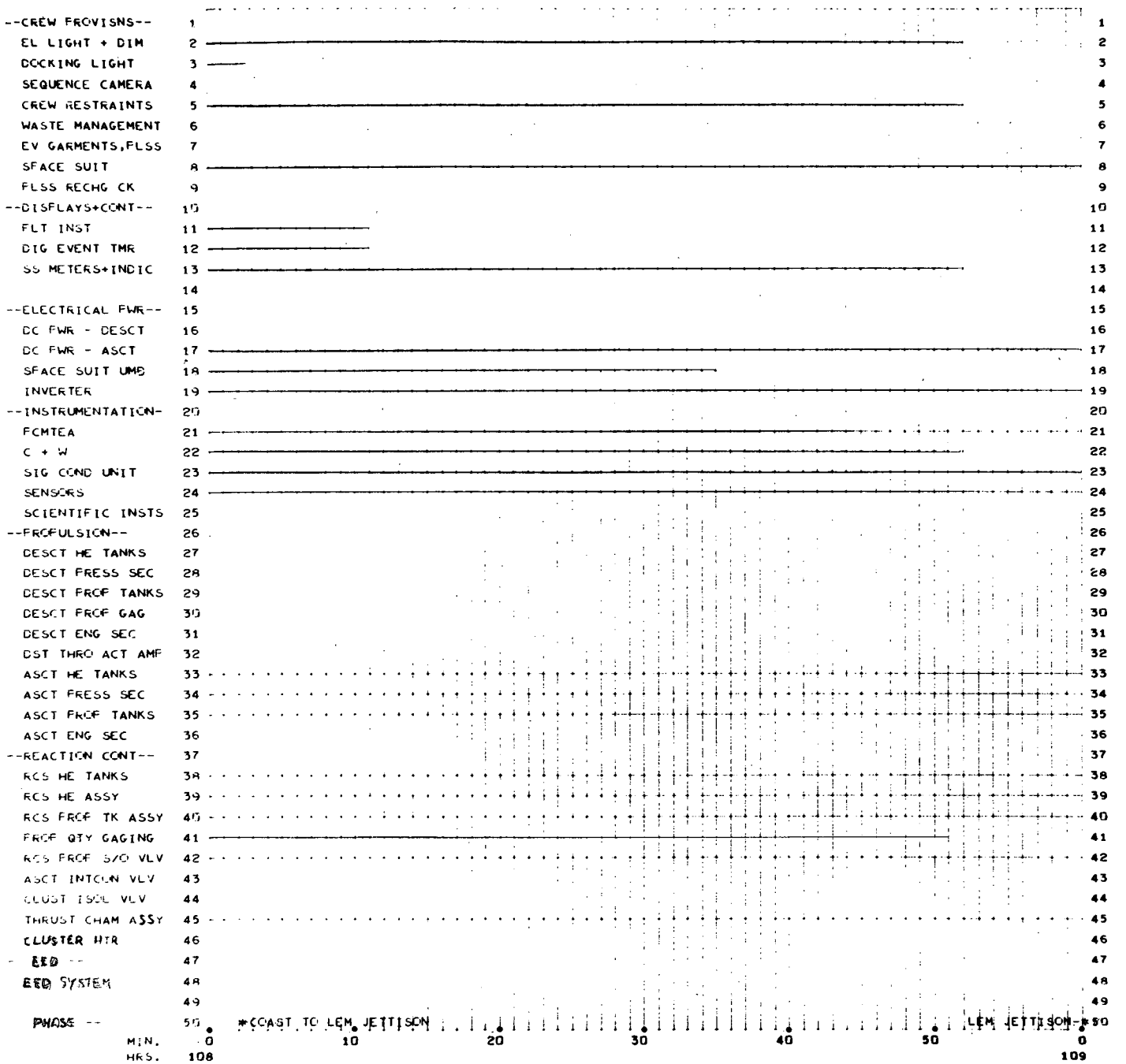


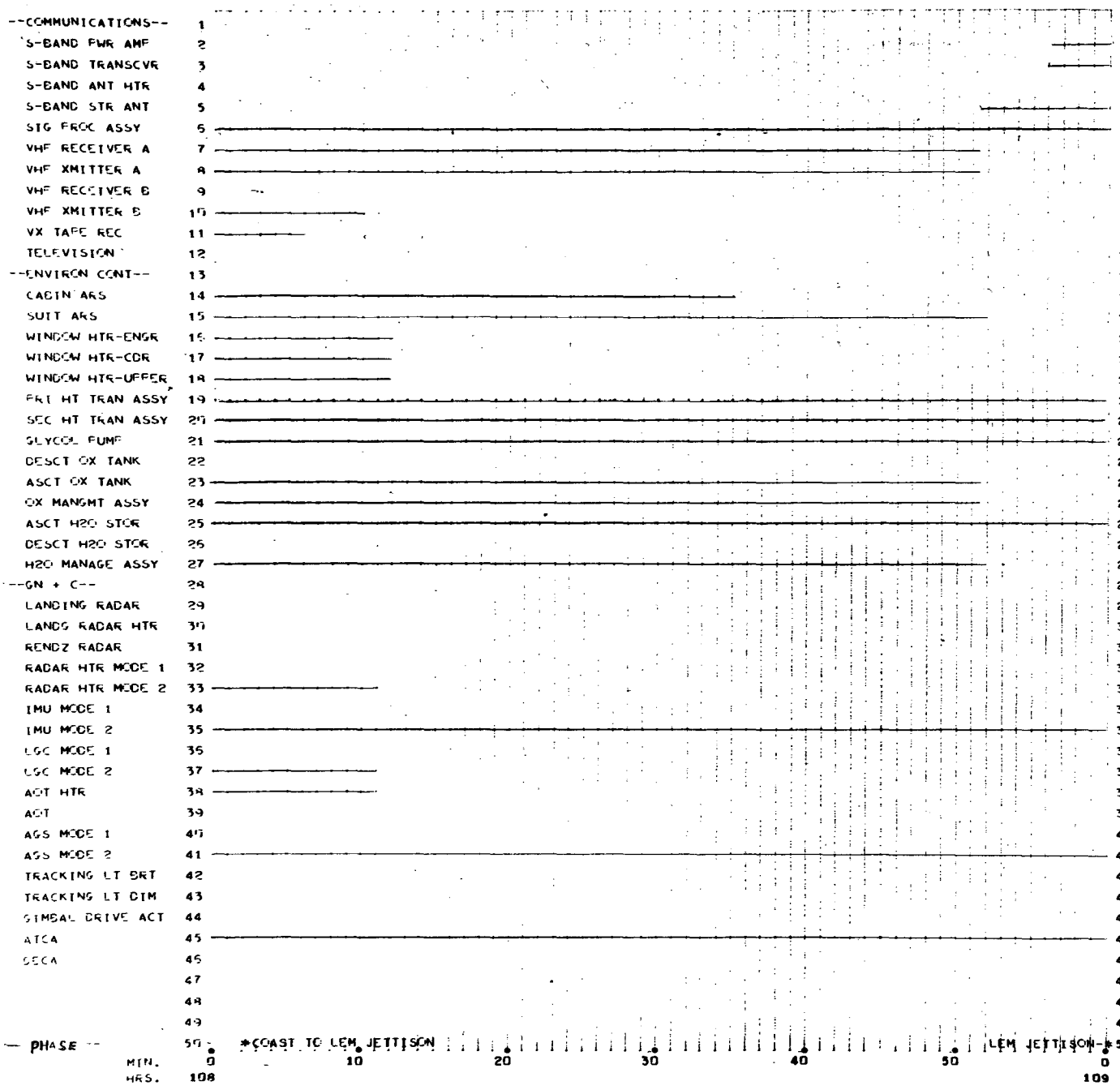
Mission Time in 1 Min. Intervals

Figure E-2 LM Duty Cycles (Continued)



Mission Time in 1 Min. Intervals

Figure E-2 LM Duty Cycles (Continued)



Mission Time in 1 Min. Intervals

Figure E-2 LM Duty Cycles (Continued)

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APPENDIX F ENGINE PERFORMANCE

F.1 GENERAL

The time variation of delta-V, thrust and fuel consumed for each powered flight phase of the DRM IIA are presented in Figures F-1 through F-18. The text describes each powered flight phase and refers to specifications, ground rules, and supporting documents, when necessary. Recommendations are presented where appropriate.

Tables F-1 (from ref F.7) and F-2 (from ref F.8) present engine characteristics for the launch vehicle and spacecraft, respectively.

F.2 ENGINE PERFORMANCE PARAMETERS

F.2.1 Earth Ascent

Figure F-1 presents thrust, fuel consumed and delta-V for the S-IC burn during earth ascent. Figures F-2 and F-3 present the S-II and S-IVB engine performance parameters including thrust, delta-V and fuel consumed during earth ascent.

F.2.2 Translunar Injection

Thrust, delta-V and fuel consumed during the 396-second TLI S-IVB burn are presented in Figure F-4.

F.2.3 Lunar Orbit Insertion

Engine performance parameters including thrust, delta-V and fuel consumed during the 408 second SPS LOI burn are presented in Figure F-5. No SM-RCS ullage burn is necessary for this phase of the mission.

F.2.4 LM Separation

The LM separation maneuver is accomplished through the utilization of two - 100 lb. thrust, minus X axis, RCS thrusters which fire for 2.5 seconds. At the completion of this burn, the RCS thrusters have supplied a delta-V of 0.5 fps. Figure F-6 presents thrust, fuel consumed and delta-V during the LM separation maneuver burn period.

F.2.5 Transfer Orbit Insertion (TOI)

Prior to the TOI maneuver, four -100 lb. thrust, X-axis thrusters are fired for 5.5 seconds to supply ullage (reference F.2). The reason for the ullage burn, which is required under zero gravity conditions prior to a main engine burn, is to settle the propellant.

The LM TOI maneuver is initiated at 30% (3150 lb. thrust) of the nominal reference thrust level of 10500 lb. Although specifications (reference F.5) show that the descent engine shall be capable of igniting at any thrust level, the initial 30% start-up thrust has been adopted because of test facility limitations. After 3 seconds at 30%, the thrust is reduced to 1050 lb. or 10% of reference maximum. The descent engine continues to burn for 23 seconds at the 10% thrust level in order to accomplish descent engine gimbal stabilization. The LM center of gravity can deviate from its nominal location due to an unbalance of engine propellant between tanks. Since the relatively slow descent engine gimbal rate of 0.2 degrees per sec. (maximum gimbal angle is ± 6 degrees) is used in trim control, low thrust insures moment control capability by the RCS.

After the 26-second startup period, descent engine thrust is increased to the FTP, which for the phase was considered to be 10185 lb. or approximately 97% of nominal maximum. The 97% thrust level is maintained for the remaining 6.1 seconds of the TOI phase.

DRM IIA shows a Fixed Throttle Position (FTP) thrust of 97% during the TOI maneuver. However, it must be noted that this thrust is the high side of the thrust level. Grumman studies indicate that an optimum propellant-thrust consumption relationship occurs (reference F.9) at 92.5 percent thrust.* The tolerance variation between engines is plus or minus 1-1/2-percent and in addition there is a ±1-1/2 percent tolerance for a given engine. Thus a 91 to 97 percent thrust level variation exists for any given descent engine at a fixed throttle position (FTP), as reflected in current descent engine specifications (reference F.5). As per the specifications, descent engine thrust changes from maximum to minimum and vice-versa in one second.

Figure F-7 presents fuel consumed, thrust and delta-V during the LM TOI maneuver.

F.2.6 LM Powered Descent Braking

The braking phase startup period of LM powered descent (fig. F-8)-including ullage, 30% and 10% thrust--is exactly the same as that used for TOI.

* Later this was amended to 94.0%.

At startup period completion, the descent engine thrust is again increased to the FTP, which for this phase was considered to be 9950 lb. or approximately 95% of nominal maximum. This thrust level is maintained for 6.34 minutes through braking phase termination at hi-gate.

It must be noted that the descent engine does not thrust at a constant 95% during the high thrust portion of braking operations. A 91% to 97% initial variation in thrust about the nominal is possible as reflected in section F.2.5 regarding the high thrust portion of TOI.

Because the present descent engine is non-throttleable between a range of 60% of nominal maximum thrust and a maximum fixed-throttle position point, an additional modification to the powered descent braking high thrust profile exists (reference F.9). This uses MIT-modified braking phase guidance laws which, in order to comply with hi-gate boundary conditions, require a 343-second burn beginning at 92.5 thrust,* followed by a 100-second burn at the reduced throttle setting of 58% thrust*as per ground rule A2.10.4 of Appendix A. Any off-nominal thrust variations during the high thrust phase are corrected by a reduced throttle setting which varies from the 58%* nominal value.

Figure F-8 illustrates fuel consumption, thrust and delta-V during the braking pahse of LM powered descent, as currently available.

F.2.7 Final Approach

Powered descent final approach is initiated at hi-gate with a rapid pitchover maneuver to an attitude at which the landing site may be observed. Simultaneously, the descent engine throttle setting is reduced to approximately 50% of maximum to maintain the proper flight path. Thrust is gradually increased through final approach phase termination at lo-gate. The vertical component of thrust/weight ratio is reduced to approximately one at lo-gate.

It must be noted that descent engine thrust decreases gradually from 58% to 40% during proposed MSC final approach operations (reference F.4). Such a thrust profile is considered more appropriate than the current thrust profile.

Figure F-9 illustrates delta-V, thrust and propellant consumption during final approach.

* Later, these were amended to 94.0% and 60% per ground rule A.2.10.4 of Appendix A.

F.2.8 Landing

The current landing phase engine performance parameters are based upon a respective 700 ft., 75 ft./sec., -15 ft./sec., 4000 ft. altitude, relative forward velocity, altitude rate and range-to-go at lo-gate. These values will be changed to 500 ft., 50 ft./sec., -15 ft./sec. and 2340 ft., respectively, as per ground rule A.2.10.5.2 in Appendix A, thus modifying the current engine performance parameters.

Figure F-10 presents thrust, propellant consumed and delta-V during the LM separation maneuver. The figure was constructed, using as a basis the landing trajectory developed during Grumman IIIB landing simulation studies, as described in Section 4.10.6 of Volume I.

F.2.9 Powered Ascent

LM powered ascent begins with a 12-second vertical rise from the lunar surface during which a total of 140 lb. of APS propellant is consumed and delta-V achieves 132 fps. The APS propellant is consumed through the APS engine as well as the pulsing +X-axis RCS thrusters by means of the APS-RCS interconnect. The DRM IIA ascent trajectory was developed by considering the plus X-axis pulsing of 2 RCS thrusters to overcome a linearly increasing unbalanced moment due to center-of-gravity offset.* The effective thrust of the pulsing RCS was computed to be 135.5 lb. This value, combined with specific impulse values of the APS, and pulsing RCS, given in Table F-2 result in an effective specific impulse of the APS-RCS combination of 304.3 sec.

The ascent engine was considered non-canted for this trajectory. Preliminary studies have indicated that the non-canted ascent engine unbalanced torque envelope exceeds the single X-axis jet failure control boundary prior to burnout. By canting the ascent engine 2 degrees in the minus Y direction and 3 1/2 degrees ± 2 degrees in the minus Z direction, the canted ascent engine unbalanced torque envelope would remain within the single X-axis jet failure control boundary from liftoff through burnout. Future reference missions should therefore have the ascent engine canted in this manner as well as illustrate a nominal initial unbalanced moment of 333 ft.-lb. which increases linearly with time to 625 ft.-lb. at burnout (Reference F.6).

Although no RCS propellant was assumed to be consumed during the DRM IIA powered ascent, a current ground rule (A.2.12.1 of Appendix A) permits the RCS use of APS propellant only during the period from 10 sec. after liftoff to 10 sec. prior to APS shutdown.

*See Table F-2.

Figure F-11 illustrates fuel consumption, thrust and delta-V during the 410-second main powered ascent burn.

F.2.10 Concentric Sequence Initiation (CSI)

The CSI maneuver phase of LM ascent operations is accomplished by a 53-second, 2 jet, plus Z-axis, RCS thruster maneuver.

Figure F-12 illustrates thrust, fuel consumption and delta-V during CSI.

F.2.11 Constant Delta Height (CDH)

The CDH maneuver which places the LM in a coasting circular orbit is accomplished through utilization of two, plus Z-axis, RCS thrusters for 53 seconds.

Fuel consumption, delta-V and thrust are illustrated in Figure F-13.

F.2.12 Terminal Phase Initiation (TPI)

Two plus Z-axis RCS thrusters are utilized for 23 seconds to accomplish the TPI maneuver.

Thrust, delta-V and fuel consumption are presented in Figure F-14.

F.2.13 Terminal Rendezvous

The LM terminal rendezvous maneuver is accomplished through a series of RCS burns that reduce range-rate according to a specific range/range-rate schedule as per ground rule A.2.12.9 in Appendix A. For the specific intercept trajectory flown in the DRM IIA, the terminal rendezvous maneuver consists of 4 rendezvous gates of which the first gate is by-passed due to the low range-rate in effect. The next three rendezvous gates require -Z axis RCS burns of 4, 8, and 4 seconds, to reduce the range-rate in accordance with the prescribed schedule.

Thrust, delta-V and fuel consumption during terminal rendezvous is presented in Figures F-15 thru F-17.

F.2.14 Docking

Line-of-sight rates and range-rate are nulled to zero (manual maneuver) 50 ft. in front of the CSM docking hatch at rendezvous phase termination. A pitchover and subsequent plus X-axis translation to the soft dock contact point is then executed. A LM delta-V equal to

25 fps. is assumed for docking operations. Detailed thrust, fuel consumption and delta-V used during this phase are not included due to the complicated manner in which manual RCS pulsing is accomplished.

F.2.15 Transearth Injection

Figure F-18 presents SPS engine performance parameters (thurst, delta-V, fuel consumed) during the 104-second transearth injection burn which is preceded by a 15-sec. SM-RCS ullage burn.

REFERENCES

F.1 LMO-310-46, "Analysis of RCS Requirements to Settle Descent and Ascent Propellants", 9 August 1963.

F.2 LMO-310-46, Revision B, "Analysis of RCS Requirements to Settle Descent and Ascent Propellants",17 February 1965.

F.3 LED-540-12, "Design Reference Mission I - Appendices to Volume I - Mission Description - Appendix C - Engine Performance Parameters",30 October 1964.

F.4 Cheatham, Donald C. and Bennett, Floyd V., "Apollo Lunar Module Landing Strategy" paper presented at Apollo Lunar Landing Mission Symposium (Volume I) on June 25-27, 1966.

F.5 LSP-470-2A, "Master End Item Specifications for the Lunar Excursion Module", June 1965.

F.6 "LEM Critical Design Review No. 1, Part #3 Mission Capability and Operations". GAEC handouts, 7 March 1966, Confidential.

F.7 "Reference Trajectory Subpanel Interface Document, Volume I, MSC/MSFC Lunar Landing Mission Reference Trajectory (U) ",October 1965.

F.8 "AS-504A, Preliminary Spacecraft Reference Trajectory Volume I (U) ",1 July 1966.

F.9 LMO-500-364, "Estimated Duty Cycles for the Restricted Throttleable Descent Engine", 22 November 1965.

TABLE F-1

LAUNCH VEHICLE PERFORMANCE SUMMARY

PHASE OR STAGE	EVENT	THRUST LEVEL POUNDS	ISP SEC.	TIME AFTER STAGE IGNITION, SEC
S-IC	Liftoff	7,610,000	263.5	0
S-IC	Inboard Engine Cutoff	6,088,000	263.5	154.579
S-II	S-II Ignition	1,025,000	426.0	0
S-II	Mixture Ratio Shift	1,150,000	423.1	2.5
S-II	Mixture Ratio Shift	950,000	427.47	280.401
S-IVB	S-IVB Ignition	205,000	428.2	0
S-IVB	S-IVB Re-ignition	180,000	426.1	0
S-IVB	Mixture Ratio Shift	205,000	428.2	168.7

TABLE F-2

SPACECRAFT PERFORMANCE SUMMARY

SERVICE MODULE			
Propulsion System	Isp, sec.	F/engine, lb.	$\dot{W}$/engine, lb./sec.
RCS<5 sec. burn	280	100	0.357
RCS>5 sec. burn	275	100	0.364
SPS	314.9	20,000	63.51

LUNAR MODULE				
Propulsion Subsystem	Nominal Rq'd Thrust, lb.	% Relative Throttle	Isp, sec.	$\dot{W}$ lb./sec.
	10500	100		
LM descent	9713	92.5	302.0	32.16
	6300	60	303.2	20.78
	5250	50	302.7	17.34
	2625	25	300.3	8.74
	1050	10	285.0	3.68
LM ascent	*3635.5		304.3*	11.95
RCS pulsed	100 ± 2.5 (3 σ)		Variable with pulse width	
RCS steady state	100 ± 2.5 (3 σ)		273 ± 7 (3 σ)	0.364

*Effective thrust and specific impulse assumes 3500-pound thrust and 306 Isp from APS and 135.5 lb. thrust and 263 sec. from RCS pulsed to overcome a linearly increasing c.g. moment unbalance of 550 ft.-lb. at liftoff and 1040 ft.-lb. at burnout.

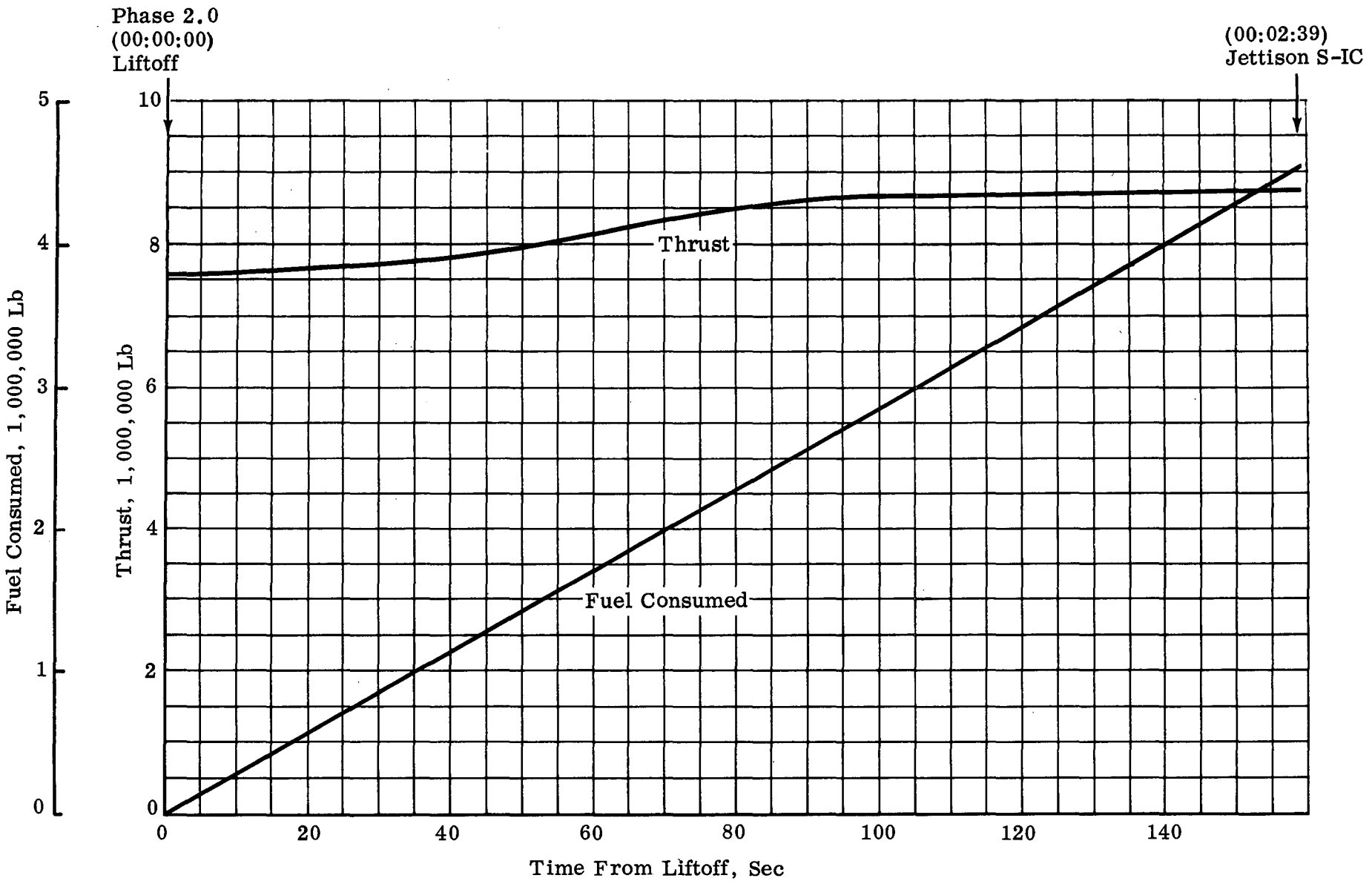

Figure F-1 Earth Ascent Engine Performance Parameters (S-IC)

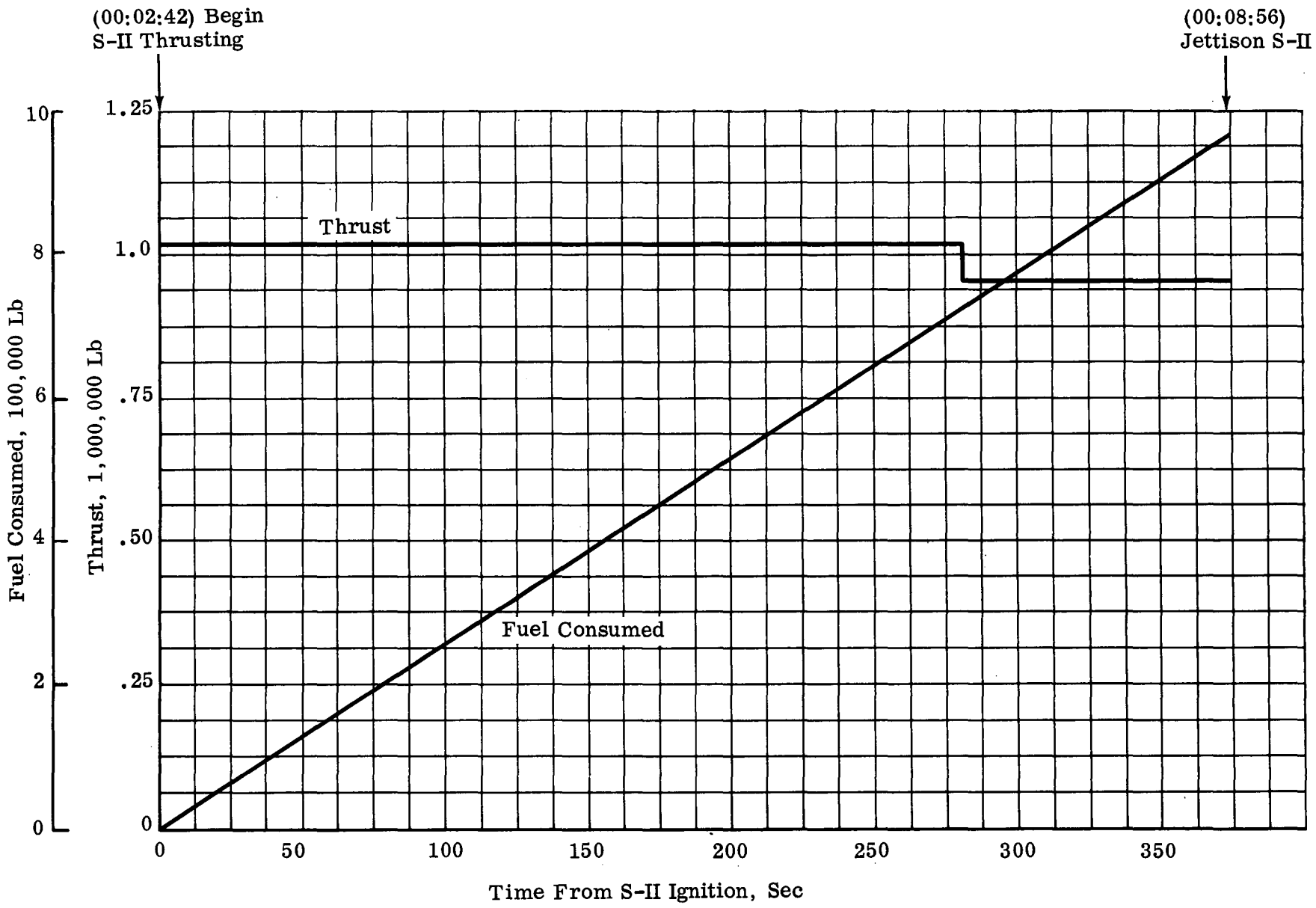

Figure F-2 Earth Ascent Engine Performance Parameters (S-II)

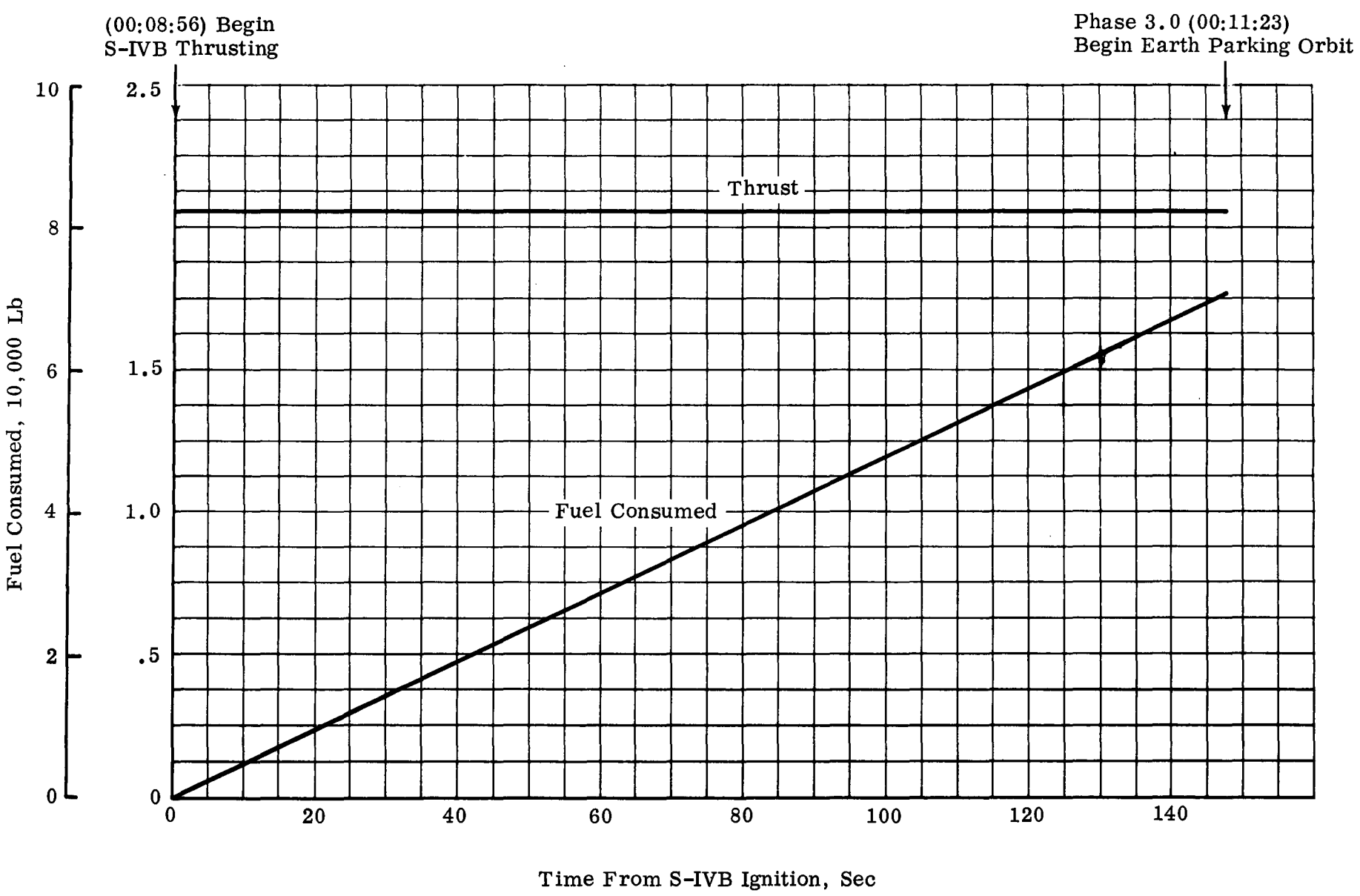

Figure F-3 Earth Ascent Engine Performance Parameters (S-IVB)

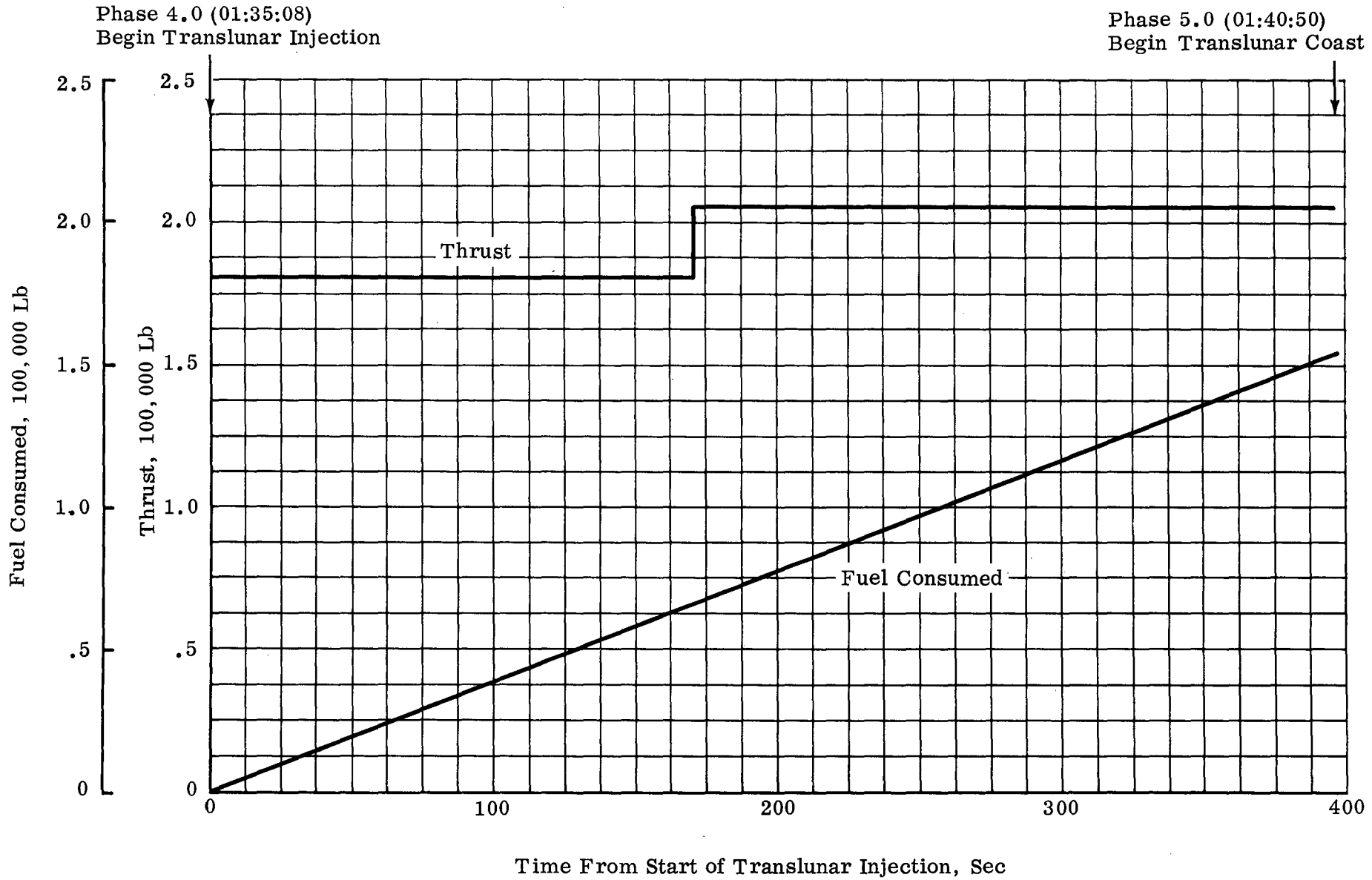

Figure F-4 Translunar Injection Engine Performance Parameters

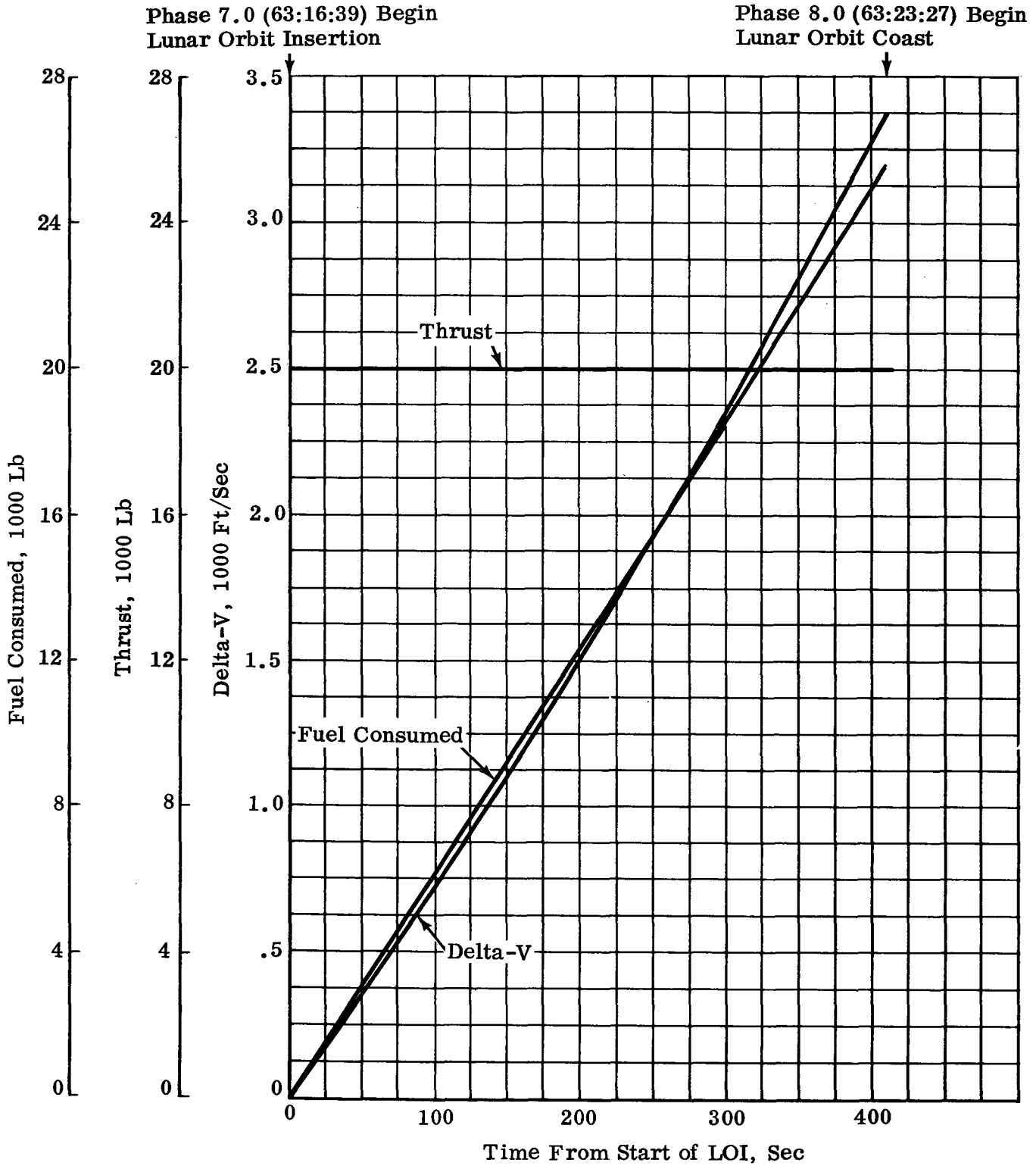

Figure F-5 LOI Engine Performance Parameters

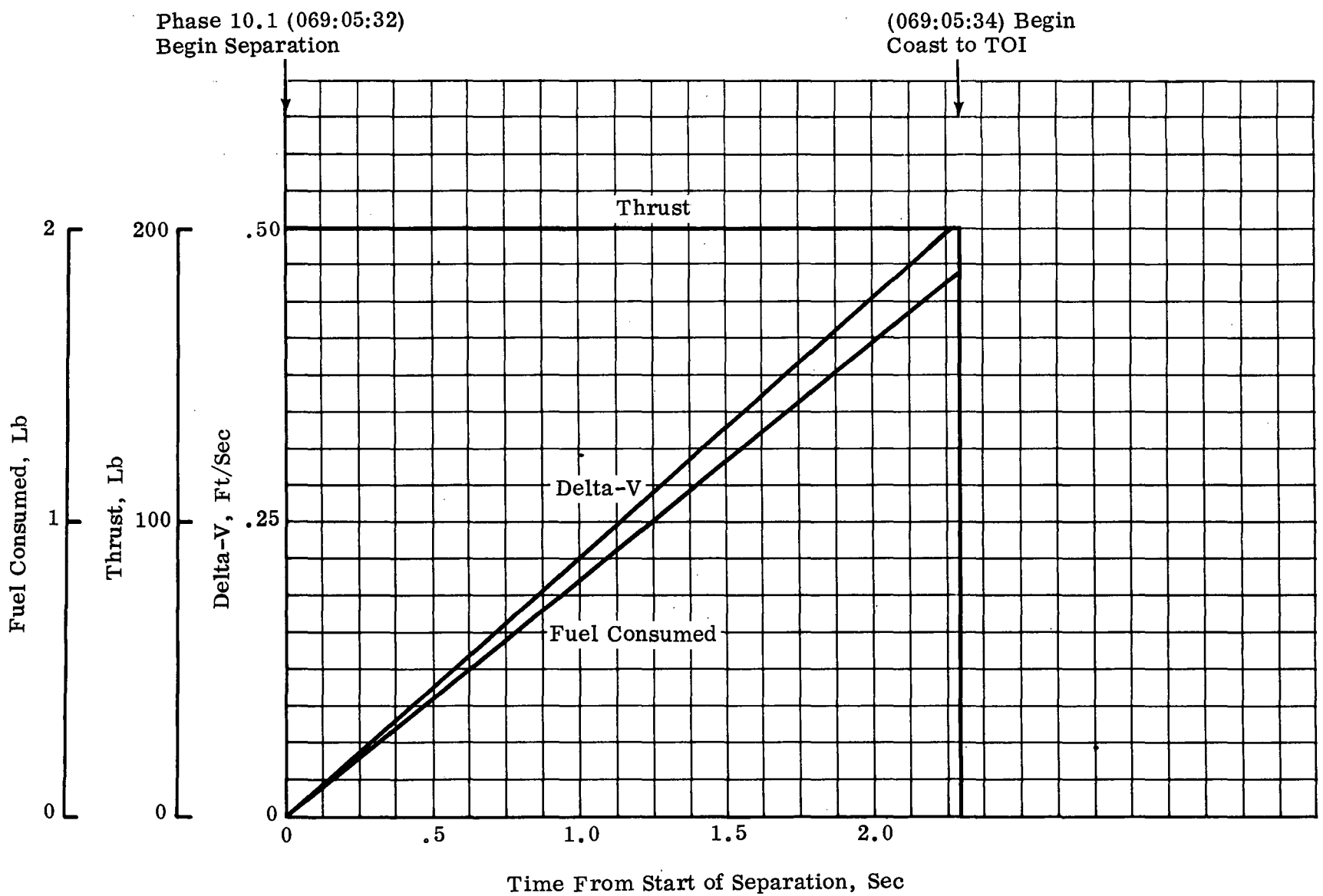

Figure F-6 LM Separation Engine Performance Parameters

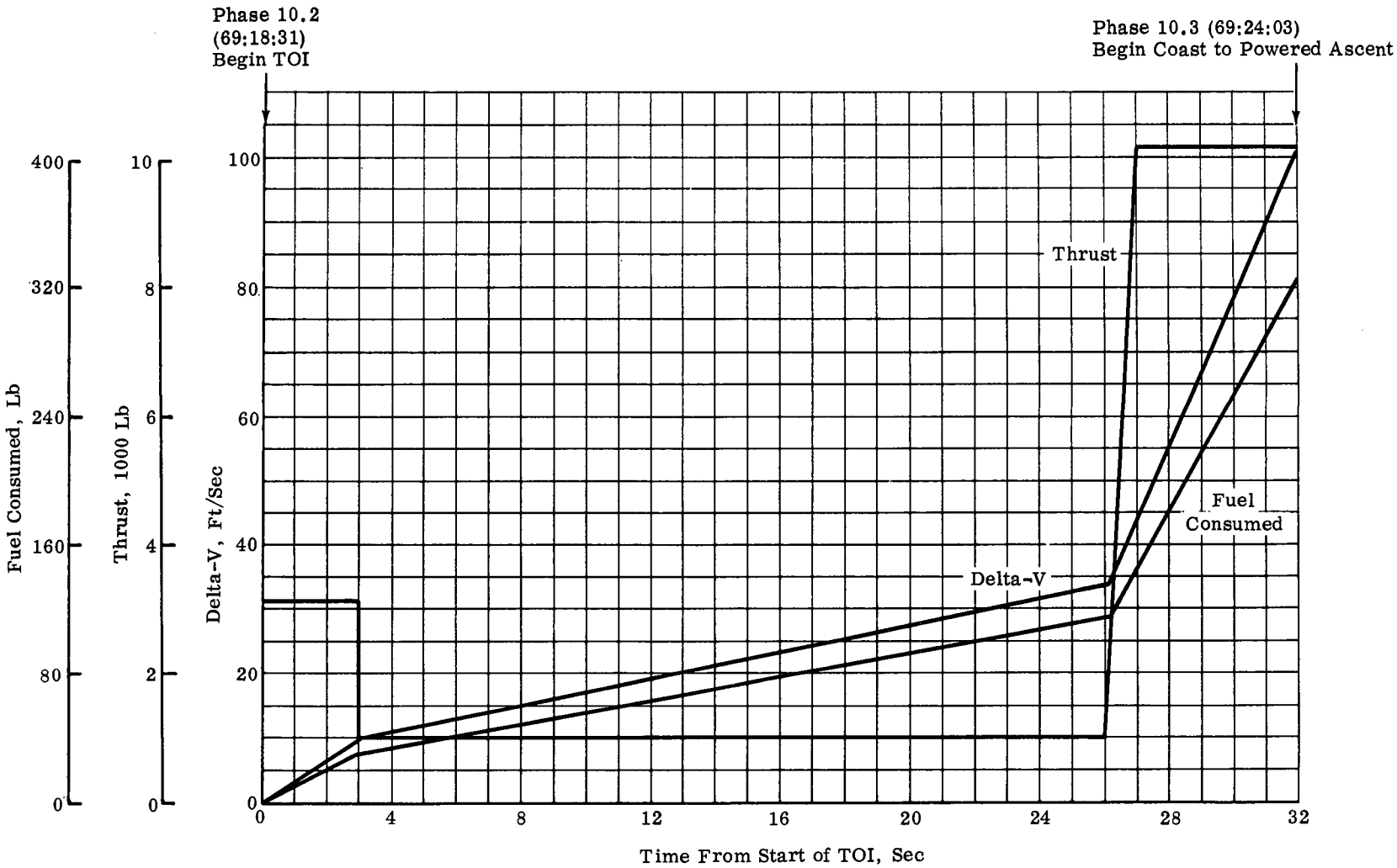

Figure F-7 LM Transfer Orbit Insertion Engine Performance Parameters

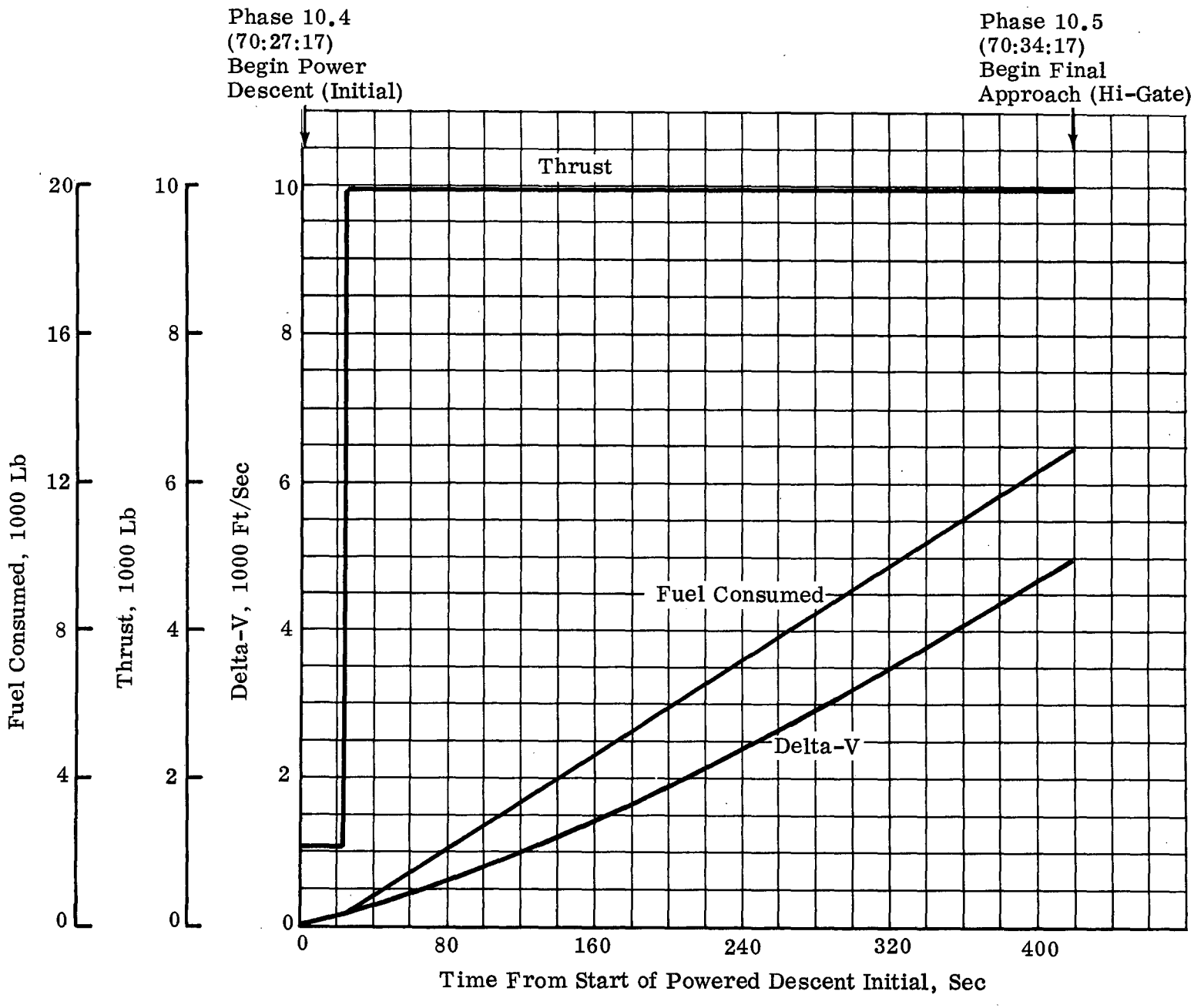

Figure F-8 LM Powered Descent Braking Engine Performance Parameters

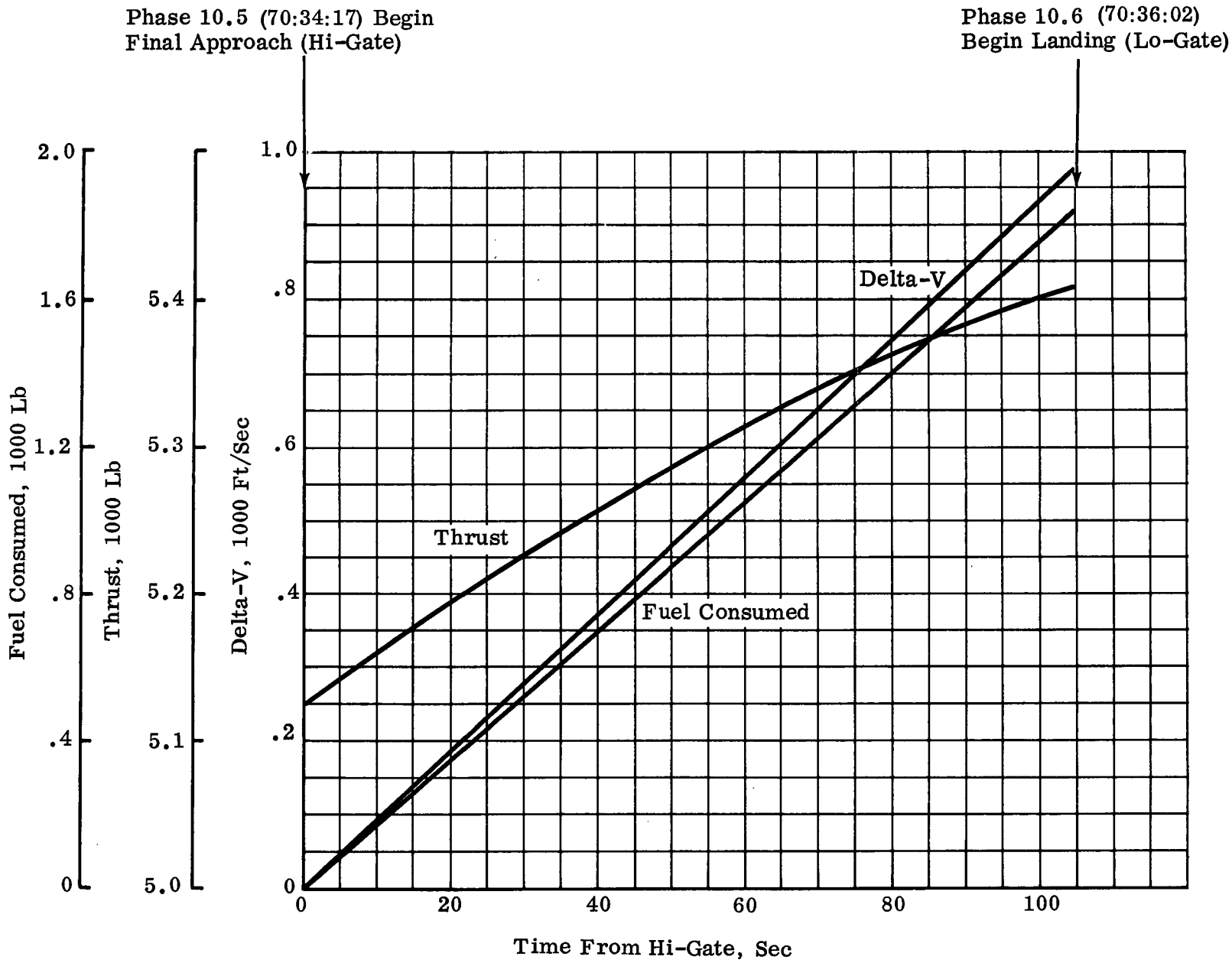

Figure F-9 LM Final Apprach Engine Performance Parameters

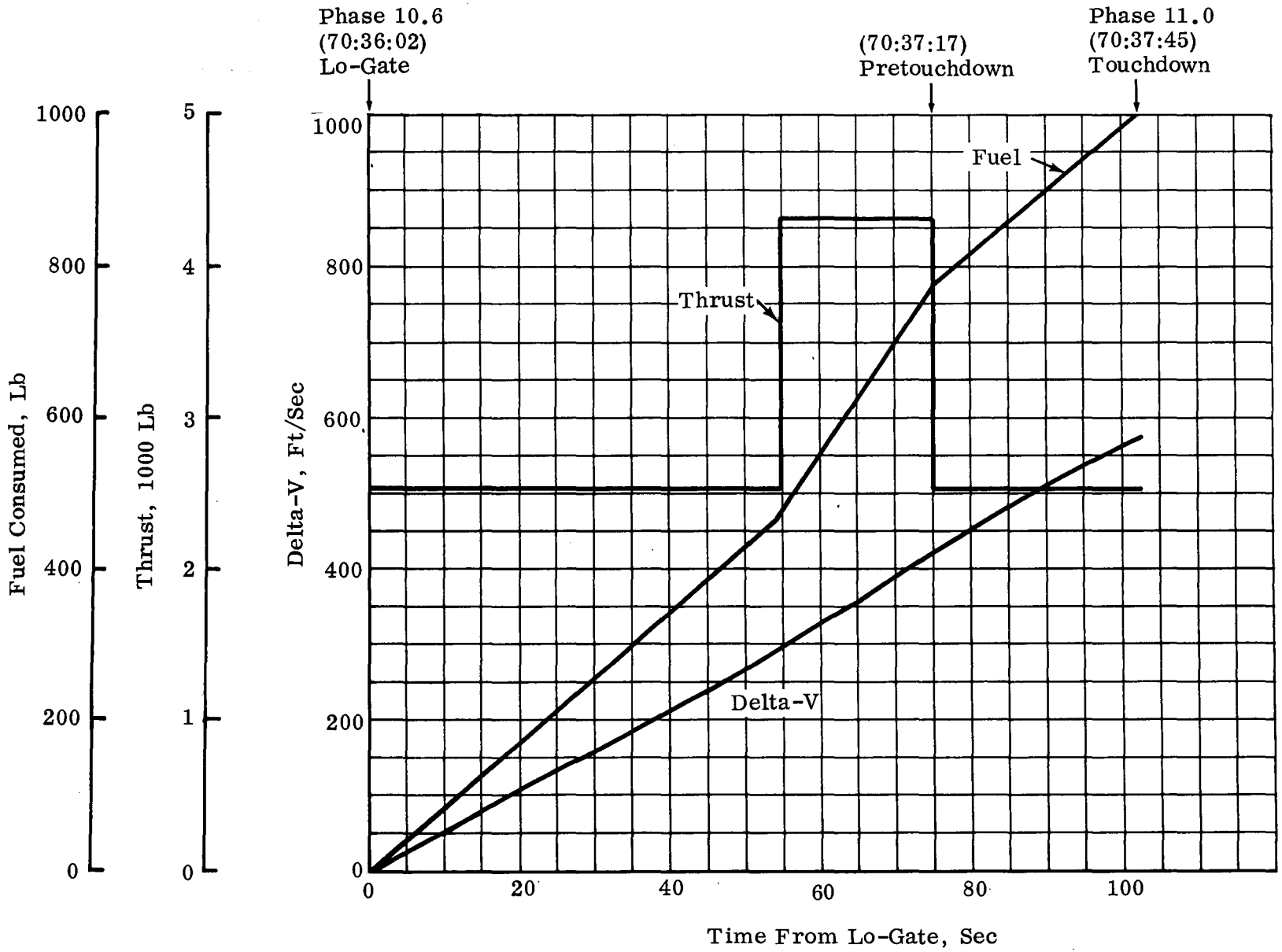

Figure F-10 LM Landing Engine Performance Parameters

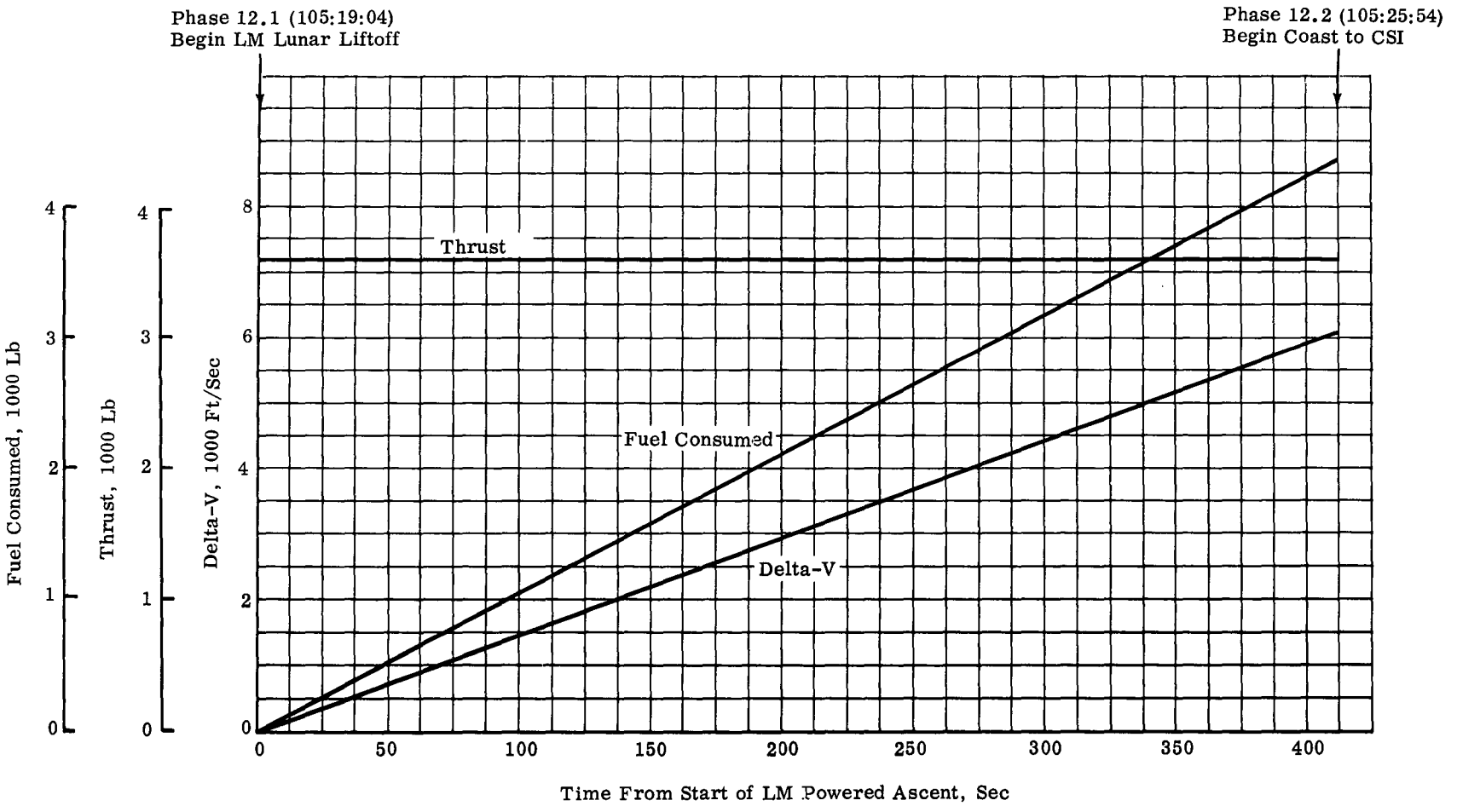

Figure F-11 LM Powered Ascent Engine Performance Parameters

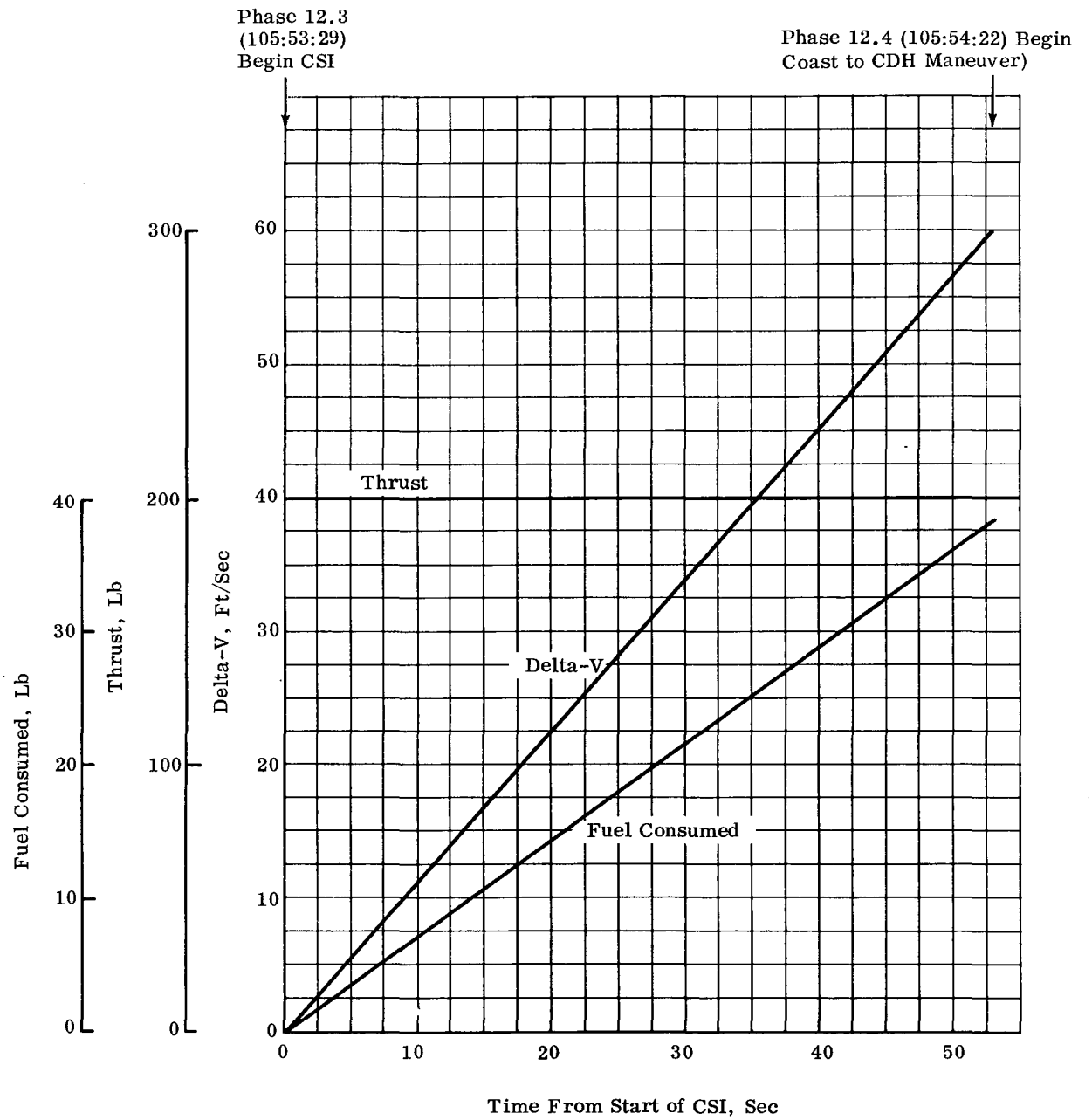

Figure F-12 LM CSI Engine Performance Parameters

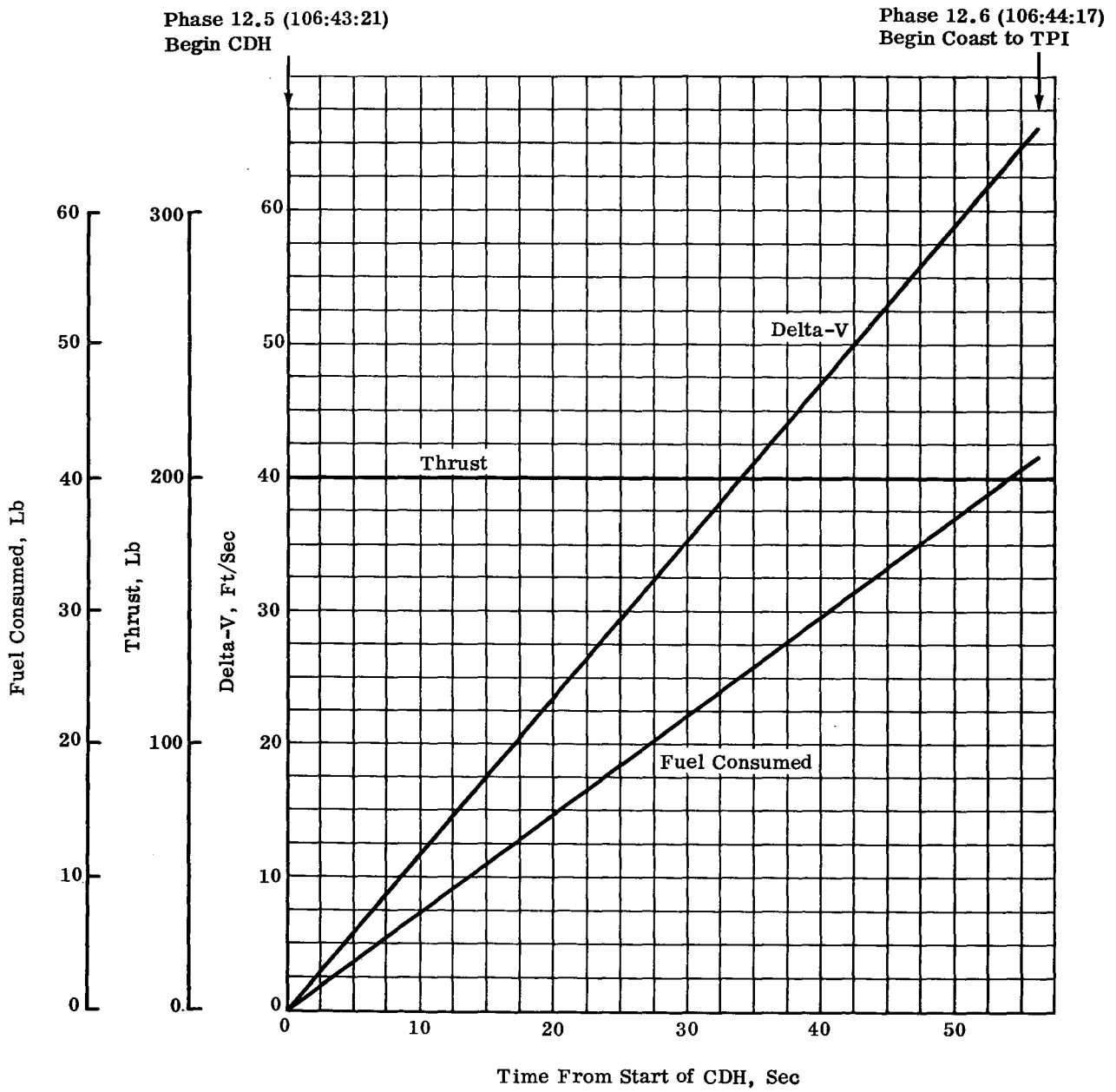

Figure F-13 LM CDH Engine Performance Parameters

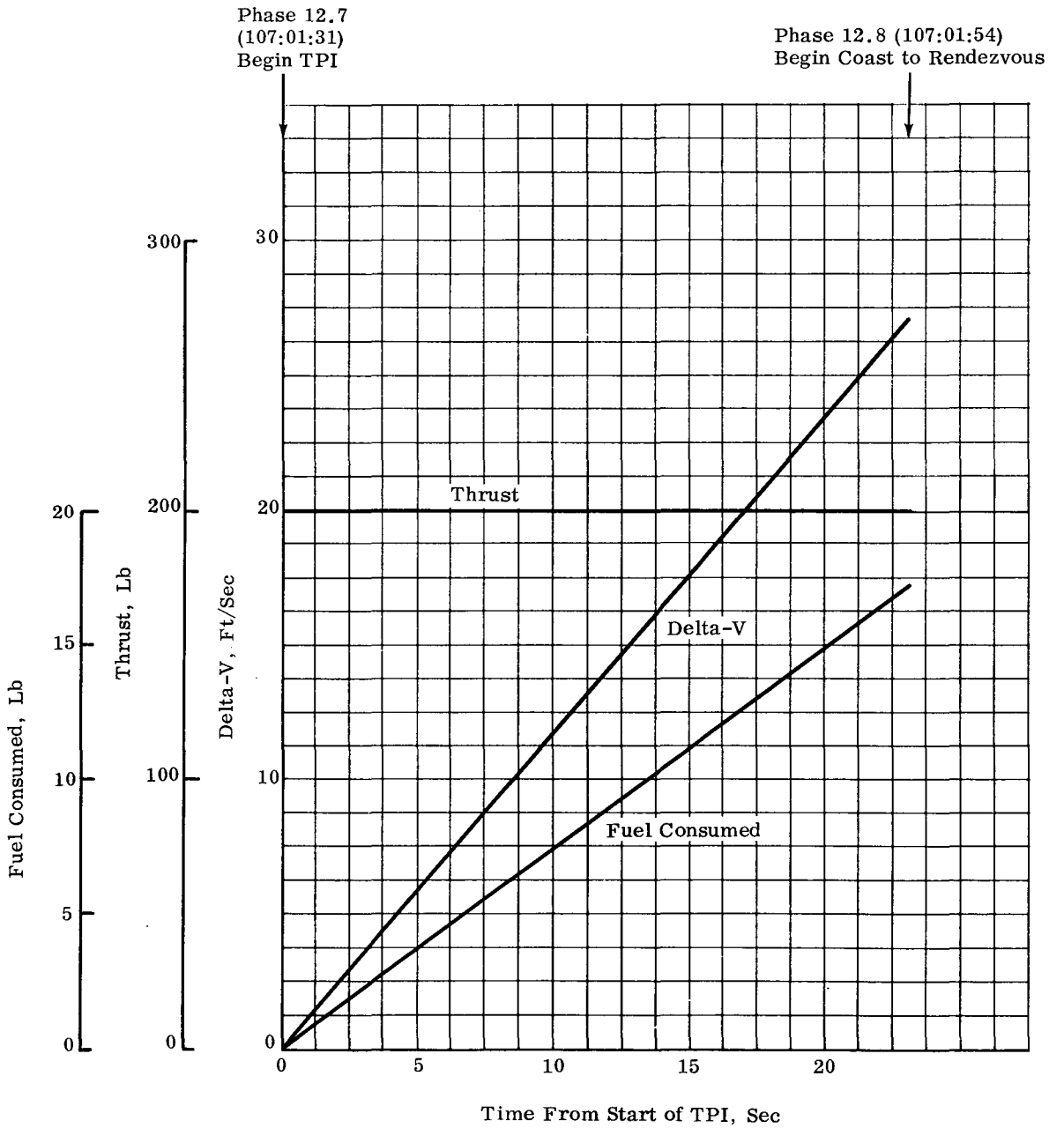

Figure F-14 LM TPI Engine Performance Parameters

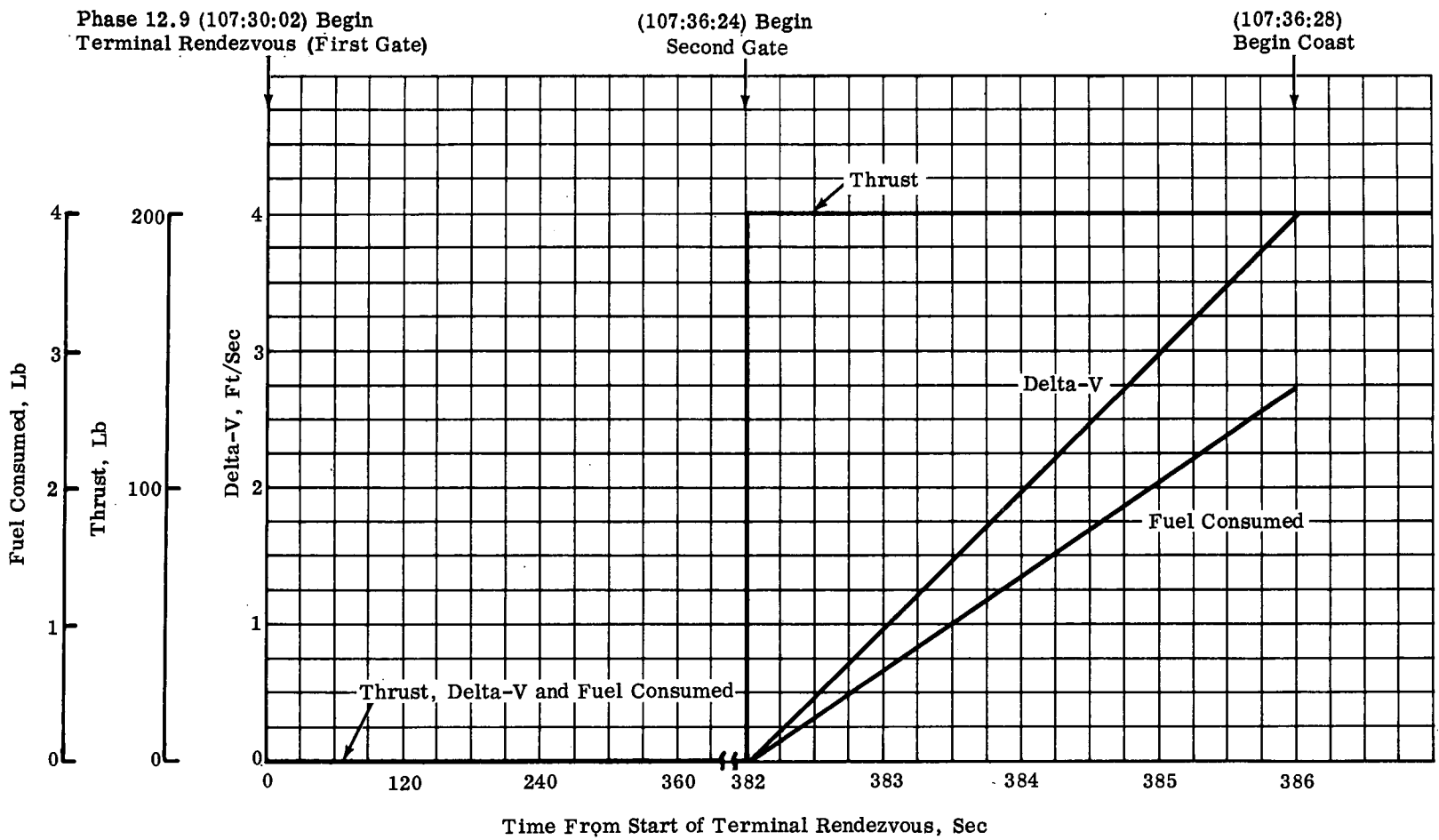

Figure F-15 LM Terminal Rendezvous Engine Performance Parameters - First Burn

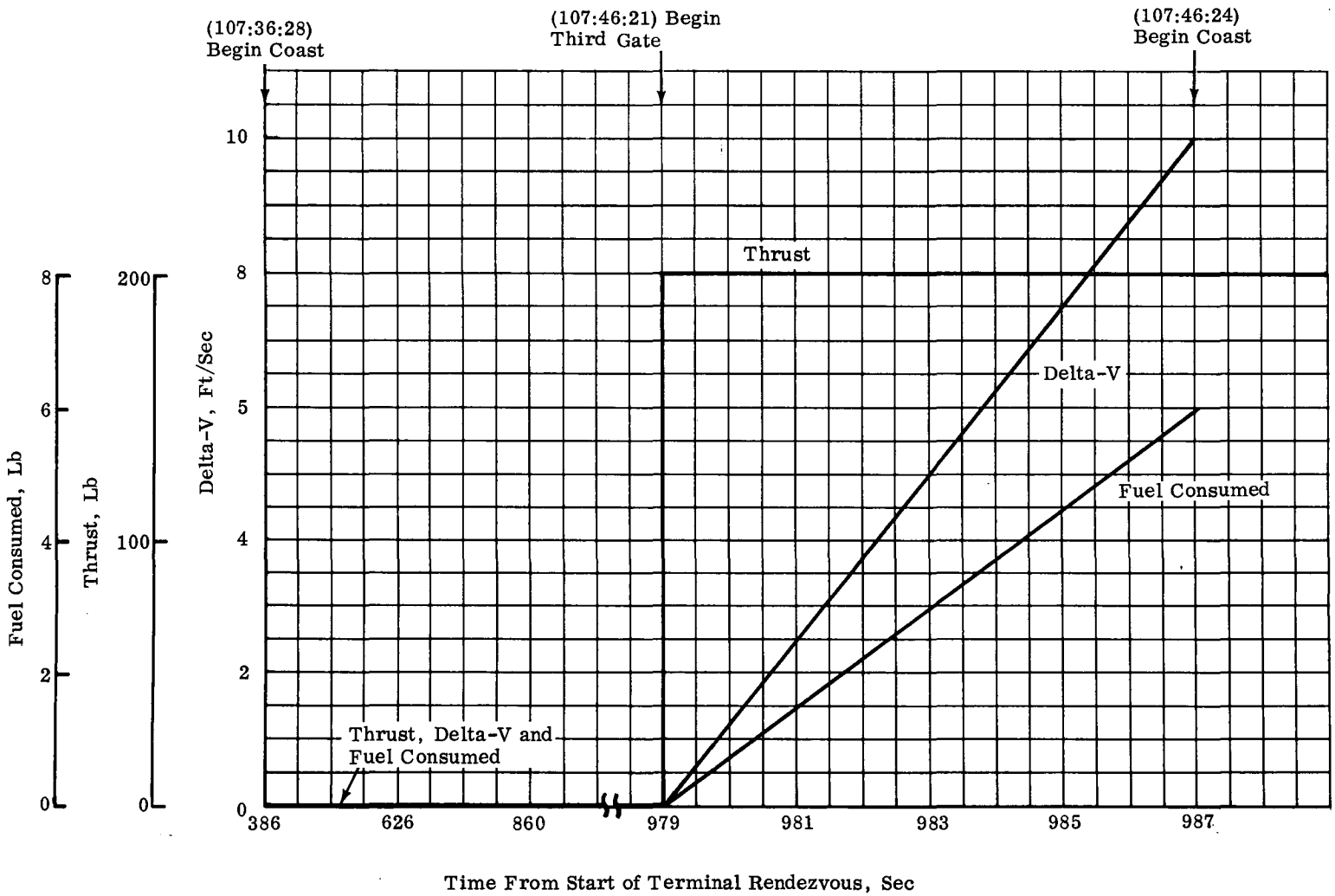

Figure F-16 LM Terminal Rendezvous Engine Performance Parameters - Second Burn

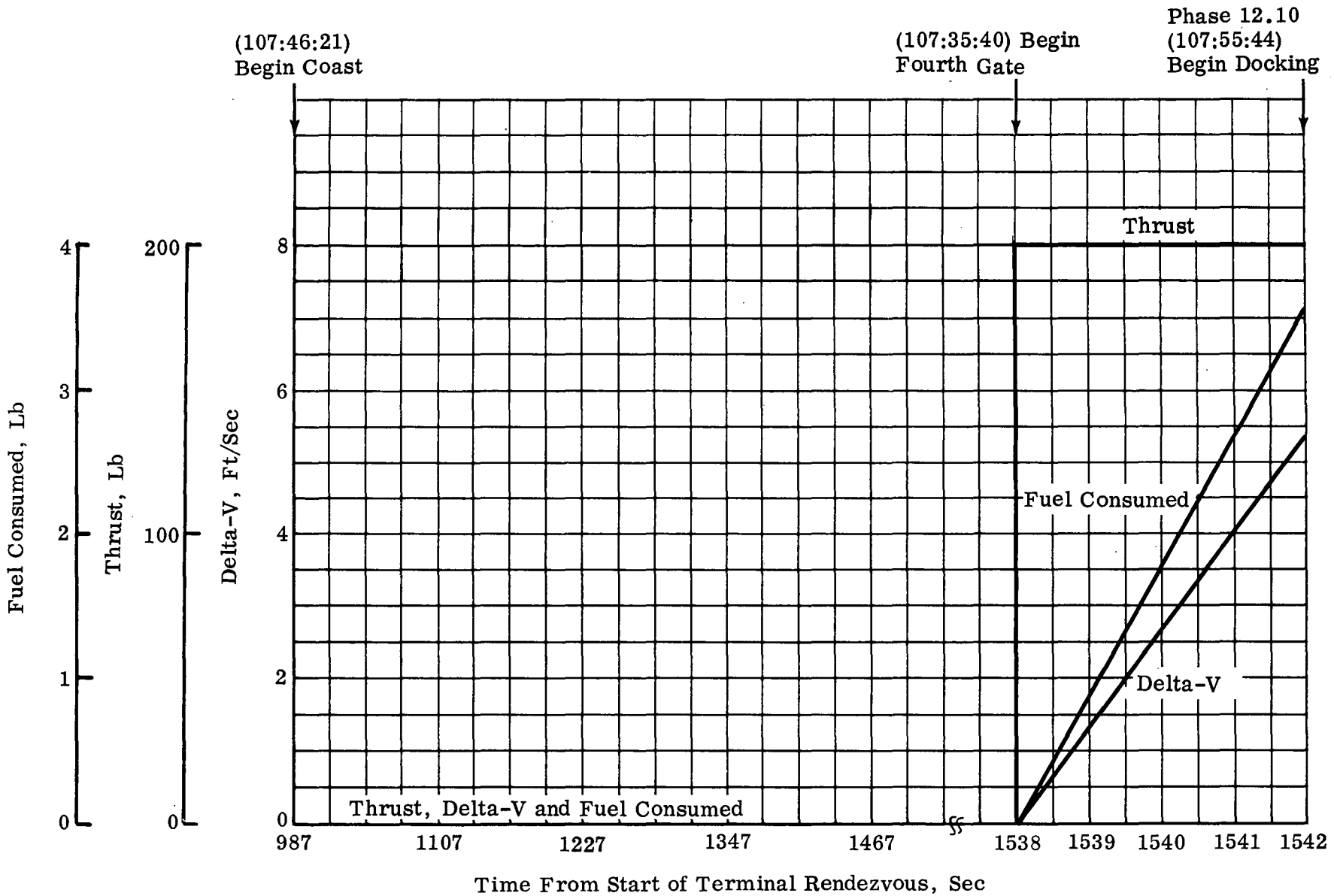

Figure F-17 LM Terminal Rendezvous Engine Performance Parameters - Third Burn

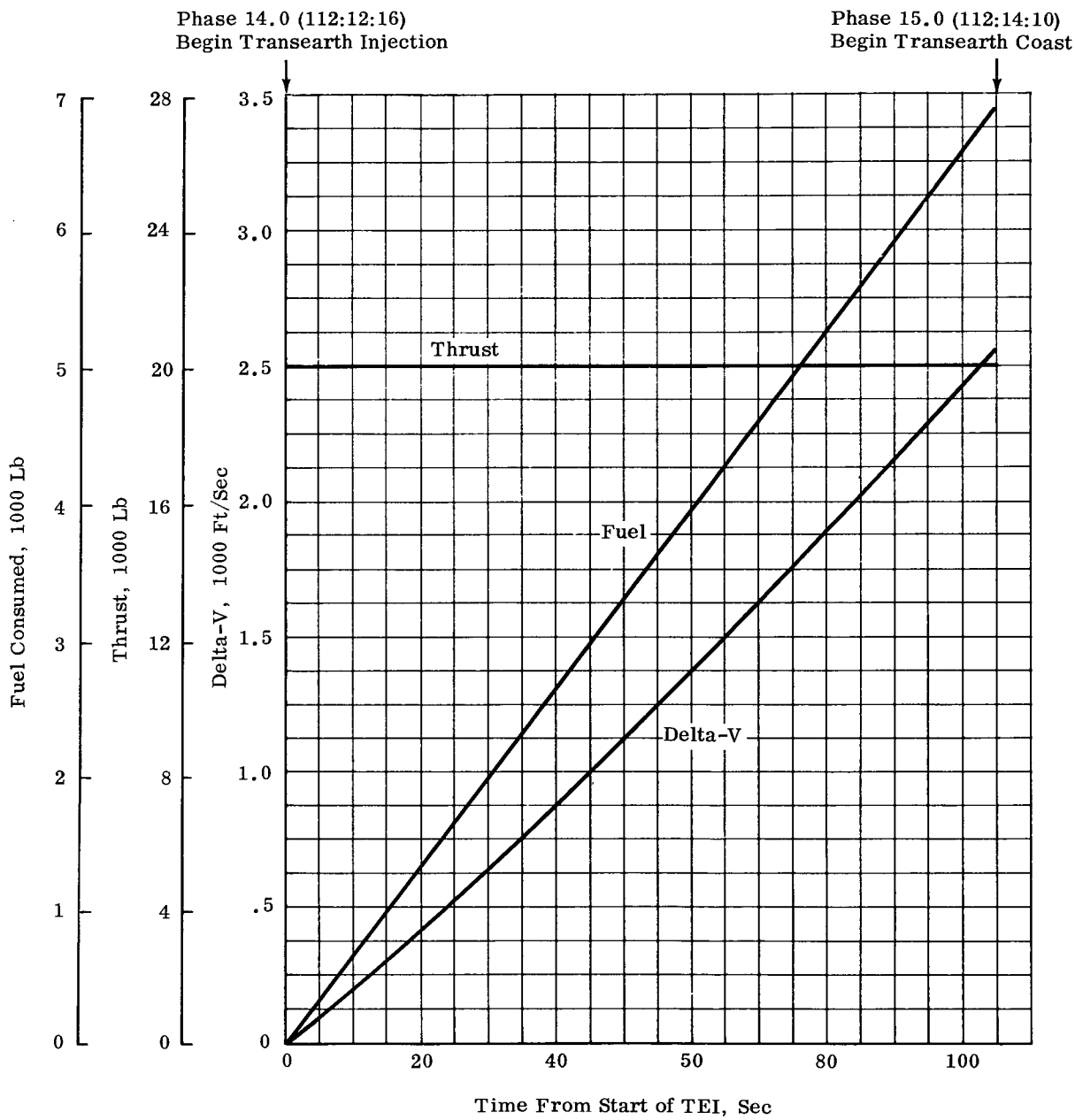

Figure F-18 Transearth Injection Engine Performance Parameters

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APPENDIX G SPACECRAFT CONSUMABLES TIME HISTORY

G-1 INTRODUCTION

This appendix contains a summary of the spacecraft consumables throughout the mission, from prelaunch through post landing operations. Consideration is given to both discrete and continuous functions, to jettisoned and expelled materials, and to those items transformed or transferred within the spacecraft. For ease of interpretation and user convenience detailed discussions of specific consumables are grouped according to major space vehicle element, the launch vehicle, the CSM and the LM. Content includes important considerations, assumptions, and significant factors governing the trend or shape of consumables usage, along with tabulated usages and the balance remaining in storage at the end of consumable-significant mission segments.

These data were derived from subsystem performance characteristics in conjunction with the mission timeline and related information in Volumes I and III. Further, starting times for consumables expenditures, tanking operations and crew boarding times were obtained from Volume II. The weight summaries of the consumables expended and removed from the spacecraft weight are incorporated as input data for the Mission Weights Appendix (Appendix H). Commensurate with the overall DRM IIA objective of providing only a mission base for program software needs, these data are limited in depth, leaving comprehensive treatment of complex consumables to special analysis by cognizant groups where they may be tailored to satisfy particular problem or visibility needs. Specifically, those consumables requiring rigorous supporting analyses involving uncontrollable or random factors were simplified to the extent necessary to serve the following DRM IIA needs:

> Establish the gross adequacy of the spacecraft for performing a nominal mission, define consumables feedback or potential influences on the mission and operations profile, and provide a first iteration refinement on initial weights for propellant calculations.

Launch vehicle propellant expenditures appear in Appendix H. Other launch vehicle consumables expended are not presented.

G.2 CSM CONSUMABLES

G.2.1 General

The CSM consumables calculations include expenditure of SPS propellant, cryogenics, water, food and life support, the generation of potable water and waste water and

metabolic wastes and their storage, and the transfer of weights and structure jettison. Some mission segments are of a very short duration - SPS midcourse correction burns, LES jettison, LM separation, LM jettison and Service Module jettison. Consumables accounted linearly show insignificant expenditures within these short intervals. However, the previous segment subtotals are carried until reportable amounts are accumulated.

It is necessary to treat the metabolic consumption linearly, in order to maintain a constant astronaut weight and biological balance for the entire mission. Therefore changes in food and water may be shown during thrusting maneuvers.

There are three tables of consumables history. Table G. 2. 1 presents the expenditures by mission segment of Water Dumped, Cooling Water, Hydrogen, Oxygen, Urine, Non-Delta V RCS, and the total weight transfer to space. Table G. 2-2 shows the consumables balance in storage: Cryogenics, Water and Food. Table G. 2-3 is the Metabolic Balance Summary giving the quantity consumed by mission segment, including water produced, food and water consumed and all waste generated, and non-propellant or structural weight losses. The mission has been divided into 40 consumable-significant segments for the CSM expenditures. SPS and SM-RCS translational propellant are found in Table H-4 of Appendix H.

G. 2. 2 <u>SPS Propellant</u>

The SPS propellant is used for 3 translunar midcourse corrections, lunar orbit insertion, transearth injection and 3 transearth midcourse corrections.

The SPS propellant expenditures are based on precision trajectory delta-V supplied by MSC. The quantity of propellant required is based on engine performance characteristics as shown in Appendix F and weights as shown in Appendix H. These calculations reflect "start" and "tail-off" losses of 14. 38 pounds for each ignition. The spacecraft weight change during the burn is also used in the determination. No SPS propellant is required for ullage maneuvers, although a delta V of 5 fps each for the transearth injection and a delta V of 8 fps for the transearth midcourse corrections ullages is included in the delta V allotted. This ullage is provided by the SM RCS, at the rate of 21. 2 pounds each burn.

G.2.3 RCS Propellant

G.2.3.1 SM-RCS

The Service Module - RCS will be used for all attitude maneuvers from the start of transposition and docking through jettison of the Service Module, just prior to entry.

The propellant uses are based on discrete attitude maneuvers and holds as specified in Appendix D. Using the CG and inertia data (ref) and engine performance as specified in Appendix F, the propellant consumption was determined for each attitude change for the entire mission and is presented in Table G.2-2. Translational maneuvers include transposition and docking, ullage and S-IVB, LM and SM jettison.

Transposition and docking uses 58.5 pounds. Jettison of structures is accomplished through the use of:

60.78 pounds for S-IVB jettison
4.32 pounds for LM jettison
21.33 pounds for SM. jettison

Ullage maneuvers are specified as 8 fps (21.2 pounds) immediately prior to transearth injection, and each transearth midcourse correction. The attitude maneuvers will be at 0.2°/sec. The two exceptions are 0.25°/sec required for LM observation and tracking during descent and 0.5°/sec for lunar orbit IMU alignments. The pounds of propellant required are based on the rates shown in Table G.2-4 (or interpolated for the 0.25°/sec rate).

There are several minor additional expenditures. One is the minimum impulse utilized by the astronaut to gently adjust the spacecraft position during navigation sightings or IMU alignments. The minimun impulse is a series of small bursts assumed to use a total of 0.35 pounds for each series of adjustments. In Appendix D it has been shown that these will be fired twenty times during the mission for a total of 7.0 pounds. The other expenditure which does not use a major quantity is attitude hold.

One quarter of the flight is in an attitude hold mode, for which a little over nine pounds of propellant are used: two and a half pounds for 55 hours of 4.2° deadband, and the remaining 7 pounds for 19 hours of 0.5° deadband.

G.2.3.2 CM RCS

The CM RCS is used for stabilization and attitude control from SM jettison to drogue chute deployment. The variabilities affecting this include entry angle, range adjustments required, atmospheric conditions, wind gusts, etc., but these are beyond the scope of this report. The entry attitude was provided by MSC, an analysis of the CG of the Command Module and the L/D configuration has been conducted to provide the estimate of the required CM RCS.

G.2.4 CRYOGENICS

G.2.4.1 Electrical Power

The cryogenics consumption is based on DRM I, with an updated configuration and power requirement. The total power for the phase segment was averaged over the phase time specified by the DRM IIA crew task timeline (Volume III)

An approximate ratio of 0.87 pounds of cryogenics per kilowatt-hour is based on current fuel cell capabilities. This value was used to determine the cryogenic consumption.

Power generation is done by the fuel cells which use the chemical potential of hydrogen and oxygen combining to produce electricity. Depending upon the purity of the gases used the fuel cells will tend to become poisoned by the accumulation of tramp gases. To avoid power failure these gases must be purged out of the reaction zone and dumped overboard. Duty cycles assumed for the DRM IIA show such purges occurring every seven hours.

G.2.4.2 Life Support

Life support oxygen includes all uses of crew oxygen - cabin environment, tunnel pressurization, LM pressurization, PGA oxygen and any gas needed to resupply leakage.

The crew oxygen is supplied at the rate required to maintain metabolic balance (Table G.2-5.) During periods of high activity the crew consumes greater quantities of oxygen; this higher rate is used during these segments. The discrete uses for tunnel and LM pressurization are shown as specific uses and combined with the maximum design allowable leakage and shown in Table G.3-3 as Other Oxygen Uses.

The Command Module surge tank provides oxygen at high flow rates for short periods to pressurize the tunnel, etc. In addition, this tank supplies oxygen to the crew from separation of the Service Module until splashdown and equilibration with the external atmosphere. Sufficient oxygen is available in the Command Module surge tank plus the backup PLSS tank to provide life support for 50 man-hours of normal operation.

G.2.5 Water

Water is provided for the crew to drink and reconstitute their food, and to spacecraft for cooling.

The spacecraft has two storage tanks for water with a total capacity of 92 pounds. This is separated into a 36-pound potable supply primarily for astronaut metabolic use, and a 56 pound waste water tank for supplemental cooling.

The spacecraft is tanked with 16 pounds of potable water prior to EPS power on (T-00:12:20). This initial water supply plus that generated during the twelve hours of pre-launch fuel cell operation assures the crew an ample supply for metabolic use and spacecraft cooling during ascent and earth orbit. All water generated by the fuel cells flows to the potable supply tank. When this tank is full the excess is diverted to the waste water supply until it is full, then the excess is dumped, Table G.2-2 shows this supply. The spacecraft will normally be operating in such a manner that heat rejection is handled primarily by the radiators. However, there are several situations where the heat is generated more rapidly than it can be dissipated by the radiators alone. These include ascent, earth orbit, and lunar orbit. Evaporation of water accomplishes the necessary additional cooling during these periods. Refinement of current thermal balance data - radiator efficiency, crew metabolism, spacecraft wall heating and the effect of attitude variations - is necessary to determine closer cryogenic usage - water production and cooling relationships. However, this is beyond the scope of this report.

In addition to the fuel cell water generation, the astronauts generate water as dermal moisture, respiratory moisture and water from the carbon-dioxide-lithium-hydroxide reaction; these are condensed and flow to the waste water tank. See Table G.2-3.

Water is provided for post-landing metabolic use. In addition to the 36 pound supply on board the Command Module, the survival kit contains 18 pounds of water and purification materials to desalinate 25 pounds of sea water.

G.2.6 Metabolics

G.2.6.1 Carbon Dioxide

Carbon dioxide generated by the crew through metabolic reaction must be removed by filtration through chemical reactants. This reaction involves carbon dioxide reacting with LiOH to form water. Further filtration removes this water and dumps it into the waste water tank.

The carbon dioxide filter consists of a housing with a diverter valve and two LiOH cartridges. These are changed alternately, every 36 man-hours of use. The first cartridge is changed about nine hours into the mission; thus subsequent changes can be made at 12 hour intervals with one cartridge being changed each cycle, the other remaining on the line. Seventeen cartridges will be used in this mission, with at least a 48 man-hour capacity remaining at splashdown.

G.2.6.2 Food

The initial food loading is 46 pounds (including 5.7 pounds of packaging). This allows for 0.058 pounds per man per hour on a linear metabolic rate. A post-landing allowance of five and a half pounds is included (32-man hours). The metabolic balance has been based on a stable astronaut weight with input of food and water exactly balancing the waste generation as shown in Table G.2-5. Although specific times have been allocated in the crew task timeline for eating and attending to bodily waste management, the effort to provide an exact weight balance is not warranted for this study of consumables since the spacecraft weight is not significantly affected.

G.2.6.3 Urine

The current design spacecraft dumps urine directly overboard unless the crewman is in his PGA. The PGA has a storage reservoir of 950 cc capacity. The generation rate is 0.11 lbs/hr/man; therefore the storage will provide for 12 hours of use prior to dumping to space. This weight loss is shown in Table G.2-3.

G.2.6.4 Feces

The feces, though put into storage at discrete mission times, is assumed to be generated at a linear rate of 0.023 pounds per man per hour in order to maintain the metabolic balance (see Table G.2-5). The feces storage does not affect the overall spacecraft weight - only its CG shift.

G. 2. 7 Weights Lost to Space

This item is an adjunct to the tables of consumables. The total weight loss to space, including all non-delta-V propellants and CSM consumable items is shown in Table G. 2-1.

TABLE G.2-1

CSM CONSUMABLES EXPENDED (LOST TO SPACE)

Phase Number	Mission Phase Title	Time Hrs	Dumped Water	Cooling Water	Oxygen	Hydrogen	Urine	RCS Non ΔV Prop	Total Weight Loss
1.1	Pre-Launch	10.833	0.000	0.000	0.000	2.817	0.000	0.000	2.817
1.2	Count-Down	1.500	0.000	0.000	0.063	0.390	0.495	0.000	0.948
2.1	Ascent Start	0.054	0.000	1.000	0.011	0.015	0.018	0.000	1.044
2.2	LES Jett	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.3	Ascent Final	0.137	0.000	1.000	0.027	0.037	0.045	0.000	1.120
3.0	Earth Orbit	1.395	0.000	5.000	0.279	0.377	0.046	0.000	6.116
4.1	TLI	0.095	0.000	0.000	0.019	0.026	0.031	0.000	0.076
4.2	T+D Prep	0.271	0.000	0.000	0.054	0.073	0.089	0.000	0.216
5.1	Trans+DK	0.743	0.000	0.000	0.149	0.201	0.400	58.500	58.995
5.2	S-IVB Jett	0.012	0.000	0.000	0.003	0.003	0.004	60.780	60.790
6.1	TLC to MC1	2.026	0.000	0.000	0.468	0.406	0.668	8.030	9.912
6.2	1st MC	0.002	0.000	0.000	0.000	0.001	0.001	0.680	0.682
6.3	TLC to MC2	49.946	30.255	0.000	9.767	9.389	16.482	6.460	72.353
6.4	2nd MC	0.002	0.006	0.000	0.000	0.001	0.001	0.680	0.688
6.5	TLC to MC3	10.599	16.649	0.000	2.183	2.120	3.498	11.480	35.930
6.6	3rd MC	0.001	0.003	0.000	0.000	0.000	0.000	0.680	0.683
6.7	TLC to LOI	0.994	1.561	0.000	0.199	0.199	0.528	3.110	5.397
7.0	LOI	0.113	0.297	0.000	0.023	0.031	0.037	2.510	2.898
8.1	Pre-LM SEP	5.701	12.138	0.000	9.703	1.197	1.881	3.630	28.549
8.2	LM SEP	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001
9.0	Lunar Orbit	38.945	45.133	58.417	8.167	8.176	4.967	13.020	137.197

TABLE G.2-1 (Continued)

CSM CONSUMABLES EXPENDED (LOST TO SPACE)

Phase Number	Mission Phase Title	Time Hrs	Dumped Water	Cooling Water	Oxygen	Hydrogen	Urine	RCS Non ΔV Prop	Total Weight Loss
12.10	Docking	0.167	0.193	0.250	0.033	0.000	0.055	0.040	0.579
13.0	Pre-LM Jett	0.808	0.136	1.212	0.162	0.000	0.267	0.000	1.777
	LM Jett	0.000	0.000	0.000	0.000	0.000	0.000	4.320	4.320
	Pre-TEI	3.192	5.328	0.000	0.636	0.032	1.053	21.160	28.219
14.0	TEI	0.032	0.083	0.000	0.006	0.000	0.011	0.070	0.170
15.0	TEC to MC4	9.959	15.643	0.000	2.055	0.064	3.286	22.680	43.728
15.2	4th MC	0.000	0.001	0.000	0.000	0.000	0.000	0.511	0.511
15.3	TEC to MC5	30.000	47.121	0.000	6.315	0.126	9.900	22.680	86.142
15.4	5th MC	0.000	0.001	0.000	0.000	0.000	0.000	0.511	0.511
15.5	TEC to MC6	47.195	55.129	19.000	9.817	0.224	15.514	22.680	122.424
15.6	6th MC	0.000	0.000	0.000	0.000	0.000	0.000	0.510	0.511
15.7	Pre-SM Jett	0.882	0.000	0.000	0.176	0.000	0.291	0.511	0.967
15.8	SM Jett	0.001	0.000	0.000	0.000	0.000	0.000	21.330	21.330
15.9	Pre-Entry	0.117	0.000	0.000	0.023	+	0.039	+	0.062
16.1	Entry	0.204	0.000	0.000	0.041		0.067		0.018
16.2	Rel Drogues	0.016	0.000	0.000	0.003		0.005		0.008
17.0	Main Desc.	0.086	0.000	0.000	0.017		0.028		0.045
18.1	Rel Chutes	0.001	0.000	0.000	0.000		0.000		0.000
18.2	Retrieval	1.000	0.000	0.000	0.000		0.330		0.330

+ SM JETTISON REMOVES SUPPLY

TABLE G.2-2

CSM CONSUMABLES STORAGE

Phase No.	Mission Phase	Phase Time Hrs	SM-RCS Prop	CM-RCS Prop	Cryo Oxygen	Cryo Hydrogen	Pot Water	Waste Water	Food
1.0	Pre-Launch	10.833	790.00	270.00	640.000	56.000	16.000	0.000	46.000
1.1	Count-Down	1.500	790.00	270.00	616.817	53.183	36.000	6.000	46.000
2.0	Ascent Strt	0.054	790.00	270.00	613.169	52.761	36.000	9.253	45.745
2.1	LES Jett	0.000	790.00	270.00	613.005	52.747	36.000	8.394	45.736
2.2	Ascent Finl	0.137	790.00	270.00	613.005	52.747	36.000	8.395	45.736
3.0	Earth Orbit	1.395	790.00	270.00	612.591	52.710	36.000	7.753	45.713
4.0	TLI	0.095	790.00	270.00	608.364	52.301	36.000	6.406	45.475
4.1	T+D Prep	0.271	790.00	270.00	608.077	52.276	36.000	6.655	45.459
5.0	Trans + Dk	0.743	790.00	270.00	607.256	52.202	36.000	7.364	45.413
5.1	S-IVB Jett	0.013	731.50	270.00	604.005	52.002	36.000	9.310	45.287
6.0	TLC To MC1	2.025	670.72	270.00	603.996	51.998	36.000	9.343	45.285
6.1	1St MC	0.002	662.69	270.00	599.784	51.594	36.000	12.511	44.941
6.2	TLC To MC 2	46.946	662.01	270.00	598.777	51.594	36.000	12.517	44.940
6.3	2ND MC	0.002	665.55	270.00	503.629	42.012	36.000	56.000	36.959
6.4	TLC To MC 3	10.599	654.87	270.00	503.622	42.012	36.000	56.000	36.959
6.5	3RD MC	0.001	643.39	270.00	481.936	39.860	36.000	56.000	35.157
6.6	TLC To LOI	0.994	642.71	270.00	481.933	39.860	36.000	56.000	35.157
7.0	LOI	0.113	639.60	270.00	479.905	39.661	36.000	56.000	34.998
8.0	Pre-LM Sep	5.701	637.09	270.00	479.563	39.630	36.000	56.000	34.969
8.1	LM Sep	0.000	633.46	270.00	458.856	38.401	36.000	56.000	33.999
9.0	Lunar Orbit	36.945	633.46	270.00	458.856	38.401	36.000	56.000	33.999

TABLE G.2-2 (Continued)

CSM CONSUMABLES STORAGE

Phase No.	Mission Phase	Phase Time Hrs	SM-RCS Prop	CM-RCS Prop	Cryo Oxygen	Cryo Hydrogen	Pot Water	Waste Water	Food
12.6	Docking	0.167	620.44	270.00	381.756	30.062	36.000	56.000	27.379
12.8	Pre-LM Jet	0.808	620.40	270.00	380.424	30.027	36.000	56.000	27.350
13.0	LM Jett	0.000	620.40	270.00	378.699	29.856	36.000	56.000	27.213
13.1	Pre-TEI	3.192	616.08	270.00	378.699	29.656	36.000	56.000	27.213
14.0	TEI	0.032	594.92	270.00	371.804	29.155	36.000	56.000	26.670
15.0	TEC To MC 4	9.959	594.22	270.00	371.708	29.147	36.000	56.000	26.665
15.1	4th MC	0.000	571.54	270.00	351.328	27.091	36.000	56.000	24.972
15.2	TEC To MC 5	30.000	571.03	270.00	351.327	27.091	36.000	56.000	24.972
15.3	5th MC	0.000	548.35	270.00	289.812	20.963	36.000	56.000	19.872
15.4	TEC To MC6	47.195	547.84	270.00	289.812	20.963	36.000	56.000	19.872
15.5	6th MC	0.000	525.16	270.00	193.156	11.300	36.000	56.000	11.849
15.6	Pre-SM Jett	0.662	524.65	270.00	193.156	11.300	36.000	56.000	11.849
15.7	SM Jett	0.001	524.15	270.00	190.483	11.062	36.000	53.551	11.699
15.8	Pre-Entry	0.117	+	270.00	3.350	+	35.999	53.552	11.698
16.0	Entry	0.204		248.00	3.321		35.825	53.699	11.679
16.1	Rel Drogues	0.015		208.00	3.270	7	35.520	53.956	11.644
17.0	Main Descent	0.086		x	3.266		35.497	53.976	11.641
18.0	Rel Chutes	0.001			3.244		35.370	54.083	11.627
18.1	Retrieval	1.000			2.994		33.879	55.574	11.457

+ SM JETTISON REDUCES BALANCE TO ZERO, EXCEPT OXYGEN IN CM SURGE TANK

x CM-RCS PROPELLANT IS JETTISONED WHEN CHUTES OPEN.

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TABLE G.2-3

CSM CREW METABOLIC BALANCE BY MISSION PHASE

Phase No.	Mission Phase	Phase Time Hrs	Pot Water Prod	Pot Water Used	Pot Waste Water	Food Con-sumed	Crew Oxygen	Urine Pro-duced	Feces Pro-duced	Waste Water Resp.	Waste Water Persr.	CO_2 From Crew
1.0	Pre-Launch	10.833	26.000	0.000	6.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1	Count-Down	1.500	3.600	2.235	1.365	0.235	0.375	0.615	0.105	0.690	1.020	0.435
2.0	Ascent Strt	0.054	0.154	0.080	0.073	0.009	0.013	0.022	0.004	0.025	0.037	0.016
2.1	LES Jett	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2	Ascent Finl	0.137	0.389	0.203	0.186	0.023	0.034	0.056	0.010	0.063	0.093	0.040
3.0	Earth Orbit	1.395	3.975	2.078	1.897	0.237	0.349	0.572	0.098	0.642	0.948	0.405
4.0	TLI	0.095	0.271	0.142	0.129	0.016	0.024	0.039	0.007	0.044	0.065	0.026
4.1	T+D Prep	0.271	0.772	0.404	0.368	0.046	0.068	0.111	0.019	0.125	0.184	0.079
5.0	Trans + DK	0.743	2.118	1.107	1.011	0.126	0.186	0.305	0.052	0.342	0.505	0.215
5.1	S-IVB Jett	0.013	0.036	0.019	0.017	0.002	0.003	0.005	0.001	0.006	0.009	0.004
6.0	TLC To MC 1	2.025	3.645	2.068	1.559	0.344	0.486	0.830	0.142	0.932	0.466	0.547
6.1	1st MC	0.002	0.006	0.002	0.004	0.000	0.001	0.001	0.000	0.001	0.001	0.001
6.2	TLC To MC 2	46.946	84.504	48.355	36.149	7.981	11.267	19.248	3.286	21.595	10.798	12.676
6.3	2nd MC	0.002	0.006	0.002	0.004	0.000	0.001	0.001	0.000	0.001	0.001	0.001
6.4	TLC To MC 3	10.599	19.079	10.917	8.162	1.802	2.544	4.346	0.742	4.876	2.438	2.862
6.5	3rd MC	0.001	0.003	0.001	0.002	0.000	0.000	0.000	0.000	0.001	0.000	0.000
6.6	TLC to LOI	0.994	1.789	1.024	0.765	0.169	0.239	0.407	0.070	0.457	0.229	0.268
7.0	LOI	0.113	0.323	0.117	0.206	0.019	0.027	0.046	0.008	0.052	0.026	0.031
8.0	Pre-LM Sep	5.701	10.833	5.872	4.960	0.964	1.368	2.338	0.399	2.623	3.877	1.653
8.1	LM Sep	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9.0	Lunar Orbit	38.945	73.995	19.472	54.523	6.621	3.116	15.967	2.726	17.915	26.482	11.294

TABLE G.2-3 (CONTINUED)

CSM CREW METABOLIC BALANCE BY MISSION PHASE

Phase No.	Mission Phase	Phase Time Hrs	Pot Water Prod	Pot Water Used	Pot Waste Water	Food Con-sumed	Crew Oxygen	Urine Pro-duced	Feces Produ-ced	Waste Water Resp.	Waste Water Persr.	CO_2 From Crew
12.8	Docking	0.167	0.317	0.083	0.233	0.028	0.013	0.068	0.012	0.077	0.113	0.048
12.9	Pre-LM Jet	0.808	1.535	1.204	0.331	0.137	0.202	0.331	0.057	0.372	0.549	0.234
13.0	LM Jett	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13.1	Pre-TEI	3.192	6.066	4.757	1.309	0.543	0.798	1.309	0.223	1.469	2.171	0.926
14.0	TEI	0.032	0.090	0.047	0.043	0.005	0.008	0.013	0.002	0.015	0.022	0.009
15.0	TEC To MC 4	9.959	17.927	10.258	7.669	1.693	2.390	4.083	0.697	4.581	2.291	2.689
15.1	4th MC	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15.2	TEC To MC 5	30.000	54.000	30.900	23.100	5.100	7.200	12.300	2.100	13.800	6.900	8.109
15.3	5th MC	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15.4	TEC To MC 6	47.195	84.951	48.611	36.340	8.023	11.327	19.350	3.304	21.710	10.855	12.743
15.5	6th MC	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15.6	Pre-SM Jett	0.882	2.514	1.314	1.200	0.150	0.221	0.362	0.062	0.406	0.600	0.256
15.7	SM Jett	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15.8	Pre-Entry	0.117	0.000	0.174	0.000	0.020	0.029	0.048	0.006	0.054	0.079	0.034
16.0	Entry	0.204	0.000	0.304	0.000	0.035	0.051	0.084	0.014	0.094	0.139	0.059
16.1	Rel Drogues	0.016	0.000	0.023	0.000	0.003	0.004	0.006	0.001	0.007	0.011	0.005
17.0	Main Descnt	0.086	0.000	0.128	0.000	0.015	0.021	0.035	0.006	0.039	0.058	0.025
18.0	Rel Chutes	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18.1	Retrieval	1.000	0.000	1.490	0.000	0.170	0.250	0.410	0.070	0.460	0.640	0.290

TABLE G.2-4

SM RCS PROPELLANT REQUIRED AS A FUNCTION OF PHASE AND RATE

ROTATIONAL - (Pounds/Maneuvers)

Phase	Mode	3 Axes	Roll	Pitch or Yaw	Roll Control
Translunar Coast	G&N @ 0.2°/sec	3.1	0.24	2.6	0.68 ea
	Man @ 0.2°/sec	4.76	0.24	—	MC
Lunar Orbit with LM	G&N @ 0.2°/sec	—	0.16	1.72	LOI
	G&N @ 0.5°/sec	5.2	0.43	4.3	2.51
	Man @ 0.5°/sec	8.52	0.43	—	
Lunar Orbit without LM	G&N @ 0.2°/sec	—	0.04	0.28	TEI
	G&N @ 0.5°/sec	1.08	0.19	0.71	0.70
	Man @ 0.5°/sec	1.68	0.19	—	
Transearth Coast	G&N @ 0.2°/sec	0.45	0.07	0.31	0.51 ea
	Man @ 0.2°/sec	0.57	0.07	—	MC

ATTITUDE HOLD - (Pounds/Hour)

Phase	0.5° Deadband	4.2° Deadband
Translunar	0.14	0.015
Lunar Orbit with LM	0.19	0.020
Lunar Orbit without LM	0.57	0.060
Transearth	0.71	0.075

MINIMUM IMPULSE

The minimum impulse used in IMU alignment and navigation sightings is a series of small bursts using a total of 0.35 pounds of propellant for each series.

TABLE G.2-5

CREW METABOLIC REQUIREMENTS SUMMARY (Rates in Pounds per Hour per Man)

(References G.11 and G.12)

METABOLIC RATES

	Nominal	Emergency
Consumption		
FOOD	0.058	0.058
OXYGEN	0.077	0.082
WATER	0.275	0.517
Output		
CO_2	0.089	0.095
WATER	0.2	0.408
URINE	0.11	0.11
FECES	0.011	0.011
Metabolic Heat	470 Btu	500 Btu

LIQUID BALANCE

Water	+	Food Oxidation	=	Water Vapor +	Urine
0.275	+	0.035	=	0.2	+ 0.11

WEIGHT BALANCE

Water	+	Oxygen	+	Food	=	Water Vapor	+ CO_2	+ Urine	+ Feces	
0.275	+	0.077	+	0.058	=	0.2	+ 0.089	+ + 0.11	+ 0.011	

G.3 LM CONSUMABLES

G.3.1 General

The LM consumables calculations include expenditures of DPS, APS and RCS propellant, as well as life support oxygen, lithium hydroxide, water, food and metabolic wastes. The expenditure to space, storage, and the transfer of weights and jettisoned structure are included.

Table G.3-1 presents a history of LM consumables according to the 32 LM consumable significant segments of the mission. Similar to the CSM, some of the consumables (e.g. food, water, oxygen, LiOH and urine) are retained on the vehicle; whereas others are expelled from the vehicle during flight (e.g. oxygen, water, and propellant.) These are itemized separately. The consumables eliminated from the system, listed as sub-totals in Table G.3-1 are incorporated as inputs to the Mission Weight Timeline Program to produce Table H-5 of the Mission Weights Appendix (Appendix H).

G.3.2 Descent Propellant

The LM DPS propellant is utilized for the Transfer Orbit Insertion and the LM powered descent maneuvers. The DPS propellant expenditure for these maneuvers are based on the DRM IIA trajectory delta V, the engine performance characteristics as shown on Appendix F, and on weights as depicted in Appendix H. The effect of non-propulsive and RCS orientation consumables usage was considered in determining the propellant consumption. See Table H-5 for DPS propellant expenditure.

G.3.3 Ascent Propellant

The APS propellant is required for only the powered ascent phase of the mission. Subsequent maneuvers are achieved through the utilization of RCS propellant. The APS propellant expenditure for the powered ascent maneuver is based on the DRM IIA trajectory delta V, the engine performance characteristics as shown in Appendix F, and on weights as depicted in Appendix H. Due to a center of gravity offset (i.e., the APS thrust line of action does not pass through the center of gravity of the LM), a moment unbalance exists. To offset this effect two X-axis RCS thrusters are pulsed utilizing APS propellant, through the interconnect. See Table H-5 for APS propellant expenditure.

G.3.4 RCS PROPELLANT

G.3.4.1 RCS Non-Translation

For purposes of estimating RCS non-translational propellant expediture during the mission the following modes of PGNCS operation were assumed to be available:

(1) Automatic -
  (a) powered flight: 0.3° or 1° deadband, 1.0 deg/sec max rate
  (b) coasting flight, except for (c) below: 5° deadband, 3.0 deg/sec max rate
  (c) 1.0° deadband 10 sec prior to transfer burn maneuver

(2) Attitude hold (manual) - 0.3° or 5° deadband available by means of LGC DSKY operations, 20 deg/sec max rate

(3) Pulse mode - single, minimum impulse per hand controller discretes, 0.3° deadband.

Prior to separation, the LM/CSM system has an attitude rate of 0.5 deg/sec. See Table G.3-3 for RCS attitude requirements and Table G.3-1 for RCS non-delta V propellant expenditures.

From propellant economy considerations, the 3.0° deg/sec attitude rate for coasting flight was chosen over the 5.0° deg/sec rate which heretofore had been used. The 3.0° deg/sec rate was considered adequate from the standpoint of crew activities.

Prior to both separation and lunar liftoff, the 16 RCS thrusters are given a sequential hot-fire checkout for a total "on time" for each checkout of .75 sec. Previous mission analysis assumed that the pre-separation LM IMU alignment is performed under CSM control. In DRM IIA this maneuver is under LM RCS control. However, after the IMU alignment is completed, CSM RCS is used to orient the LM/CSM to the separation attitude.

For the DRM IIA, IMU alignments are performed by LM RCS using two stars separated by approximately 90°, as well as a third star for checking purposes (with the exception of the pre-separation maneuver where only two stars are employed).

G.3.4.2 RCS Translation - In the case of ullage burns, nulling moment unbalance during powered ascent, the transfer burn maneuvers subsequent to powered ascent (i.e. CSI,

CDH, TPI, midcourse connections, rendezvous, and docking), the RCS propellant is expended to produced a delta V change in the velocity vector.

During the powered ascent phase, two pulsing +X-axis RCS thrusters contribute to delta V while overcoming the moment unbalance (sec. G-3.3).

For the DRM IIA transfer burn maneuvers, (CSI, CDH, TPI, and midcourse corrections) the Z-axis thrusters are employed. This is not the case for all missions, but was peculiar to this mission due to the attitude constraints in effect (see Appendices A and D).

Rendezvous and docking is achieved by using the Z-axis thrusters to reduce the LM/CSM range rate. (See Appendix A) See Table H-5 for LM RCS propellant expenditure.

G.3.5 Orbital Contingency Considerations

Although the DRM IIA mission is a nominal mission, the oxygen and water are loaded in such quantities to enable the possibility of an orbital contingency: that is, a period of time (8.14 hrs.) after the CDH maneuver has been accomplished during which the spacecraft is powered down to a somewhat quiescent state. Since the DRM IIA mission does not include the occurrence of an orbital contingency in the mission (see Table G.3-1 for consumables expended during the DRM IIA mission), at the termination of the LM mission sizable quantities of water and oxygen remain on board. Had and 8.14 hr. orbital contingency coast been required, the expenditure of oxygen and water would be such that the useable quantity of these consumables 15 minutes after the completion of the last rendezvous burn would be zero (see Table G.3-11).

G.3.6 Water

The Water Management Section provides for storage and distribution of water used in the LM for metabolic consumption by the crew, evaporative cooling (which is lost to space), and refill of the PLSS water tanks. In addition, this section provides for the utilization in the water boilers of the water produced in the LiOH bed and condensed water vapor from the crew.

The water boiler requirement is determined from a summation of all the heat loads on the Heat Transport Section for each phase of the mission. The heat loads include electrical equipment loads, metabolic heat, heat rejection in the CO_2 absorption process, and the cabin heat load resulting from heat transfer between the cabin walls and the cabin gas.

The electrical equipment heat loads have been determined from the Grumman LM Electrical Power Subsystem (EPS) current status electrical power profile which utilized the LM duty cycles Appendix E and was based on current status power levels as of 20 May 1966 (see Figure G.3-10). The total descent and ascent battery energy requirements of 39.4 KW-hrs and 8.4 KW-hrs, respectively, for this mission falls within the design capability of 46.9 KW-hrs for the descent batteries and 17.8 KW-hrs for the ascent batteries. For a mission with an orbital contingency, the ascent battery requirement is 16.3 KW-hrs (see figure G.3-11).

Since the electrical input is not equivalent to the heat absorbed by the coolant, the EPS profile has to be adjusted for any differences between electrical input and internal heat dissipation and for the differences between the internal heat dissipation the heat absorbed by the coolant. The proportion of the internal heat dissipation which is absorbed by the coolant was determined from the computer output of the Grumman Nominal LM Thermal Design Mission analysis (see reference G. 13). The cabin heat load was taken directly from the computer of the Nominal LM Thermal Design Mission Analysis.

Using the heat loads discussed above, the water quantities required for the DRM IIA mission were determined* and are shown in Table G.3-4. The useable loading requirements of 199.6 pounds of water in the descent tank and 72.0 pounds of water in the ascent tanks were derived based on the orbital contingency analysis to be discussed. The tanks are actually loaded to 206.8 and 74.6 lb. of water, respectively, to account for unuseable quantities.

While the DRM IIA is a nominal mission (i.e., no orbital contingency), water loading was predicated on such a contingency. If in a real mission, such a contingency were to occur, the useable storage at the end of the LM active phase would be zero at a point 15 minutes after the completion of the last rendezvous burn, the nominal end of the active LM for such a contingency. Table G.3-5 presents the water quantities expended for the DRM IIA orbital contingency mission.

In determining the water "lost to space" (Table G.3-1) it has been assumed that all PLSS refills dissipated during the explore phase with the exception of the final (seventh) refill which has been assumed to be stored on board the ascent stage. It has been assumed that the quantity of nonreclaimable drinking water accumulated up to the last explore phase was transferred to the descent stage in the form of urine and PLSS waste metabolic water during the last explore phase and was, therefore, lost to space.

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*See Reference G.14 and G.15

G.3.7 Oxygen

The Oxygen Supply and Cabin Pressure Control Section maintains cabin or suit pressurization by supplying oxygen in sufficient quantities to replenish losses due to crew metabolic consumption and cabin at suit leakage (the leakage quantities are considered lost to space).

Oxygen is also lost to space by other means; tank leakage, cabin leakage when cabin is pressurized, leakage from oxygen components in the cabin when it is unpressurized, and oxygen utilized to fill the PLSS tanks, and oxygen dissipated when the cabin is depressurized.

The oxygen required to accomplish the functions noted above for the DRM IIA mission is shown in Table G.3-6. The descent tank is loaded to 46.40 lb. useable oxygen and the ascent tanks (2) are loaded to a total of 4.42 lb. useable oxygen. The actual descent and ascent stage oxygen loading is 47.29 and 4.75 lb., respectively, when unuseable storage quantities are accounted for.

It should be noted that although a full fifth and sixth refill of the PLSS oxygen tank is shown in Table G.3-6 only a partial refill will be obtained due to insufficient oxygen storage pressure at that time. The oxygen used for the partial seventh refill of the PLSS tanks is not included in the "lost to space" column since it is assumed to be stored on board the ascent stage for extravehicular transfer, if necessary.

In the same manner as for the water loading, the oxygen is loaded to account for a possible orbital contingency of 8.14 hr. For such an orbital contingency occurence, the quantity of oxygen would be zero 15 minutes after the completion of the last rendezvous burn. Table G.3-7 presents the oxygen expended for the DRM IIA orbital contingency mission.

G.3.8 Metabolics.

G.3.8.1 Lithium Hydroxide. - Carbon dioxide is removed from the atmosphere by absorption in a bed of lithium hydroxide. One of the by-products of this chemical reaction is water which is recovered and circulated to the Water Management Section for use in the water boilers as a heat sink.

There are two primary cartridges, each containing 5.0 pounds of LiOH with an approximate lifetime of 41 man-hours. Only one of the primary cartridges is employed at a time. When the initial cartridge has been used to its capacity it is replaced by the other cartridge. During this changeover operation, the ventilating gas is temporarily diverted to a secondary LiOH

canister containing a PLSS cartridge (3 pounds of LiOH). There are seven PLSS cartridges aboard the LM besides the one stored in the secondary canister.

If both primary cartridges are used to capacity (which could occur if a limited number of excursions are made) the PLSS cartridges will be used for CO_2 removal (they will be available since a limited number of excursions are made). This is not the case, however, for the DRM IIA mission as shown in Table G.3-8. There is still 18.05 man-hours of capacity remaining on the second primary cartridge at the end of the mission. Changeover to this second cartridge occurs approximately 2 hours and 12 minutes after completion of the third exploration period. It has been assumed, as indicated in Table G.3-8, that the spent primary cartridge was removed from the ascent stage during the final exploration phase. Table G.3-9 presents the LiOH expenditure for the DRM IIA orbital contingency mission.

G.3.8.2 Food. - The food is vacuum packed in pliable plastic bags in a dehydrated form. A total of 8.8 lbs. of food is loaded on the LM. It is reconstituted by adding potable water through a one-way valve on the neck of the bag. After kneading the bag, the neck is torn off and placed in the mouth. The standard for computing total food required is 3,200 calories per day per man. The menu is of a low residue nature in order to minimize biological wastes. It is estimated that 1 lb. of food will be jettisoned to the lunar surface prior to lunar lift-off.

G.3.8.3 Urine. - The collection and disposal of urine is controlled by the Waste Management Section (WMS). The WMS uses the controlled pressure differential between the Pressure Garment Assembly (PGA) and the cabin as the force to transfer the contents of the PGA urine receptacle bag to the LM waste collection bag assembly. Each dry urine bag weighs approximately 1/2 lb. The waste fluid collection bag can be removed to be off-loaded on the lunar surface prior to lunar ascent. The PGA urine receptacle can store up to 400 cc of waste fluid. An external collection bag can store 9000 cc.

G.3.9 Transferred Weights.

Items transferred between LM and CSM and between LM and the lunar surface are listed in Appendix H, Table H-3.

TABLE G.3-1 SUMMARY - EXPENDABLES, TRANSFERRED WEIGHTS, AND USEABLE STORAGE - LM

Mission Phase Number	Mission Phase Title	Phase Time (Hrs.)	Weight Loss to Space (Lbs.)				Useable Storage at Beginning of Phase (Lbs.)								
			Oxygen	Water	RCS NonΔV Propellant	Sub-total	Total Oxygen	Descent Oxygen	Ascent Oxygen	Total Water	Descent Water	Ascent Water	Net Increase In Weight of LiOH Cartridge	Urine and PLSS Waste Water	Food
1.0	Fill GOX & Hold	20.500	0.205	-	-	0.205	50.815	46.392	4.423	271.57	199.57	72.00	-	-	8.800
2.0 - 8.1	Launch To Lunar Orbit Coast	66.295	0.663	-	-	0.663	50.610	46.187	4.423	271.57	199.57	72.00	-	-	8.800
8.2	Crew Trans/LM Act.	2.795	0.061	15.78	34.8	50.64	49.947	45.524	4.423	271.57	199.57	72.00	-	-	8.800
10.1	LM Separation	0.384	0.078	2.04	30.0	32.12	49.859	45.436	4.423	255.40	183.40	72.00	0.289	0.62	8.465
10.2	Transfer Orbit Insert.	0.008	0.002	0.04	1.7	1.74	49.694	45.271	4.423	253.31	181.31	72.00	0.348	0.70	8.419
10.3	Coast To Powered Descent	0.970	0.199	5.43	16.4	22.03	49.690	45.267	4.423	253.26	181.26	72.00	0.349	0.70	8.409
10.4	Braking	0.117	0.024	0.96	24.7	25.68	49.272	44.849	4.423	247.70	175.70	72.00	0.502	0.92	8.293
10.5	Final Approach	0.030	0.006	0.24	7.7	7.95	49.222	44.799	4.423	246.72	174.72	72.00	0.521	0.95	8.279
10.6	Landing	0.028	0.006	0.25	55.0	55.26	49.208	44.785	4.423	246.47	174.47	72.00	0.526	0.96	8.275
11.1	Post Landing Checkout	1.750	6.953	9.00	-	15.95	49.195	44.772	4.423	246.21	174.21	72.00	0.531	0.97	8.272
11.2	1st Lunar Explore	3.000	1.946	22.18	-	24.13	48.450	44.027	4.423	236.96	164.96	72.00	0.814	1.36	8.062
11.3	LM Internal Activity	9.250	8.480	31.90	-	40.38	48.224	43.801	4.423	226.66	154.66	72.00	0.896	4.19	7.702
11.4	2nd Lunar Explore	3.000	1.900	20.38	-	22.28	36.405	31.982	4.423	178.82	106.82	72.00	1.933	6.23	6.592
11.5	LM Internal Activity	2.670	7.130	8.73	-	15.86	36.345	31.922	4.423	169.32	97.32	72.00	1.933	10.01	6.232
11.6	3rd Lunar Explore	3.000	1.900	19.95	-	21.85	26.942	22.519	4.423	145.56	73.56	72.00	2.232	10.60	5.912
11.7	LM Internal Activity	7.250	8.070	25.07	-	33.14	26.882	22.459	4.423	136.49	64.49	72.00	2.232	14.38	5.552
11.8	4th Lunar Explore	3.000	1.912	20.61	-	22.52	15.797	11.374	4.423	95.75	23.75	72.00	0.626	15.98	4.682
11.9	Pre-Launch Prep. (Descent)	1.500	0.307	6.65	-	6.96	15.698	11.275	4.423	86.19	14.19	72.00	0.646	3.62	4.322
11.9	Pre-Launch Prep. (Ascent)	0.270	0.054	1.52	4.4	5.97	4.423	-	4.423	72.00	-	72.00	0.816	3.95	4.142
12.1	Powered Ascent	0.114	0.023	0.72	5.0	5.74	4.325	-	4.325	70.44	-	70.44	0.846	4.01	4.110
12.2	Coast To CSI	0.460	0.092	3.08	2.6	5.77	4.276	-	4.276	69.71	-	69.71	0.865	4.03	4.096
12.3	CSI	0.015	0.003	0.10	2.8	2.90	4.100	-	4.100	66.56	-	66.56	0.923	4.14	4.041
12.4	Coast To CDH	0.816	0.163	5.45	5.3	10.91	4.094	-	4.094	66.46	-	66.46	0.925	4.14	4.039
12.5	CDH Maneuver	0.015	0.003	0.10	3.0	3.10	3.782	-	3.782	60.90	-	60.90	1.028	4.32	3.941
12.6	Coast To TPI	0.287	0.057	1.88	1.4	3.34	3.776	-	3.776	60.80	-	60.80	1.029	4.32	3.939
12.7	TPI	0.007	0.001	0.05	1.2	1.25	3.667	-	3.667	60.75	-	60.75	1.066	4.38	3.905
12.8	Terminal Phase Coast	0.469	0.094	3.33	8.9	12.32	3.664	-	3.664	58.83	-	58.83	1.067	4.38	3.904
12.9	Terminal Rendezvous	0.428	0.086	3.18	4.9	8.17	3.485	-	3.485	55.44	-	55.44	1.126	4.48	3.848
12.10	Docking	0.108	0.022	0.71	14.1	14.83	3.313	-	3.313	52.26	-	52.26	1.185	4.57	3.797
13.1	Coast To LM Jettison	0.974	0.194	3.06	0.4	3.65	1.170	-	1.170	51.54	-	51.54	1.200	4.59	3.784
13.2	LM Jettison	0.002	-	-	-	-	0.847	-	0.847	48.40	-	48.40	1.354	4.71	3.667

TABLE G.3-2 SUMMARY - EXPENDABLES, TRANSFERRED WEIGHTS, AND USEABLE STORAGE (ORBITAL CONTINGENCY) - LM

Mission Phase Number	Mission Phase Title	Phase Time (Hrs.)	Weight Loss to Space (Lbs.)				Useable Storage at Beginning of Phase (Lbs.)								
			Oxygen	Water	RCS NonΔV Propellant	Sub-total	Total Oxygen	Descent Oxygen	Ascent Oxygen	Total Water	Descent Water	Ascent Water	Net Increase In Weight of LiOH Cartridge	Urine and PLSS Waste Water	Food
1.0	Fill GOX & Hold	20.500	0.205	-	-	0.205	50.815	46.392	4.423	271.57	199.57	72.00	-	-	8.800
2.0 - 8.1	Launch To Lunar Orbit Coast	66.295	0.663	-	-	0.663	50.610	46.187	4.423	271.57	199.57	72.00	-	-	8.800
8.2	Crew Trans/LM Act.	2.795	0.061	15.78	34.8	50.64	49.947	45.524	4.423	271.57	199.57	72.00	-	-	8.800
10.1	LM Separation	0.384	0.078	2.04	30.0	32.12	49.859	45.436	4.423	255.40	183.40	72.00	0.289	0.62	8.465
10.2	Transfer Orbit Insert.	0.008	0.002	0.04	1.7	1.74	49.694	45.271	4.423	253.31	181.31	72.00	0.348	0.70	8.419
10.3	Coast To Powered Descent	0.970	0.199	5.43	16.4	22.03	49.690	45.267	4.423	253.26	181.26	72.00	0.349	0.70	8.409
10.4	Braking	0.117	0.024	0.96	24.7	25.68	49.272	44.849	4.423	247.70	175.70	72.00	0.502	0.92	8.293
10.5	Final Approach	0.030	0.006	0.24	7.7	7.95	49.222	44.799	4.423	246.72	174.72	72.00	0.521	0.95	8.279
10.6	Landing	0.028	0.006	0.25	55.0	55.26	49.208	44.785	4.423	246.47	174.47	72.00	0.526	0.96	8.275
11.1	Post Landing Checkout	1.750	6.953	9.00	-	15.95	49.195	44.772	4.423	246.21	174.21	72.00	0.531	0.97	8.272
11.2	1st Lunar Explore	3.000	1.946	22.18	-	24.13	48.450	44.027	4.423	236.96	164.96	72.00	0.814	1.36	8.062
11.3	LM Internal Activity	9.250	8.480	31.90	-	40.38	48.224	43.801	4.423	226.66	154.66	72.00	0.896	4.19	7.702
11.4	2nd Lunar Explore	3.000	1.900	20.38	-	22.28	36.405	31.982	4.423	178.82	106.82	72.00	1.933	6.23	6.592
11.5	LM Internal Activity	2.670	7.130	8.73	-	15.86	36.345	31.922	4.423	169.32	97.32	72.00	1.933	10.01	6.232
11.6	3rd Lunar Explore	3.000	1.900	19.95	-	21.85	26.942	22.519	4.423	145.56	73.56	72.00	2.232	10.60	5.912
11.7	LM Internal Activity	7.250	8.070	25.07	-	10.58	26.882	22.459	4.423	136.49	64.49	72.00	2.232	14.38	5.552
11.8	4th Lunar Explore	3.000	1.192	20.61	-	22.52	15.797	11.374	4.423	95.75	23.75	72.00	0.626	15.98	4.682
11.9	Pre-Launch Prep. (Descent)	1.500	0.307	6.65	-	6.96	15.698	11.275	4.423	86.19	14.19	72.00	0.646	3.62	4.322
11.9	Pre-Launch Prep. (Ascent)	0.270	0.054	1.65	4.4	6.10	4.423	-	4.423	72.00	-	72.00	0.816	3.95	4.142
12.1	Powered Ascent	0.114	0.023	0.77	5.0	5.79	4.325	-	4.325	70.31	-	70.31	0.846	4.01	4.110
12.2	Coast To CSI	0.460	0.092	3.52	2.6	6.21	4.276	-	4.276	69.53	-	69.53	0.865	4.03	4.096
12.3	CSI	0.015	0.003	0.12	2.8	2.92	4.100	-	4.100	65.94	-	65.94	0.923	4.14	4.041
12.4	Coast To CDH	0.816	0.163	6.00	5.3	11.46	4.094	-	4.094	65.82	-	65.82	0.925	4.14	4.039
12.5	CDH Maneuver	0.015	0.003	0.11	3.0	3.11	3.782	-	3.782	59.71	-	59.71	1.028	4.32	3.941
12.5A	O.C. Subsystem Shutdown Coast	0.500	0.100	2.78	-	2.88	3.776	-	3.776	59.60	-	59.60	1.029	4.32	3.939
12.5B	O.C. Coast	6.640	1.328	35.71	-	37.04	3.595	-	3.595	56.75	-	56.75	1.086	4.43	3.879
12.5C	O.C. Subsystem Startup Coast	1.000	0.200	6.48	-	6.68	1.191	-	1.191	20.12	-	20.12	1.830	5.89	3.082
12.6	Continue Coast To TPI	0.287	0.057	2.28	1.4	3.74	0.829	-	0.829	13.50	-	13.50	1.942	6.11	2.962
12.7	TPI	0.007	0.001	0.06	1.2	1.26	0.720	-	0.720	11.18	-	11.18	1.978	6.17	2.928
12.8	Terminal Phase Coast	0.469	0.094	3.86	8.9	12.85	0.717	-	0.717	11.12	-	11.12	1.979	6.17	2.927
12.9	Terminal Rendezvous	0.428	0.086	3.50	4.9	8.49	0.538	-	0.538	7.20	-	7.20	2.038	6.27	2.871

TABLE G.3-2 SUMMARY - EXPENDABLES, TRANSFERRED WEIGHTS, AND USEABLE STORAGE (ORBITAL CONTINGENCY) - LM

Mission Phase Number	Mission Phase Title	Phase Time (Hrs.)	Weight Loss to Space (Lbs.)				Useable Storage at Beginning of Phase (Lbs.)								
			Oxygen	Water	RCS NonΔV Propellant	Sub-total	Total Oxygen	Descent Oxygen	Ascent Oxygen	Total Water	Descent Water	Ascent Water	Net Increase Weight of LiOH Cartridge	Urine and PLSS Waste Water	Food
12.10	Docking	0.108	0.022	0.77	14.6	14.89	0.366	--	0.366	3.65	--	3.65	2.048	6.36	2.820
13.1	Coast To LM Jettison	0.947	0.194	2.78	0.4	3.37	0.323	--	0.323	2.87	--	2.87	2.113	6.38	2.807
13.2	LM Jettison						0.0	--	0.0	0.0	--	0.0	2.266	6.50	2.690

TABLE G. 3-3

LM ATTITUDE TIMELINE

DRM-IIA DESCENT

Phase No.	Mission Hr Mn Sc	Phase Time Hr Mn Sc	Mission Phase Title	Maneuver Description	M*ode	Duration Time Sec	Dead Band Deg.	Max Rate Deg/Sec Pitch	Yaw	Roll
8.0			Lunar Orbit Coast to LM Separation	1. Checkout***	M					
				2. Constant Attitude	C					
				3. Pitch And Yaw To IMU Alignment Attitude	M	116.0	5.0	0.5	0.5	
				4. IMU Alignment**	M	360.0	5.0	0.5	0.5	
		01:54:59		5. Pitch and Yaw To Separation Attitude	C					
10.1	69:05:32		LM Separation	1. Constant Attitude Separation	A	2.0	1.0			
				2. Constant Attitude	A	95.0	1.0			
				3. Pitch To Attitude For Visual Inspection	M	16.0	5.0	10.0		
				4. Yaw Maneuver During Check	M	48.0	5.0		10.0	
				5. Pitch And Yaw To TOI Attitude	A	14.0	5.0	3.0	3.0	
				6. Maintain Attitude	A	342.5	5.0			
				7. IMU Alignment And Alignment Check**	M	540.0	5.0	3.0	3.0	
				8. Pitch And Roll To TOI Attitude	A	311.5	5.0	3.0		3.0
				9. Maintain Attitude At Minimum Deadband	A	4.5	1.0			
		00:22:59		10. Ullage Burn	A	5.5	1.0			
10.2	69:28:31		Transfer Orbit Insertion	1. Maintain Gradual Pitchover At 30% Thrust	A	3.0	1.0			
				2. Maintain Gradual Pitchover At 10 % Thrust	A	23.0	1.0			
		00:00:32		3. Maintain Gradual Pitchover At 97 % Thrust	A	6.3	1.0			
10.3	69:29:03		Coast To Powered Descent	1. Pitch To Coasting Attitude	A	28.0	5.0	3.0		
				2. Maintain Attitude	A	2491.5	5.0			
				3. Pitch And Yaw To IMU Alignment	A	57.0	5.0	3.0	3.0	
				4. IMU Alignment And Alignment Check**	A	540.0	5.0	3.0	3.0	
				5. Maintain Attitude	M	286.0	5.0			
				6. Pitch and Roll To Powered Descent	A	20.0	5.0	3.0		3.0
				7. Maintain Powered Descent Attitude	A	61.5	5.0			
				8. Maintain Attitude At Minimum Deadband	A	4.5	1.0			
		00:58:14		9. Ullage Burn	A	5.5	1.0			
10.4	70:27:17		Braking Maneuver	1. Maintain Gradual Pitchover At 30% Thrust	A	3.0	1.0			
				2. Maintain Gradual Pitchover At 10% Thrust	A	23.0	1.0			
				3. Maintain Gradual Pitchover At 95% Thrust	A	394.0	1.0			
		00:07:00								

TABLE G. 3-3

LM ATTITUDE TIMELINE (Cont.)

DRM-IIA DESCENT

Phase No.	Mission Time Hr Mn Sc	Phase Time Hr Min Sc	Mission Phase Title	Maneuver Description	M* o d e	Dura-tion Time Sec	Dead Band Deg.	Max Rate Deg/Sec Pitch	Yaw	Roll
10.5	70:34:17		Final Approach	1. Pitchover To Visibility	A	7.5	1.0	10.0		
				2. Maintain Gradual Pitchup	A	97.5	1.0			
		00:01:45								
10.6	70:36:02		Landing	1. Pitchover To Landing Attitude	M	18.0	0.3	5.0		
				2. Attitude Hold	M	32.0	0.3			
				3. Pitchup To Braking Attitude	M	10.0	0.3	5.0		
				4. Attitude Hold	M	8.0	0.3			
				5. Pitchover To Landing Attitude	M	7.0	0.3	5.0		
		00:01:43		6. Attitude Hold To Touch-down	M	28.0	0.3			

*: M-Manual, A-Automatic, C-Under CSM Control

**: Drift Rate Set Up By Manually Operating Hand Controller While In PGNCS Mode-3 Axis Maneuvers

***: Hot Fire Check - 16 Jets; Total On-Time = 0.75 Sec.

TABLE G. 3-3 (Cont.)
LM ATTITUDE TIMELINE
DRM IIA - ASCENT

Phase No.	Mission Time Hr Mn Sc	Phase Time Hr Mn Sc	Mission Phase Title	Maneuver Description	M*ode	Duration Time Sec	Dead Band Deg.	Max Rate Deg/Sec Pitch	Yaw	Roll
12.1	105:19:04		Powered*** Ascent	1. Inertial Attitude Hold During Vertical Rise	A	12.0	1.0			
				2. Rapid Pitchover And Yaw Steering	A	6.0	1.0	10.0		5.0
		00:06:50		3. Maintain Gradual Pitch-over	A	392.0	1.0			
12.2	105:25:54		Coast To CSI	1. Pitchover And Roll Maneuver To CSM Orbit Plane	A	22.0	5.0	3.0		3.0
				2. Inertial Attitude Hold	A	1211.0	5.0			
				3. Pitch To CSI Attitude	A	20.0	5.0	3.0		
				4. Inertial Attitude Hold	A	392.0	5.0			
		00:27:35		5. Inertial Attitude Hold At Minimum Deadband	A	10.0	1.0			
12.3	105:53:29	00:00:53	CSI Maneuver	1. CSI Maneuver	A	53.0	1.0			
12.4	105:54:22		Coast To CDH Maneuver	1. Inertial Attitude Hold	A	733.0	5.0			
				2. Pitch Maneuver To Tracking Attitude	A	17.0	5.0	3.0		
				3. Inertial Attitude Hold	A	883.0	5.0			
				4. IMU Alignment**	M	540.0	5.0	3.0	3.0	
				5. Pitch And Yaw Maneuver To Tracking Attitude	A	51.0	5.0	3.0	3.0	
				6. Inertial Attitude Hold	A	685.0	5.0			
				7. Pitch To CDH Attitude	A	10.0	5.0	3.0		
				8. Inertial Attitude Hold	A	10.0	5.0			
		00:48:59		9. Inertial Attitude Hold At Minimum Deadband	A	10.0	1.0			
12.5	106:43:21	00:00:56	CDH Maneuver	1. CDH Maneuver	A	56.0	1.0			
12.6	106:44:17		Coast To TPI							
				1. Inertial Attitude Hold	A	1011.0	5.0			
				2. Pitch To TPI Attitude	A	5.0	5.0	3.0		
				3. Inertial Attitude Hold	A	8.0	5.0			
		00:17:14		4. Inertial Attitude Hold At Minimum Deadband	A	10.0	1.0			
12.7	107:01:31	00:00:23	TPI Maneuver	1. TPI Maneuver	A	23.0	1.0			
12.8	107:01:54		Terminal Coast	1. Pitch To Coasting Attitude	A	8.0	5.0	3.0		
				2. Inertial Attitude Hold	A	489.0	5.0			
				3. Pitch and Yaw To First MC Attitude	A	15.0	5.0	3.0	3.0	
				4. Inertial Attitude Hold	A	40.0	5.0			
				5. Inertial Attitude Hold At Minimum Deadband	A	10.0	1.0			

TABLE G. 3-3 (Cont.)

LM ATTITUDE TIMELINE
DRM IIA - ASCENT

Phase No.	Mission Time Hr Mn Sc	Phase Time Hr Mn Sc	Mission Phase Title	Maneuver Description	M* o d e	Duration Time Sec	Dead Band Deg.	Max Rate Deg/Sec Pitch	Yaw	Roll
				6. Maintain Attitude During First MC	A	25.0	1.0			
				7. Pitch And Yaw To Coasting Attitude	A	15.0	5.0	3.0	3.0	
				8. Inertial Attitude Hold	A	468.0	5.0			
				9. Pitch And Yaw To Second MC Attitude	A	15.0	5.0	3.0	3.0	
				10. Inertial Attitude Hold	A	30.0	5.0			
				11. Inertial Attitude Hold at Minimum Deadband	A	10.0	1.0			
				12. Maintain Attitude During Second MC	A	4.0	1.0			
				13. Pitch And Yaw To Coasting Attitude	A	15.0	5.0	3.0	3.0	
		00:28:08		14. Inertial Attitude Hold	A	544.0	5.0			
12.9	107:30:02		Terminal Rendezvous	1. Inertial Attitude Hold	A	362.0	5.0			
				2. Pitch To Second Rendezvous Gate Attitude	A	2.0	5.0	3.0		
				3. Inertial Attitude Hold	A	8.0	5.0			
				4. Inertial Attitude Hold At Minimum Deadband	A	10.0	1.0			
				5. Second Rendezvous Gate Burn	A	4.0	1.0			
				6. Inertial Attitude Hold	A	573.0	5.0			
				7. Pitch To Third Rendezvous Gate Attitude	A	2.0	5.0	3.0		
				8. Inertial Attitude Hold	A	8.0	5.0			
				9. Inertial Attitude Hold At Minimum Deadband	A	10.0	1.0			
				10. Third Rendezvous Gate Burn	A	8.0	1.0			
				11. Inertial Attitude Hold	A	531.0	5.0			
				12. Pitch To Fourth Rendezvous Gate Attitude	A	2.0	5.0	3.0		
				13. Inertial Attitude Hold	A	8.0	5.0			
				14. Inertial Attitude Hold At Minimum Deadband	A	10.0	1.0			
		00:25:42		15. Fourth Rendezvous Gate Burn	A	4.0	1.0			
12.10	107:55:44		Docking	1. Translate To A Point 50 Feet In Front Of CSM	M	180.0	5.0			
				2. Maintain Zero Range Rate To CSM (Pulse Mode)	M	90.0	0.3			
				3. Pitchover To Acquire CSM In Overhead Window (Pulse Mode)	M	20.0	0.3	3.0		
		00:06:30		4. Final Translation To CSM (Pulse Mode)	M	100.0	0.3			

TABLE G. 3-3 (Cont.)

LM ATTITUDE TIMELINE
DRM IIA - ASCENT

Phase No.	Mission Time Hr Mn Sc	Phase Time Hr Mn Sc	Mission Phase Title	Maneuver Description	M* o d e	Dura-tion Time Sec	Dead Band Deg.	Max Rate Deg/Sec Pitch	Yaw	Roll
13.1	108:02:14		Coast To LM Jettison	1. LM-CSM Docked Con - figuration Maneuvers (SM-RCS Active)	C	2976.0				
		00:58:28		2. Inertial Attitude Hold For LM/CSM (LM RCS Active)	M	532.0	5.0			
13.2	109:00:42		LM Jettison							

*: M-Manual, A-Automatic, C-Under CSM Control

**: Drift Rate Set Up By Manually Operating Hand Controller While In PGNCS Mode

***: Hot Fire RCS Check During Prelaunch Checkout--16 Jets, Total On-Time = 0.75 Sec

TABLE G.3-4 Water Requirements - DRM IIA Mission

PHASE (Descent)	Time	Water Boiler Requirement	PLSS Refills	LiOH Water Produced	Cabin Condensation & Decomp. Loss	Non-Recl. Drinking Water	Water Required From Storage	Useable** Water In Tank At Beginning Of Phase
	Hrs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Crew Transfer/LEM Act.	2.80	15.78		0.23		0.62	16.17	271.57
LM Separation	0.38	2.04		0.03		0.08	2.09	255.40
Trans. Orbit Insert./ Coast	0.98	5.47		0.08		0.22	5.61	253.31
Braking	0.12	0.96		0.01		0.03	0.98	247.70
Final Approach	0.03	0.24		-		0.01	0.25	246.72
Landing	0.03	0.25		-		0.01	0.26	246.47
Post Landing C/O	1.75	8.75		0.14	0.25	0.39	9.25	246.21
1st Explore	3.00	7.52		0.05		2.83	10.30	236.96
Internal Activity	9.25	31.73	14.66	0.76	0.17	2.04	47.84	226.66
2nd Explore	3.00	5.72		-		3.78	9.50	178.82
Internal Activity	2.67	8.56	14.66	0.22	0.17	0.59	23.76	169.32
3rd Explore	3.00	5.29				3.78	9.07	145.56
Internal Activity	7.25	24.90	14.66	0.59	0.17	1.60	40.74	136.49
4th Explore	3.00	5.95		0.01		3.62	9.56	95.75
Pre-Launch Prep. (Descent)	1.50	6.65	7.33	0.12		0.33	14.19	86.19

**: Total Ascent and Descent Stage

TABLE G.3-4 (continued)

PHASE (Ascent)	Time	Water Boiler Requirement	PLSS Refills	LiOH Water Produced	Cabin Condensation & Decomp. Loss	Non-Recl. Drinking Water	Water Required From Storage	Useable** Water In Tank At Beginning Of Phase
	Hrs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Pre-Launch Prep. (Ascent)	0.27	1.52		0.02		0.06	1.56	72.00
Powered Ascent	0.11	0.72		0.01		0.02	0.73	70.44
Coast To CSI	0.48	3.18		0.04		0.11	3.25	69.71
Coast To CDH	0.83	5.55		0.07		0.18	5.66	66.46
Coast To T PI	0.29	1.93		0.02		0.06	1.97	60.80
Terminal Coast	0.47	3.33		0.04		0.10	3.39	58.83
Terminal Rendezvous	0.43	3.13		0.04		0.09	3.18	55.44
Docking	0.11	0.71		0.01		0.02	0.72	52.26
Coast to LM Jettison	0.98	3.06		0.04		0.12	3.14	51.54

**: Total Ascent and Descent Stage

TABLE G.3-5 Water Requirements - DRM IIA - Orbital Contingency Mission

PHASE (Descent)	Time	Water Boiler Requirement	PLSS Refills	LiOH Water Produced	Cabin Condensation & Decomp. Loss	Non-Recl. Drinking Water	Water Required From Storage	Useable** Water In Tank At Beginning Of Phase
	Hrs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Crew Transfer/LM Act.	2.80	15.78		0.23		0.62	16.17	271.57
LM Separation	0.38	2.04		0.03		0.08	2.09	255.40
Trans. Orbit Insert./ Coast	0.98	5.47		0.08		0.22	5.61	253.31
Braking	0.12	0.96		0.01		0.03	0.98	247.70
Final Approach	0.03	0.14		-		0.01	0.25	246.72
Landing	0.03	0.25		-		0.01	0.26	246.47
Post Landing C/O	1.75	8.75		0.14	0.25	0.39	9.25	246.21
1st Explore	3.00	7.52		0.05		2.83	10.30	236.96
Internal Activity	9.25	31.73	14.66	0.76	0.17	2.04	47.84	226.66
2nd Explore	3.00	5.72		-		3.78	9.50	178.82
Internal Activity	2.67	8.56	14.66	0.22	0.17	0.59	23.76	169.32
3rd Explore	3.00	5.29		-		3.78	9.07	145.56
Internal Activity	7.25	24.90	14.66	0.59	0.17	1.60	40.74	136.49
4th Explore	3.00	5.95		0.01		3.62	9.56	95.75
Pre-Launch Prep. (Descent)	1.50	6.65	7.33	0.12		0.33	14.19	86.19

**: Total Ascent and Descent Stage

TABLE G. 3-5 (Continued)

PHASE (Ascent)	Time	Water Boiler Requirement	PLSS Refills	LioH Water Produced	Cabin Condensation & Decomp. Loss	Non-Recl. Drinking Water	Water Required From Storage	Useable Water In Tank At Beginning Of Phase
	Hrs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Pre-Launch Prep. (Ascent)	0.27	1.65		0.02		0.06	1.69	72.00
Powered Ascent	0.11	0.77		0.01		0.02	0.78	70.31
Coast to CSI	0.48	3.64		0.04		0.11	3.71	69.53
Coast to CDH	0.83	6.11		0.07		0.18	6.22	65.82
O.C. Subsystem Shutdown Coast	0.50	2.78		0.04		0.11	2.85	59.60
Q.C. Coast	6.64	35.71		0.54		1.46	36.63	56.75
O.C.Subsystem Start up Coast	1.00	6.48		0.08		0.22	6.62	20.12
Coast to TPI	0.29	2.34		0.02		0.06	2.38	13.50
Terminal Coast	0.47	3.86		0.04		0.10	3.92	11.12
Terminal Rendezvous	0.43	3.50		0.04		0.09	3.55	7.20
Docking	0.11	0.77		0.01		0.02	0.78	3.65
Coast to LM Jettison	0.98	2.79		0.04		0.12	2.87	2.87
LM Jettison								0.00

TABLE G.3-6 Oxygen Requirements - DRM IIA Mission

PHASE (Descent)	Time	Metabolic and Leakage	PLSS Refills	Cabin Pressurization	Oxygen Required From Storage	Useable** Oxygen In Tanks At Beginning Of Phase
	Hrs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Gox Fill to Crew Transfer	86.80	0.87			0.87	50.82
Crew Transfer/LM Act.	2.80	0.09			0.09	49.95
LM Separation	0.38	0.16			0.16	49.86
Trans. Orbit Insert. / Coast	0.98	0.42			0.42	49.70
Braking	0.12	0.05			0.05	49.27
Final Approach	0.03	0.01			0.01	49.22
Landing	0.03	0.01			0.01	49.21
Post Landing C/O	1.75	0.74			0.74	49.20
1st Explore	3.00	0.23			0.23	48.45
Internal Activity	9.25	3.36	1.84	6.62	12.10	48.22
2nd Explore	3.00	0.06			0.06	36.41
Internal Activity	2.67	0.94	1.84	6.62	9.68	36.34
3rd Explore	3.00	0.06			0.06	26.94
Internal Activity	7.25	2.63	1.84*	6.62	11.37	26.88
4th Explore	3.00	0.10			0.10	15.80
Pre-Launch Prep. (Descent)	1.50	0.55	0.22*	6.62	7.69	15.70

*: Due to insufficient gox pressure the 5th, 6th, and 7th PLSS Refills actually are 0.84, 0.68, and 0.25 lbs., respectively.

**: Total Ascent and Descent Stage

TABLE G. 3-6 (Continued)

PHASE (Ascent)	Time	Metabolic and Leakage	Weight Transferred	Cabin Pressurization	Oxygen Required from Storage	Useable Oxygen In Tanks At Beginning Of Phase
	Hrs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Pre-Launch Prep. (Ascent)	0.27	0.10			0.10	4.42
Powered Ascent	0.11	0.05			0.05	4.32
Coast to CSI	0.48	0.18			0.18	4.27
Coast to CDH	0.83	0.32			0.32	4.09
Coast to TPI	0.29	0.11			0.11	3.77
Terminal Coast	0.47	0.18			0.18	3.66
Terminal Rendezvous	0.43	0.17			0.17	3.48
Docking	0.11	0.04	-2.10		2.14	3.31
Coast to LM Jettison	0.98	0.32			0.32	1.17

TABLE G-3.7 Oxygen Requirements -DRM IIA - Orbital Contingency Mission

PHASE (Descent)	Time	Metabolic And Leakage	PLSS Refills	Cabin Pressurization	Oxygen Required From Storage	Useable** Oxygen In Tanks At Beginning Of Phase
	Hrs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Gox Fill to Crew Transfer	86.80	0.87			0.87	50.82
Crew Transfer/LM Act.	2.80	0.09			0.04	49.95
LM Separation	0.38	0.16			0.16	49.86
Trans. Orbit Insert./ Coast	0.98	0.42			0.42	49.70
Braking	0.12	0.05			0.05	49.27
Final Approach	0.03	0.01			0.01	49.22
Landing	0.03	0.01			0.01	49.21
Post Landing C/O	1.75	0.74			0.74	49.20
1st Explore	3.00	0.23			0.23	48.45
Internal Activity	9.25	3.36	1.84	6.62	12.10	48.22
2nd Explore	3.00	0.06			0.06	36.41
Internal Activity	2.67	0.94	1.84	6.62	9.68	36.34
3rd Explore	3.00	0.06			0.06	26.94
Internal Activity	7.25	2.63	1.84*	6.62	11.37	26.88
4th Explore	3.00	0.10			0.10	15.80
Pre-Launch Prep. (Descent)	1.50	0.55	0.22*	6.62	7.69	15.70

*: Due to insufficient gox pressure the 5th, 6th, and 7th PLSS Refills actually are 0.84, 0.68, and 0.25 lbs., respectively.

**: Toatl Ascent and Descent Stage

TABLE G.3-7 (Continued)

PHASE (Ascent)	Time	Metabolic And Leakage	PLSS Refills	Cabin Pressurization	Oxygen Required From Storage	Useable** Oxygen In Tanks At Beginning Of Phase
	Hrs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Pre-Launch Prep. (Ascent)	0.27	0.098			0.098	4.423
Powered Ascent	0.11	0.049			0.049	4.325
Coast to CSI	0.46	0.182			0.182	4.276
Coast to CDH	0.83	0.318			0.318	4.094
O.C. Subsystem Shutdown Coast	0.50	0.181			0.181	3.776
O.C. Coast	6.64	2.404			2.404	3.595
O.C. Subsystem Startup Coast	1.00	0.362			0.362	1.191
Coast to TPI	0.29	0.112			0.112	0.829
Terminal Coast	0.47	0.179			0.179	0.717
Terminal Rendezvous	0.43	0.172			0.172	0.538
Docking	0.11	0.043			0.043	0.366
Coast to LM Jettison	0.97	0.323			0.323	0.323
LM Jettison						0.000

**: Total Ascent and Descent Stage

TABLE G.3-8 CO_2 Removal; LiOH Cartridge Weight Increase and Useable Capacity

PHASE (Descent)	Time	Net Increase In Weight Of Cartridge	Useable LiOH Capacity At Beginning Of Phase	
	Hrs.	Lbs.	Man-Hrs.	
Crew Transfer/LM Act.	2.80	0.289	41.00	
LM Separation	0.38	0.348	36.11	
Trans Orbit Insert./ Coast	0.98	0.502	35.10	
Braking	0.12	0.521	32.49	
Final Approach	0.03	0.526	32.17	
Landing	0.03	0.531	32.08	
Post Landing C/O	1.75	0.814	31.99	
1st Explore	3.00	0.896	27.19	
Internal Activity	9.25	1.933	25.80	
2nd Explore	3.00	-	8.22	
Internal Activity	2.67	2.232	8.22	
3rd Explore	3.00	-	3.16	
Internal Activity	7.25 2.19 5.06	2.419 0.626	3.16 41.00 *	
4th Explore	3.00	0.646	30.39 **	
Pre-Launch Prep. (Descent)	1.50	0.816	30.06	

*: Start second cartridge
**: Remove first cartridge from ascent stage

TABLE G. 3-8 (Continued)

PHASE (Ascent)	Time	Net Increase In Weight Of Cartridge	Useable LiOH Capacity At Beginning Of Phase	
	Hrs.	Lbs.	Man-Hrs.	
Pre-Laucnh Prep. (Ascent)	0.27	0.846	27.18	
Powered Ascent	0.11	0.865	26.66	
Coast to CSI	0.48	0.925	26.35	
Coast to CDH	0.83	1.029	25.33	
Coast to TPI	0.29	1.067	23.55	
Terminal Coast	0.47	1.126	22.92	
Terminal Rendezvous	0.43	1.185	21.92	
Docking	0.11	1.200	20.91	
Coast to LM Jettison	0.98	1.354	20.65	

TABLE G.3-9 CO_2 Removal; LiOH Cartridge Weight Increase and Useable Capacity (Orbital Contingency Mission)

PHASE (Descent)	Time	Net Increase In Weight Of Cartridge	Useable LiOH Capacity At Beginning Of Phase	
	Hrs.	Lbs.	Man-Hrs.	
Crew Transfer/LM Act.	2.80	0.289	41.00	
LM Separation	0.38	0.348	36.11	
Trans. Orbit Inser./ Coast	0.98	0.502	35.10	
Braking	0.12	0.521	32.49	
Final Approach	0.03	0.526	32.17	
Landing	0.03	0.531	32.08	
Post Landing C/O	1.75	0.814	31.99	
1st Explore	3.00	0.896	27.19	
Internal Activity	9.25	1.933	25.80	
2nd Explore	3.00	-	8.22	
Internal Activity	2.67	2.232	8.22	
3rd Explore	3.00	-	3.16	
Internal Activity	7.25 2.19 5.06	2.419 0.626	3.16 41.00 *	
4th Explore	3.00	0.646	30.39 **	
Pre-Launch Prep. (Descent)	1.50	0.816	30.06	

*: Start second cartridge
**: Remove first cartridge from ascent stage

TABLE G.3-9 (Continued)

PHASE (Ascent)	Time	Net Increase In Weight Of Cartridge	Useable LiOH Capacity At Beginning Of Phase	
	Hrs.	Lbs.	Man-Hrs.	
Pre-Launch Prep. (Ascent)	0.27	0.846	27.18	
Powered Ascent	0.11	0.865	26.66	
Coast to CSI	0.47	0.925	26.35	
Coast to CDH	0.83	1.029	25.33	
O.C. Subsystem Shutdown Coast	0.50	1.086	23.55	
O.C. Coast	6.64	1.830	22.60	
O.C. Subsystem Startup Coast	1.00	1.942	9.98	
Continue Coast to TPI	0.29	1.979	8.08	
Terminal Coast	0.47	2.038	7.45	
Terminal Rendezvous	0.43	2.098	6.45	
Docking	0.11	2.113	5.44	
Coast to LM Jettison	0.97	2.266	5.18	

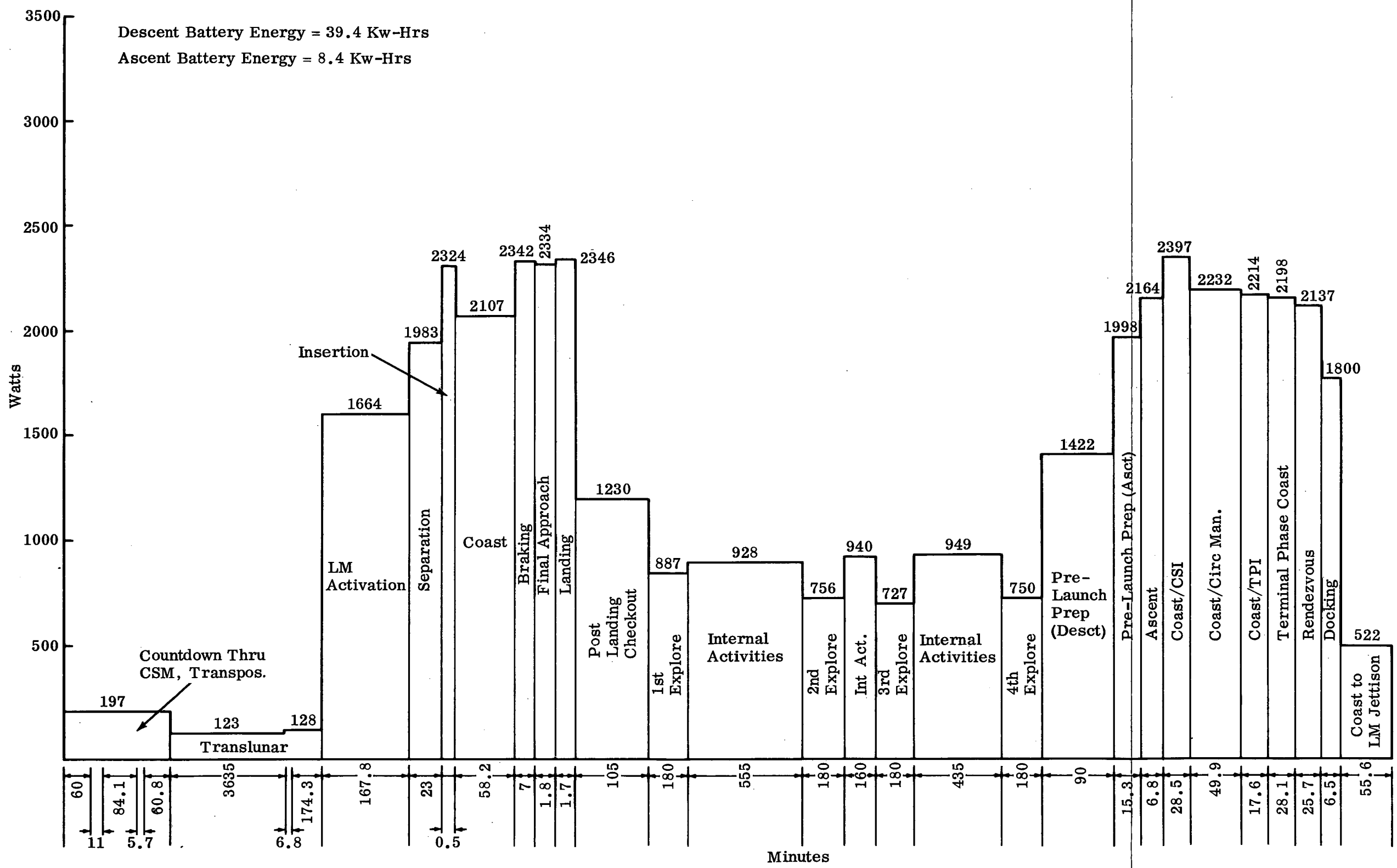

Figure G.3-10 EPS Profile - DRM IIA Mission

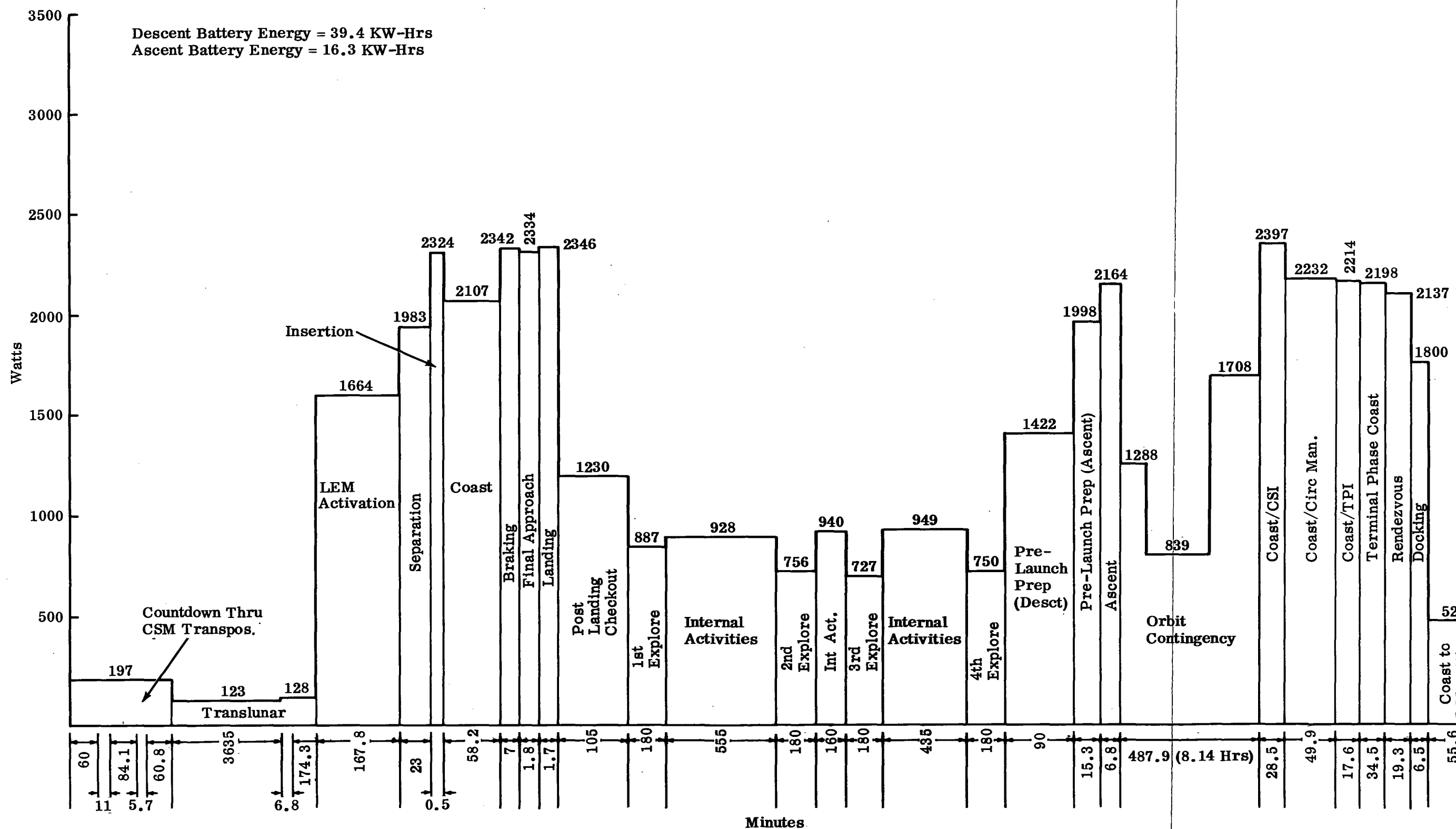

Figure G.3-11 EPS Profile - Orbital Contingency Mission

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APPENDIX H MISSION WEIGHTS

H.1 MODULAR WEIGHTS

The weights breakdown for the launch vehicle and spacecraft is presented in Table H.1. The Saturn launch vehicle weight breakdown is by stage and the spacecraft weight breakdown is by module. The Saturn V weight summary in the table is based on data presented in Volumes I and II of the Reference Trajectory Subpanel Interface Document (Reference H.1). The CSM propellant loading is based on the current CSM delta-V budget of reference H.5. The LM propellant loading, based on the current LM delta-V budget of reference H.4 and, considering an orbital contingency mission, is presented in Table H.2. The booster payload weight of 94,000 pounds used for the DRM IIA is based on current LM and CSM specification data on control weights (References H.2 and H.3). Table H-3 presents a list of items transferred between modules as well as items transferred during lunar explorations.

H.2 WEIGHT HISTORY

The weight history computations provide a mission phase weight breakdown which is presented in Table H-4, for the launch vehicle and CSM, and Table H-5 for the LM. The characteristic velocities given in the DRM IIA trajectory and the consumables estimates given in Appendix G were used. Since the trajectory calculations did not include consumables, the weight computations for the CSM and LM are refinements of the corresponding computations of the trajectory. For lack of current information, consumables estimates for the spacecraft and launch vehicle during the boost phases were not included in the weight computations. However, separate calculations indicate that the effect of such consumables expended during these phases of the mission is negligible.

Because there are differences between the parameters of the weight analysis and the earlier DRM IIA trajectory analysis, it became necessary to establish definite rules and procedures in the weight analysis to arrive at results consistent with the trajectory, vehicle configuration, and nominal performance of the CSM/LM engines.

In most cases the characteristic velocity, engine specific impulse and thrust level were used to compute burn times. During LM powered descent braking and final approach, as well as LM powered ascent vertical rise and rapid pitchover, however, the burn time was kept equivalent to the DRM IIA trajectory, and thrust and engine specific impulse used to define characteristic velocity.

The characteristic velocities of the trajectory are included in Tables H-4 and H-5, together with a detailed breakdown of values allotted for ullage, midcourse corrections and docking. The table also indicates the specific impulse values used in the weight computation for each burn.

TABLE H-1

LAUNCH VEHICLE AND SPACECRAFT WEIGHT SUMMARY

STAGE	DESCRIPTION	SPACE VEHICLE WEIGHT (lbs.)	WEIGHT OF EXPENDED ITEMS OR MODULES (lbs.)
S-IC	Mass at Ignition	6,387,623	
	Mainstage Propellant Used		4,555,010
	Other Mass Expended or Transferred		7,615
	Jettison Mass		374,030
S-II	Mass at Ignition	1,450,968	
	Mainstage Useable Propellant		969,071
	Other Mass Expended or Transferred		935
	S-IC/S-II Interstage		9,770
	Launch Escape System		8,200
	Jettison Mass		99,986
S-IVB	Mass at Ignition	363,006	
	Mainstage Propellant Used		224,915
	Other Mass Expended or Transferred		1,345
	S-IVB Thrust Buildup and Decay Mass		593
	SLA Jettison Mass		3,800
	S-IVB Jettison Mass		42,078
S/C	Mass at Ignition	94,000	
	CSM Inert Weight		21,275
	SLA Jettison Mass		3,725
	SPS Propellant		37,000
	LM		32,000
LM	Translunar Injection Weight	32,000	
	Descent Stage Inert Weight		4,454
	DPS Useable Propellant Weight		17,415
	Ascent Stage Inert Weight		4,853
	APS Useable Propellant Weight		4,730
	RCS Useable Propellant Weight		548

TABLE H-2

LM WEIGHT SUMMARY

DELTA-V BUDGET-ORBITAL CONTINGENCY MISSION

Description	Mission Phase	Weight (lbs)
Translunar Injection Weight	Trans-lunar	32,000
Crew and Equipment Transfer	Lunar Orbit Coast to LM Separation	+535
Electrical & ECS Umbilical Hardware Transfer		-4
Water (Descent) Expended		-16
Oxygen (Descent) Expended		-1
Oxygen (Cabin Pressurization from CSM)		+6
RCS Non- ΔV Propellant Expended		-35
Separation Weight	LM Sep.	32,485
Water (Descent) Expended	LM Separation to touchdown	-9
Oxygen (Descent) Expended		-
RCS Non- ΔV Propellant Expended		-136
RCS ΔV Propellant Expended		-19
DPS Propellant Expended		-17,415
Touchdown Weight	Touchdown	14,906
Equipment Jettisoned (Ascent Stage)	Lunar Stay	-177
Scientific Equipment (Incl. Lunar Samples)		+80
Descent Stage Left on Lunar Surface		-4,244
Water (Descent) Expended		-165
Oxygen (Descent) Expended		-39
Water (Ascent) Expended		-2
Oxygen (Ascent) Expended		-
RCS Non- ΔV Propellant Expended		-4
Equipment Jettisoned (Descent Stage)		-210
Lunar Lift-Off Weight	Liftoff	10,145
Water Expended	Powered Ascent	-1
Oxygen Expended		-
RCS Non- ΔV Propellant Expended		-5
APS Non- ΔV Propellant Expended		-5
APS ΔV Propellant - Expended RCS TCA's		-204
APS ΔV Propellant - Expended Ascent Engine		-4526

TABLE H-2 (Continued)

Description	Mission Phase	Weight (lbs)
APS Burn-Out Weight	Burnout	5404
Water Expended Oxygen Expended RCS Non- ΔV Propellant Expended RCS ΔV Propellant Expended	Powered Ascent Burnout Through Docking	-18 -1 -63 -130
Docking Weight	Docked	5192
Crew and Equipment Transferred Water Oxygen (Incl. Pressurization of CSM Tunnel) RCS Non- ΔV Propellant	Lunar Orbit Coast to LM Jettison	-609 -3 -2 -
LM Jettisoned Weight	LM Jettison	4578

TABLE H-3

LM TRANSFERRED WEIGHTS

	Mission Phase	Weight Transfer (lb) Ascent Stage	Descent Stage
8.2	Crew Trans./LM Act.	(+530.6)	
	Electrical Umbilicals	-3.1	
	Umbilical Hardware	-1.0	
	Crew	352.0	
	Spacesuits (2)	62.9	
	PLSS (Incl. Water (8.6#) & Oxygen (1#))	65.8	
	Dosimeters & Survey Meter	2.9	
	Liquid Cooled Garments (2)	8.6	
	Bio-Instrumentation (2)	2.2	
	Thermal-Meteoroid Garment	10.9	
	Emergency Oxygen System (2)	6.4	
	EV Visors (2)	5.0	
	EV Gloves	1.7	
	Helmet/Visor Storage Containers (2)	1.0	
	EV Crew Transfer Device	6.0	
	Magazine-Sequence Camera	0.6	
	Flight Data Kit	0.9	
	Television Camera	7.0	
	Telephoto Lens	0.8	
11.2	1st Lunar Exploration	(-30.0)	(-220.0)
	Scientific Equipment	-40.0	-180.0
	RTG Fuel Cask		-30.0
	PLSS Batteries (2)	10.0	-10.0
11.8	4th Lunar Exploration	(-67.0)	(+10.0)
	PLSS (Incl. Water (8.6#) & Oxygen (1#))	-65.8	
	EV Boots	-8.0	
	EMU Calibration Unit & Connector	-0.9	
	EMU Maintenance Kit (Incl. EV Gloves)	-3.7	
	Sequence Camera	-1.6	
	Lens	-0.5	
	LiOH Cartridges - PLSS (6)	-26.4	
	LiOH Cartridge - ECS	-7.6	
	PLSS Test Cable	-0.3	
	PLSS Batteries (2)	-10.0	+10.0
	Lunar Surface Lens - TV Camera	-0.5	
	RF Hardline Umbilical Connector	-0.5	
	TV Cable (Incl. Plug)	-0.7	
	Scientific Equip. (Incl. Lunar Samples)	+80.0	
	Urine/PLSS Waste Water Bag	-2.1	
	Urine and PLSS Waste Water	-16.0	
	Change in LiOH Weight Due to CO_2	-2.4	

TABLE H-3 (continued)

Mission Phase		Weight Transfer (lb) Ascent Stage	Descent Stage
13.1	Coast to LM Jettison	(-548.5)	
	Crew	-352.0	
	Spacesuits (2)	-62.9	
	PLSS (Incl. Water (8.6#) & Oxygen (1#))	-65.8	
	Dosimeters and Survey Meter	-2.9	
	Liquid Cooled Garments (2)	-8.6	
	Bio-Instrumentation (2)	-2.2	
	Thermal-Meteoroid Garment	-10.9	
	EV Visors (2)	-5.0	
	EV Gloves	-1.7	
	Helmet/Visor Storage Containers (2)	-1.0	
	Magazines-Sequence Camera	-1.2	
	Flight Data Kit	-0.9	
	Scientific Equip. (Incl. Lunar Samples)	-80.0	
	Television Camera	-7.0	
	Telephoto Lens	-0.8	
	EV Crew Transfer Device	-6.0	
	Used Cleansing Pads	+4.0	
	Spent CO_2 Cartridges	+53.6	
	Empty Food Packages	+2.8	

Table H-4 DRM IIA Mission Weight Timeline - LV and CSM

APOLLO WEIGHT	DRM-II A PERFORMANCE SUMMARY PHASE	GROSS WHT LBS	ELAPSED TIME H	M	S	PHASE TIME H	M	S	ISP SEC	DELTA-V FPS	WEIGHT * CHANGE LBS
2.0	ASCENT TO EARTH ORB	6387623.	-0	-0	0	0	0	0.	-0.	0.	0.
2.1	LIFTOFF, S-IC JTTSN	6387623.	-0	-0	0	0	0	0.	-0.	0.	0.
	THRUST, INBD SHTDN	6387623.	-0	-0	0	0	2	34.6	263.50	10172.1	4462627.4
	THRST, OUTBD SHTDN	1924996.	0	2	35	0	0	4.0	263.50	417.0	92382.4
	CONSUMABLES	1832613.	0	2	39	0	0	0.	-0.	0.	-1.0CSC
	OTHER MASS EXP	1832612.	0	2	39	0	0	0.	-0.	0.	-7614.0SGW
	JETTISON S-IC	1824998.	0	2	39	0	0	1.4	-0.	0.	-374030.0SGW
	S-II ULLAGE	1450968.	0	2	40	0	0	2.4	-0.	0.	0.
2.2	S-II THRST + JTTSN	1450968.	0	2	42	0	0	0.	-0.	0.	0.
	S-II THRUST	1450968.	0	2	42	0	0	2.5	426.00	56.0	6015.3
	MIX RATIO SHIFT	1444953.	0	2	45	0	0	23.7	423.10	619.8	64417.4
	JTTSN INTERSTAGE	1380535.	0	3	9	0	0	0.	-0.	0.	-9770.0SGW
	CONTINUE THRUST	1370765.	0	3	9	0	0	5.0	423.10	135.4	13590.2
	JETTISON LES	1357175.	0	3	14	0	0	0.	-0.	0.	-8200.0SGW
	CONTINUE THRUST	1348975.	0	3	14	0	4	9.2	423.10	9491.4	677336.6
	MIX RATIO SHIFT	671639.	0	7	23	0	1	33.5	427.40	5087.1	207711.7
	CONSUMABLES	463927.	0	8	56	0	0	0.	-0.	0.	-1.1CSC
	OTHER MASS EXP	463926.	0	8	56	0	0	0.	-0.	0.	-933.7SGW
	S-II JETTISON	462992.	0	8	56	0	0	0.	-0.	0.	-99986.0SGW
	S-IVB ULLAGE	363006.	0	8	56	0	0	0.	-0.	0.	0.
2.3	EARTH ORBIT INSERT	363006.	0	8	56	0	0	0.	-0.	0.	0.
	S-IVB THRUST	363006.	0	8	56	0	2	26.5	426.00	2949.0	70477.5
	SIV-B THRUST DECAY	292529.	0	11	23	0	0	0.	-0.	0.	-114.0
3.0	EARTH PARKING ORBIT	292415.	0	11	23	0	0	0.	-0.	0.	0.
	VENT 1LH2, LOX, ULL	292415.	0	11	23	0	0	14.2	59.82	0.56	85.1
	VENT 2LH2, ULL	292330.	0	11	37	0	0	35.8	107.47	0.59	49.9
	VENT 3LH2	292280.	0	12	13	1	17	21.3	43.10	3.41	720.1
	VENT 4LH2, ULL	291560.	1	29	34	0	5	34.0	108.72	5.54	464.7

Table H-4 (Continued)

	CONSUMABLES	291095.	1 35 8	0 0 0.	-0.	0.	-6.1CSC
	SIV-B THRUST BUILDUP	291089.	1 35 8	0 0 0.	-0.	0.	-479.0
4.0	TRANSLUN INJECTION	290610.	1 35 8	0 0 0.	-0.	0.	0.
	S-IVB THRUST	290610.	1 35 8	0 2 48.7	428.20	3815.32	68360.0
	MIX RATIO SHIFT	222249.	1 37 57	0 2 53.6	426.00	6461.35	83540.0
	CONSUMABLES	138709.	1 40 50	0 0 0.	-0.	0.	-0.3CSC
5.	COAST TO S-IVB JETTISON	138709.	1 40 50	0 0 0.	-0.	0.	0.
5.1	COAST TO TRANSPOSITION	138709.	1 40 50	0 21 -0.0	-0.	0.	0.
5.2	TRANSPOSITION/DOCKING	138709.	2 1 50	0 0 0.	-0.	0.	0.
	CSM SEPARTN/TURNAROUND	138709.	2 1 50	0 4 -0.0	-0.	0.	0. CSR
	DOCKING MANEUVERS	138709.	2 5 50	0 5 -0.0	-0.	0.	0. CSR
	HARD DOCKING	138709.	2 10 50	0 30 -0.0	-0.	0.	0.
	S-IVB JETTISON	138709.	2 40 50	0 0 0.	-0.	0.	-42078.0SGW
	SLA JETTISON	96631.	2 40 50	0 0 0.	-0.	0.	-3725.0SGW
	SIV-B RESIDUALS	92906.	2 40 50	0 0 0.	-0.	0.	-99.9SGW
	CONSUMABLES	92806.	2 40 50	0 0 0.	-0.	0.	-119.9CSC
	CSM/LEM PULLOUT	92680.	2 40 50	0 0 50.0	273.00	6.95	-0. CSR
6.	COAST TO LNR/ORB INSERTN	92680.	2 41 40	0 0 0.	-0.	0.	0.
6.1	COAST TO 1ST MIDCOURSE	92680.	2 41 40	0 0 0.	-0.	0.	0.
	CONSUMABLES	92680.	2 41 40	2 2 16.0	-0.	0.	-9.6CSC
6.2	FIRST MCC (TRANSLUNAR)	92676.	4 43 56	0 0 0.	-0.	0.	0.
	SPS START/STOP	92676.	4 43 56	0 0 0.	-0.	0.	-14.4SPS
	SPS ENGINE THRUST	92662.	4 43 56	0 0 9.1	314.90	63.40	-578.0SPS
	CONSUMABLES	92084.	4 44 6	0 0 0.	-0.	0.	-0.7CSC
6.3	COAST TO SECOND MCC	92083.	4 44 6	46 56 46.0	-0.	0.	0.
	CONSUMABLES	92083.	51 40 51	0 0 0.	-0.	0.	-72.4CSC
6.4	SECOND MCC (TRANSLUNAR)	92011.	51 40 51	0 0 0.	-0.	0.	0.
	SPS START/STOP	92011.	51 40 51	0 0 0.	-0.	0.	-14.4SPS
	SPS ENGINE THRUST	91996.	51 40 51	0 0 9.0	314.90	63.40	-573.9SPS
	CONSUMABLES	91422.	51 41 1	0 0 0.	-0.	0.	-0.7CSC
6.5	COAST TO THIRD MCC	91422.	51 41 1	10 35 56.0	-0.	0.	0.
	CONSUMABLES	91422.	62 16 57	0 0 0.	-0.	0.	-35.9CSC
6.6	THIRD MCC (TRANSLUNAR)	91386.	62 16 57	0 0 0.	-0.	0.	0.

Table H-4 (Continued)

	SPS START/STOP	91066.	62 16 57	0 0 0.	-0.	0.	-14.4SPS
	SPS ENGINE THRUST	91071.	62 16 57	0 0 4.8	314.90	34.20	-307.9SPS
	CONSUMABLES	91063.	62 17 1	0 0 0.	-0.	0.	-0.7CSC
6.7	COAST TO LNR/ORB INSERT	91063.	62 17 1	0 59 37.6	-0.	0.	0.
	CONSUMABLES	91063.	63 16 39	0 0 0.	-0.	0.	-5.4CSC
7.	LUNAR ORBIT INSERTION	91057.	63 16 39	0 0 0.	-0.	0.	0.
	SPS START/STOP	91057.	63 16 39	0 0 0.	-0.	0.	-14.4SPS
	SPS ENGINE THRUST	91043.	63 16 39	0 6 59.0	314.90	3503.16	-26613.8SPS
	CONSUMABLES	64429.	63 23 38	0 0 0.	-0.	0.	-2.9CSC
8.	LNR/ORB COAST TO LEM SEP	64426.	63 23 38	0 0 0.	-0.	0.	0.
8.1	LUNAR ORBIT COAST	64426.	63 23 38	2 54 16.0	-0.	0.	0.
8.2	CREW TRANSFER/LEM ACTIV	64426.	66 17 54	2 47 38.0	-0.	0.	0.
	CONSUMABLES	64426.	69 5 32	0 0 0.	-0.	0.	-28.6CSC
	LEM SEPARATION	64396.	69 5 32	0 0 0.	-0.	0.	-32486.0SGW
9.	CSM SOLO LUNAR ORBIT	31912.	69 5 32	0 0 0.	-0.	0.	0.
	CONSUMABLES	31912.	69 5 32	38 56 42.0	-0.	0.	-137.2CSC
13.	LNR/ORB COAST TO TEI	31774.	108 2 14	0 0 0.	-0.	0.	0.
13.1	COAST TO LEM JETTISON	31774.	108 2 14	0 0 0.	-0.	0.	0.
	LEM DOCK TO CSM	31774.	108 2 14	0 0 0.	-0.	0.	5277.0SGW
	CREW TRANS/LEM DEACT	37051.	108 2 14	0 57 28.0	-0.	0.	0.
	CONSUMABLES	37051.	108 59 42	0 0 0.	-0.	0.	-2.3CSC
	PREP FOR LEM JETTISON	37049.	108 59 42	0 1 3.0	-0.	0.	-4724.4SGW
	CONSUMABLES	32325.	109 00 45	0 0 0.	-0.	0.	-4.3CSC
13.2	LEM JETTISON TO TEI	32321.	109 00 45	0 0 0.	-0.	0.	0.
	SM RCS SEP THRUST	32321	109 00 45	0 0 17.0	273.0	2.78	-10.3CSR
	CONSUMABLES	32311.	109 00 52	3 0 17.0	-0.	0.	-28.2CSC
	SPS ULLAGE MANEUVER	32283.	112 12 02	0 0 14.0	273.00	5.57	-21.2CSR
14.	TRANSEARTH INJECTION	32262.	112 12 16	0 0 0.	-0.	0.	0.
	SPS START/STOP	32262.	112 12 16	0 0 0.	-0.	0.	-14.4SPS
	SPS ENGINE THRUST	32248.	112 12 16	0 1 54.1	314.90	2741.93	-7663.1SPS
	CONSUMABLES	24585.	112 14 10	0 0 0.	-0.	0.	-0.2CSC
15.	TRANSEARTH COAST	24585.	112 14 10	0 0 0.	-0.	0.	0.

Table H-4 (Continued)

15.1	COAST TO FOURTH MCC	24585.	112 14 10	0 0 0.	-0.	0.	0.
	CONSUMABLES	24585.	112 14 10	9 57 19.0	-0.	0.	-43.7CSC
	SPS ULLAGE MANEUVER	24541.	122 11 29	0 0 15.0	273.00	7.85	21.2CSR
15.2	FOURTH MCC (TRANSEARTH)	24520.	122 11 44	0 0 0.	-0.	0.	0.
	SPS START/STOP	24520.	122 11 44	0 0 0.	-0.	0.	-14.4SPS
	SPS ENGINE THRUST	24506.	122 11 44	0 0 1.1	314.90	27.90	-67.6SPS
	CONSUMABLES	24438.	122 11 45	0 0 0.	-0.	0.	-0.5CSC
15.3	COAST TO FIFTH MCC	24437.	122 11 45	0 0 0.	-0.	0.	0.
	CONSUMABLES	24437.	122 11 45	29 59 43.7	-0.	0.	-86.1CSC
	SPS ULLAGE MANEUVER	24351.	152 11 29	0 0 15.0	273.00	7.91	-21.2CSR
15.4	FIFTH MCC (TRANSEARTH)	24330.	152 11 44	0 0 0.	-0.	0.	0.
	SPS START/STOP	24330.	152 11 44	0 0 0.	-0.	0.	-14.4SPS
	SPS ENGINE THRUST	24316.	152 11 44	0 0 1.1	314.90	27.90	-67.1SPS
	CONSUMABLES	24249.	152 11 45	0 0 0.	-0.	0.	-0.5CSC
15.5	COAST TO SIXTH MCC	24246.	152 11 45	0 0 0.	-0.	0.	0.
	CONSUMABLES	24246.	152 11 45	47 11 25.7	-0.	0.	-122.4CSC
	SPS ULLAGE MANEUVER	24126.	199 23 11	0 0 15.0	273.00	7.98	-21.2CSR
15.6	SIXTH MCC (TRANSEARTH)	24105.	199 23 26	0 0 0.	-0.	0.	0.
	SPS START/STOP	24105.	199 23 26	0 0 0.	-0.	0.	-14.4SPS
	SPS ENGINE THRUST	24091.	199 23 26	0 0 1.4	314.90	36.80	-87.6SPS
	CONSUMABLES	24003.	199 23 27	0 0 0.	-0.	0.	-0.5CSC
15.7	COAST TO ENTRY	24002.	199 23 27	0 0 0.	-0.	0.	0.
	COAST TO SM JETTISON	24002.	199 23 27	0 52 58.6	-0.	0.	0.
	SM JETTISON	24002.	200 16 26	0 0 0.	-0.	0.	-12118.0SGW
	SM JETTISON TO ENTRY	11884.	200 16 26	0 7 -0.0	-0.	0.	0.
	CONSUMABLES	11884.	200 23 26	0 0 0.	-0.	0.	-22.4CSC
16.	ENTRY	11862.	200 23 26	0 0 0.	-0.	0.	0.
	CONSUMABLES	11862.	200 23 26	0 11 33.0	-0.	0.	-0.1CSC
17.	PARACHUTE DESCENT/TOUCHDN	11862.	200 34 59	0 0 0.	-0.	0.	0.
	CONSUMABLES	11862.	200 34 59	0 6 17.0	-0.	0.	-0.1CSC
18.	RETRIEVAL	11862.	200 41 16	0 0 0.	-0.	0.	0.

*Code: SPS = SPS Propellant, CSR = SM - RCS Propellant
CSC = CSC Consumables, SGW = Staged Weight

Table H-5 DRM IIA Mission Weight Timeline - LV and CSM

DRM-IIAWEIGHT PERFORMANCE SUMMARY-
LEM AUG 66

	PHASE	GROSS WHT	ELAPSED TIME	PHASE TIME	ISP	DELTA-V	WEIGHT* CHANGE
		LBS	H M S	H M S	SEC	FPS	LBS
8.	LU/ORB COAST TO SEP	32000.	63 23 27	0 0 0.	-0.	0.	0.
8.1	LUNAR ORBIT COAST	32000.	63 23 27	2 54 16.0	-0.	0.	0.
8.2	CREW TRANS/LEM ACT	32000.	66 17 43	2 47 49.0	-0.	0.	0.
	CONSUMABLES	32000.	69 5 32	0 0 0.	-0.	0.	-50.6LC
	CREW TRANSFER	31949.	69 5 32	0 0 0.	-0.	0.	536.4SGW
10.	LEM DESCENT	32486.	69 5 32	0 0 0.	0.	0.	0.
10.1	LEM SEPARATION	32486.	69 5 32	0 0 0.	0.	0.	0.
	SEPARATION THRUST	32486.	69 5 32	0 0 2.5	273.00	0.50	-1.8RCS
	SEPARATION COAST	32484.	69 5 34	0 22 50.8	0.	0.	0.
	CONSUMABLES	32484.	69 28 25	0 0 0.	-0.	0.	-32.1LC
	RCS ULLAGE THRUST	32452.	69 28 25	0 0 5.5	273.00	2.18	-8.1RCS
10.2	TRANS/ORB INSERTN	32444.	69 28 31	0 0 0.	-0.	0.	0.
	DPS ENGINE IGNITION	32444.	69 28 31	0 0 0.	-0.	0.	0.
	DPS 30PER THRUST	32444.	69 28 31	0 0 3.0	295.20	9.38	-32.0DPS
	DPS 10PER THRUST	32412.	69 28 34	0 0 23.0	288.60	24.00	-83.7DPS
	TOI HIGH THRUST	32328.	69 28 57	0 0 6.1	303.60	62.23	-205.3DPS
	CONSUMABLES	32123.	69 29 3	0 0 0.	0.	0.	-1.7LC
10.3	COAST TO POWERED DES	32121.	69 29 3	0 0 0.	0.	0.	0.
	DESCENT COAST	32121.	69 29 3	0 58 8.2	-0.	0.	0.
	CONSUMABLES	32121.	70 27 11	0 0 0.	0.	0.	-22.0LC
	RCS ULLAGE THRUST	32099.	70 27 11	0 0 5.5	273.00	2.21	-8.1RCS
10.4	BRAKING	32091.	70 27 17	0 0 0.	0.	0.	0.
	DPS ENGINE IGNITION	32091.	70 27 17	0 0 0.	-0.	0.	0.
	DPS 30PER THRUST	32091.	70 27 17	0 0 3.0	295.20	9.48	-32.0DPS
	DPS 10PER THRUST	32059.	70 27 20	0 0 23.0	288.60	24.27	-83.7DPS
	BRAKING HI THRUST	31975.	70 27 43	0 6 34.0	298.90	5077.14	-13115.8DPS
	CONSUMABLES	18860.	70 34 17	0 0 0.	0.	0.	-25.7LC
10.5	FINAL APPROACH	18834.	70 34 17	0 0 0.	-0.	0.	0.

Table H-5 (Continued)

	CONTINUE THRUST	18834.	70 34 17	0 1 45.0	286.30	995.99	-1930.2DPS
	CONSUMABLES	16904.	70 36 2	0 0 0.	-0.	0.	-8.0LC
10.6	LANDING	16896.	70 36 2	0 0 0.	-0.	0.	0.
	INITIATE LANDING	16896.	70 36 2	0 0 55.0	292.90	268.24	-474.1DPS
	BRAKING TO PRETD	16422.	70 36 57	0 0 20.0	288.20	170.05	-298.4DPS
	VERTICAL DESCENT	16123.	70 37 17	0 0 28.0	292.90	142.15	-241.4DPS
	CONSUMABLES	15882.	70 37 45	0 0 0.	-0.	0.	-55.3LC
11.	LEM LUNAR STAY	15826.	70 37 45	0 0 0.	-0.	0.	0.
11.1	POST LANDING CHECKS	15826.	70 37 45	0 0 0.	-0.	0.	0.
	C/O, SHUTDN SUBSYS	15826.	70 37 45	0 20 -0.0	-0.	0.	0.
	PREP 1ST EXPLOR	15826.	70 57 45	1 25 -0.0	-0.	0.	0.
	CONSUMABLES	15826.	72 22 45	0 0 0.	-0.	0.	-16.0LC
11.2	1ST LUN EXPLORATION	15810.	72 22 45	0 0 0.	-0.	0.	0.
	STAGING AREA ACTIV	15810.	72 22 45	3 0 0.	-0.	0.	0.
	CONSUMABLES	15810.	75 22 45	0 0 0.	-0.	0.	-24.1LC
	WEIGHT XFR-LUN SURF	15786.	75 22 45	0 0 0.	-0.	0.	-250.0SGW
11.3	LEM INTERNAL ACTIV	15536.	75 22 45	0 0 0.	-0.	0.	0.
	PREP REST/CHG PLSS	15536.	75 22 45	0 45 -0.0	-0.	0.	0.
	REST/OFF DUTY ACT	15536.	76 7 45	7 45 -0.0	-0.	0.	0.
	PREP 2ND EXPLOR	15536.	83 52 45	0 45 -0.0	-0.	0.	0.
	CONSUMABLES	15536.	84 37 45	0 0 0.	-0.	0.	-40.4LC
11.4	2ND LUN EXPLORATION	15496.	84 37 45	0 0 0.	-0.	0.	0.
	1ST/2ND EXCURSIONS	15496.	84 37 45	3 0 0.	-0.	0.	0.
	CONSUMABLES	15496.	87 37 45	0 0 0.	-0.	0.	-22.3LC
11.5	LEM INTERNAL ACTIV	15474.	87 37 45	0 0 0.	-0.	0.	0.
	PREP REST/CHG PLSS	15474.	87 37 45	0 45 -0.0	-0.	0.	0.
	RELAXATION	15474.	88 22 45	1 10 -0.0	-0.	0.	0.
	PREP 3RD EXPLOR	15474.	89 32 45	0 45 -0.0	-0.	0.	0.
	CONSUMABLES	15474.	90 17 45	0 0 0.	-0.	0.	-15.9LC
11.6	3RD LUN EXPLORATION	15458.	90 17 45	0 0 0.	-0.	0.	0.
	3RD/4TH EXCURSIONS	15458.	90 17 45	3 0 0.	-0.	0.	0.
	CONSUMABLES	15458.	93 17 45	0 0 0.	-0.	0.	-21.9LC
11.7	LEM INTERNAL ACTIV	15436.	93 17 45	0 0 0.	-0.	0.	0.

Table H-5 (Continued)

	PREP REST/CHG PLSS	15436.	93 17 45	0 45 -0.0	-0.	0.	0.
	REST/OFF DUTY ACT	15436.	94 2 45	5 45 -0.0	-0.	0.	0.
	PREP 4TH EXPLOR	15436.	99 47 45	0 45 -0.0	-0.	0.	0.
	CONSUMABLES	15436.	100 32 45	0 0 0.	-0.	0.	-33.1LC
11.8	4TH LUN EXPLORATION	15403.	100 32 45	0 0 0.	-0.	0.	0.
	5TH/6TH EXCURSIONS	15403.	100 32 45	3 0 0.	-0.	0.	0.
	CONSUMABLES	15403.	103 32 45	0 0 0.	-0.	0.	-22.5LC
	WEIGHT XFR-LUN SURF	15380.	103 32 45	0 0 0.	-0.	0.	-517.0SGW
11.9	PRELAUNCH PREP	15323.	103 32 45	0 0 0.	-0.	0.	0.
	PREP FLT/CHG PLSS	15323.	103 32 45	0 40 -0.0	-0.	0.	0.
	PRELAUNCH ACT, C/O	15323.	104 12 45	1 6 19.1	-0.	0.	0.
	CONSUMABLES	15323.	105 19 4	0 0 0.	-0.	0.	-13.0LC
	STAGED WEIGHT	15310.	105 19 4	0 0 0.	-0.	0.	-5165.0SGW
12.	LEM ASCENT	10145.	105 19 4	0 0 0.	-0.	0.	0.
12.1	POWERED ASCENT	10145.	105 19 4	0 0 0.	-0.	0.	0.
	APS ENGINE IGNITION	10145.	105 19 4	0 0 0.	-0.	0.	0.
	VERTICAL RISE	10145.	105 19 4	0 0 12.0	304.30	139.34	-143.4APS
	RAPID PITCHOVER	10002.	105 19 16	0 0 6.0	304.30	70.42	-71.7APS
	GRAD PITCHOVER	9930.	105 19 22	0 6 11.9	304.30	5807.35	-4443.1APS
	CONSUMABLES	5487.	105 25 34	0 0 0.	-0.	0.	-5.7LC
12.2	COAST TO CSI	5482.	105 25 34	0 27 55.0	-0.	0.	0.
	CONSUMABLES	5482.	105 53 29	0 0 0.	-0.	0.	-5.8LC
12.3	CSI MANEUVER	5476.	105 53 29	0 0 0.	-0.	0.	0.
	CSI THRUST	5476.	105 53 29	0 0 50.8	273.00	59.90	-37.2RCS
	CONSUMABLES	5439.	105 54 19	0 0 0.	-0.	0.	-2.9LC
12.4	COAST TO CDH	5436.	105 54 19	0 0 0.	-0.	0.	0.
	ASCENT COAST	5436.	105 54 19	0 49 2.0	-0.	0.	0.
	CONSUMABLES	5436.	106 43 21	0 0 0.	-0.	0.	-10.9LC
12.5	CDH MANEUVER	5425.	106 43 21	0 0 0.	-0.	0.	0.
	CDH MANEUVER	5425.	106 43 21	0 0 55.0	273.00	65.54	-40.3RCS
	CONSUMABLES	5385.	106 44 16	0 0 0.	-0.	0.	-3.1LC
12.6	COAST TO TPI	5381.	106 44 16	0 0 0.	-0.	0.	0.
	CIRCULAR ORB COAST	5381.	106 44 16	0 17 15.0	-0.	0.	0.

Table H-5 (Continued)

	CONSUMABLES	5381.	107 1 31	0 0 0.	-0.	0.	-3.3LC
12.7	TERMINAL PHASE INITIATN	5378.	107 1 31	0 0 0.	-0.	0.	0.
	TPI THRUST	5378.	107 1 31	0 0 22.9	273.00	27.43	-16.8RCS
	CONSUMABLES	5361.	107 1 54	0 0 0.	-0.	0.	-1.3LC
12.8	TERMINAL PHASE COAST	5360.	107 1 54	0 0 0.	-0.	0.	0.
	COAST TO 1ST MC	5360.	107 1 54	0 9 22.0	-0.	0.	0.
	FIRST MIDCOURSE	5360.	107 11 16	0 0 24.9	273.00	30.00	-18.3RCS
	COAST TO 2ND MC	5342.	107 11 41	0 8 58.0	-0.	0.	0.
	SECOND MIDCOURSE	5342.	107 20 39	0 0 4.1	273.00	5.00	-3.0RCS
	COAST TO TERM REND	5339.	107 20 43	0 9 19.0	-0.	0.	0.
	CONSUMABLES	5339.	107 30 2	0 0 0.	-0.	0.	-12.3LC
12.9	TERMINAL RENDEZVOUS	5326.	107 30 2	0 0 0.	-0.	0.	0.
	COAST TO 2ND GATE	5326.	107 30 2	0 6 22.0	-0.	0.	0.
	SECOND REND GATE	5326.	107 36 24	0 0 3.7	273.00	4.42	-2.7RCS
	COAST TO 3RD GATE	5324.	107 36 28	0 9 53.0	-0.	0.	0.
	THIRD REND GATE	5324.	107 46 21	0 0 8.0	273.00	9.62	-5.8RCS
	COAST TO 4TH GATE	5318.	107 46 29	0 9 11.0	-0.	0.	0.
	FOURTH REND GATE	5318.	107 55 40	0 0 4.4	273.00	5.36	-3.2RCS
	CONSUMABLES	5315.	107 55 44	0 0 0.	-0.	0.	-8.2LC
12.10	DOCKING	5306.	107 55 44	0 0 0.	-0.	0.	0.
	DOCKING MANEUVER	5306.	107 55 44	0 6 30.0	273.00	25.00	-15.1RCS
	CONSUMABLES	5291.	108 2 14	0 0 0.	-0.	0.	-14.8LC
13.	LUN ORB COAST TO TEI	5277.	108 2 14	0 0 0.	-0.	0.	0.
	STAGED WEIGHT	5277.	108 2 14	0 0 0.	-0.	0.	0. SGW
13.1	COAST TO LEM JETTISON	5277.	108 2 14	0 0 0.	-0.	0.	0.
	CREW XFR/LEM DEACT	5277.	108 2 14	0 49 39.0	-0.	0.	0.
	STAGED WEIGHT	5277.	108 51 53	0 0 0.	-0.	0.	-548.5SGW
	PREP FOR LEM JETTISON	4728.	108 51 53	0 8 52.0	-0.	0.	0.
	CONSUMABLES	4728.	108 0 45	0 0 0.	-0.	0.	-3.7LC
13.2	LEM JETTISON TO TEI	4724.	109 0 45	0 0 0.	-0.	0.	-4724.4

*Code: DPS = LM DPS Propellant, APS = LM APS Propellant
RCS = LM RCS Propellant, LC = LM Consumables
SGW = Staged Weight

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