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PRELIMINARY
SKELETAL OPERATIONS PLAN
FOR APOLLO

A Systems Engineering Support Document

January 31, 1964

Bellcomm, Inc.
Washington, D. C.

Prepared by
Operations Planning Group
with assistance from
Bell Telephone Laboratories,
Incorporated

PRELIMINARY SKELETAL OPERATIONS PLAN FOR APOLLO

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1. INTRODUCTION

1.1 Purpose and Scope

The Preliminary Skeletal Operations Plan is a statement of the operational concept for Apollo. This draft contains a description of the conduct of the Apollo LOR landing mission and a mission profile. It provides the basis for more detailed mission planning, for generating functional criteria for equipment design, and for measuring the adequacy of the current Apollo hardware for satisfying operational needs.

It is recognized that the operations described in this preliminary document may differ from concepts now in use in parts of the Apollo program, and may not be completely compatible with the current equipment design. In order to identify any such differences and their significance, this document will be reviewed with the major NASA organizations in the first few months after its issuance. After this review, a new draft will be prepared and studies instituted to resolve the major problem areas that are developed during the review.

The operations described in this document are based on the Apollo System Specification (M-DM 8000.001). Ideas that are developed during the above review will be measured against the Apollo System Specification, and in accordance with the dynamic nature of this Specification, the ideas will be reflected in changes to the Specification that are found to be feasible and worthwhile.

System characteristics or quantities which are significant to operational planning, but are tentative or unknown at this time, are enclosed in brackets /¯ _/.

1.2 Command and Control Guide Lines

Mission operations as outlined will conform at all times to the following basic guide lines for command and control. Specific rules and constraints governing trajectories, timing, and performance requirements are included, where appropriate, in later sections of this document.

1.2.1 Command

Authority and responsibility for setting or altering mission objectives and for making major commitment decisions rests with the Operations Director throughout the mission. For reasons of efficiency, timeliness of action, or discontinuity of communications, limited command authority may be predelegated to other personnel. Such delegations and the corresponding assignments of responsibility to subordinates are defined in Section 2.

The criterion for continuing the nominal mission profile shall be that critical systems are functioning within acceptable limits. The criterion for modifying the nominal mission profile shall be that the out-of-tolerance performance of one or more system functions prevents the execution of the nominal mission profile but does not require the expeditious return of the space vehicle to earth. The criterion for abort shall be that the out-of-tolerance performance of one or more system functions requires the expeditious return of the space vehicle to earth.

Major commitment events will not be initiated without prior concurrence of the Operations Director.

The Flight Crew Commander has delegated authority to abbreviate the mission for reasons of crew safety in emergencies if the system response time or communication limitations preclude the obtaining of prior authorization. The Flight Crew shall not accept, for purposes of mission success, risks greater than those inherent in the nominal mission profile without direct approval of the Operations Director or the Flight Director.

1.2.2 Control

Evaluation of system performance through monitoring and scheduled checkout, and determination of guidance parameters and operations schedules are joint responsibilities of the spacecraft crew and ground operations personnel. Selection of modes and configurations, and adjustment of operating controls are the responsibility of the local operators.

Control systems will be designed to reduce the nominal work-load of the crew when this reduction increases crew efficiency, effectiveness or overall probability of mission success.

All foreseeable control actions will be translated into standard operating procedures that have been validated by previous missions or by simulation and training exercises in preparation for the mission. Such procedures will be included in the mission control documents - i.e., handbooks, countdown specifications, checkoff lists, mission plans and rules and computer control data retrieval system reference files.

1.3 Mission Phases and Commitment Decisions

The mission profile as defined in paragraph 3.2 of the Apollo System Specification involves human decisions and control actions which are described in this document. The gross mission phases used in this document are defined in Figure 1. The related decisions which require formal concurrence or coordination before proceeding with nominal commitment action and significant mission events are related to these phases. The essential decision capabilities and responsibilities and control action requirements, including those related to initiation of contingency options, are defined in subsequent sections.

1.4 Contingency Options

The mission options available for operational contingencies which cannot be resolved simply by minor adjustment of equipment or selection of a back-up mode, are referenced to significant mission events in Figure 2. The choice of a particular option will be based on first assuring the safe return of the flight crew to earth,and second effectively utilizing the remaining flight capabilities to achieve mission objectives. On this basis, mission contingency options are ranked in order of preference below:

(1) Deferred Decision - alteration in the event sequence or scheduling to complete the nominal mission.

(2) Modified Nominal Mission - accomplishing the mission's objectives by deviations that involve acceptable additional risk or increased operational difficulty.

(3) Curtailed Lunar Mission

- (a) Shortening
- (b) Omitting

the lunar surface operations phase

  1. The lunar landing
  2. The LEM descent
  3. Separate LEM operations, or
  4. Lunar orbit insertion (circumlunar flight only)

(4) Cis-Lunar Mission -- with Apollo-type reentry

(5) Near-Earth, long-duration Mission -- with deboost reentry (available through /‾75%_7 of the trans-lunar injection burn)

(6) Mission Termination and Aborts -- restricting further flight activities to those operations necessary to effect a successful return to earth:

- (a) Termination actions timed to effect a landing in a preferred recovery area;
- (b) Termination actions timed to effect a landing in a contingency landing area; and
- (c) Emergency return to effect a landing using a minimum time of flight trajectory.

(7) Disaster Prevention Alternative -- using space vehicle capabilities in special emergency modes and configurations not considered as normal back-up for Apollo operations. This is a zero set at the beginning of the mission because any alternative found prior to the mission will be included in the above options.

1.5 Command Organization

The basic command organization used in writing this document is given in Figures 3,4, and 5. The decisions that are made by specific elements are given in Section 2. The functions and responsibilities assigned to subordinate elements will be covered in Section 3, which will be supplied later.

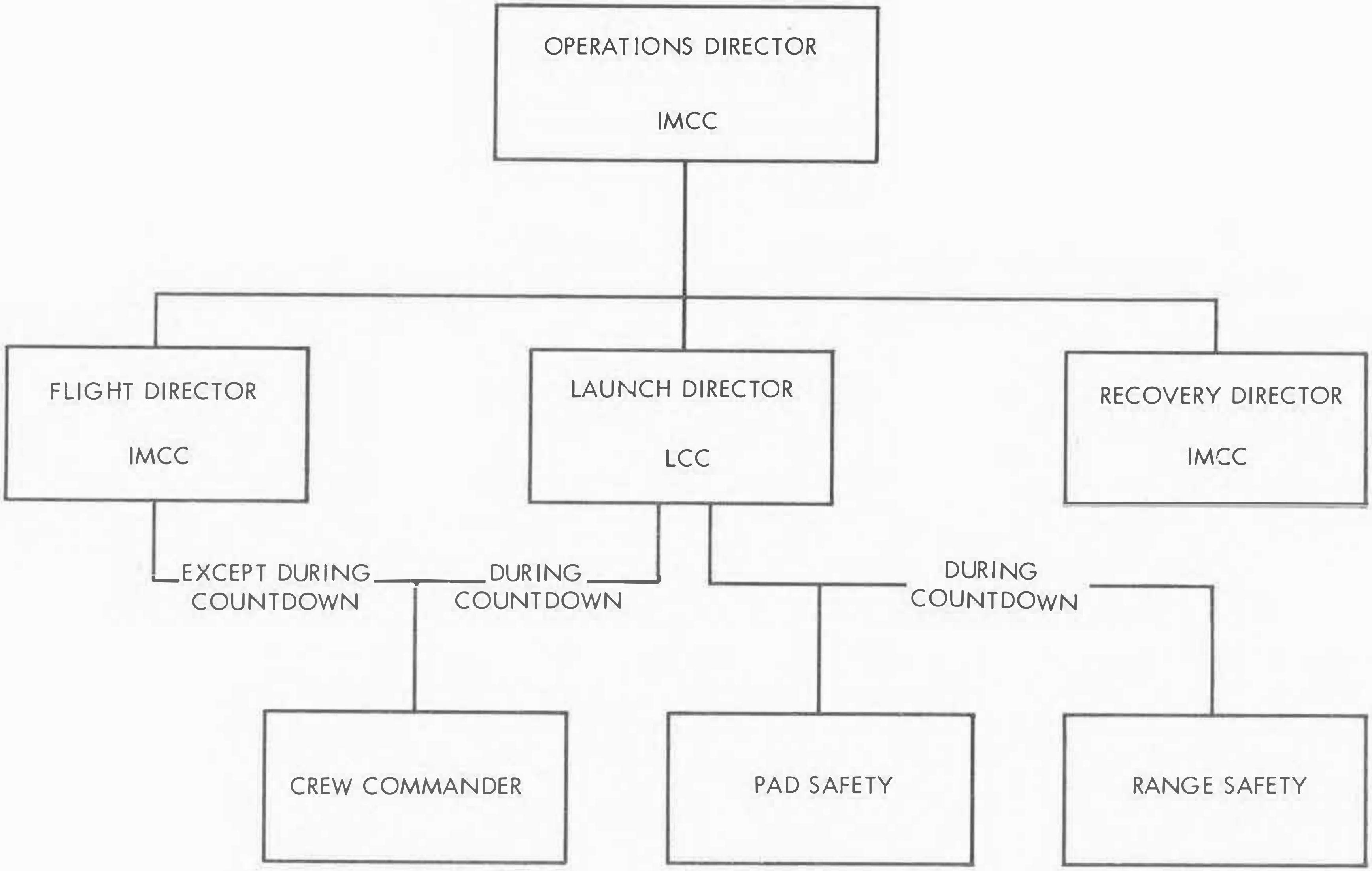


FIGURE 3 PREFLIGHT COMMAND ORGANIZATION

(BEGINNING IN THE PREMISSION AND ENDS WITH INITIATION OF THE S/C FIRING SEQUENCE)

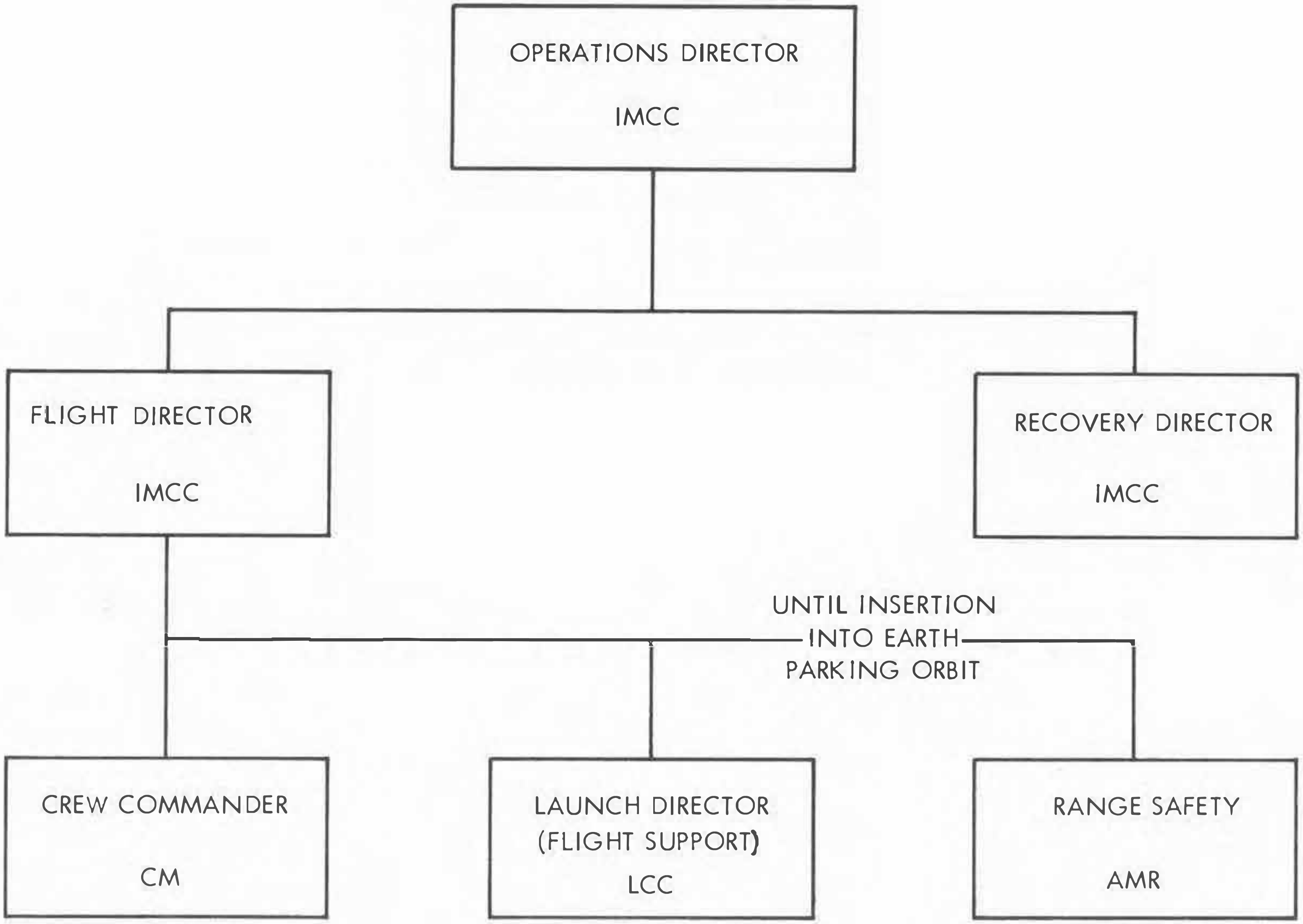


FIGURE 4 NEAR EARTH COMMAND ORGANIZATION

(FROM BEGINNING INITIATION OF S/C FIRING SEQUENCE THROUGH SIVB STAGE OFF)

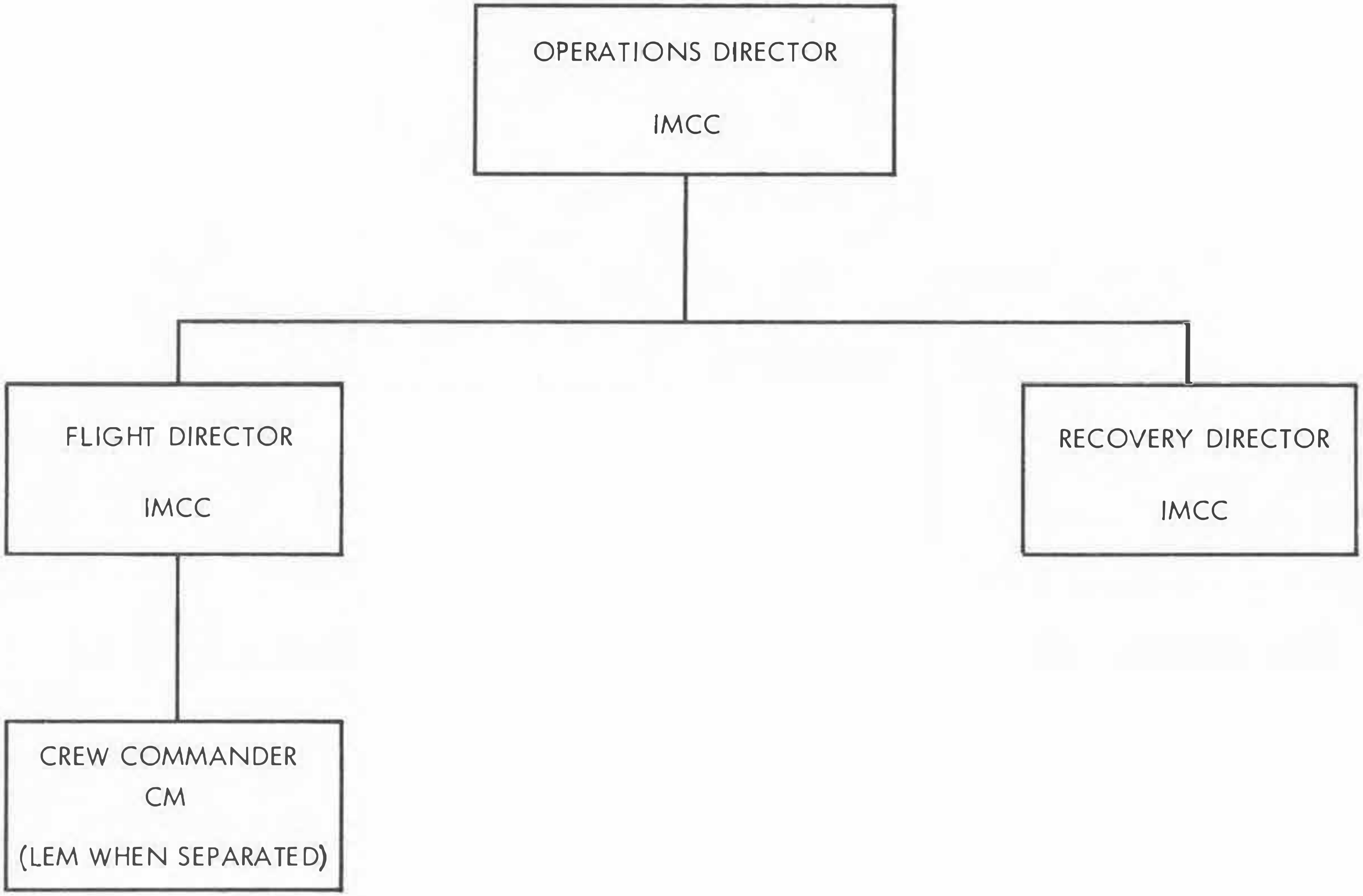


FIGURE 5 DEEP SPACE COMMAND ORGANIZATION

(FROM SIVB STAGE OFF THROUGH CM TOUCHDOWN ON THE EARTH)

2. OPERATIONAL DESCRIPTION OF MISSION

Section 2 of the Skeletal Operations Plan contains an operational description of the Apollo Lunar Landing Mission. It is divided into 18 mission phases. The discussion of most phases is divided into three subsections. The first subsection defines the phase and its time duration. The second subsection describes the nominal mission, including a skeletal outline of the operations that occur and the related decisions and information required. The third subsection discusses alternate mission options and decision responsibilities for deviating from the nominal mission and selecting an alternate mission option.

2.1 PRE-FLIGHT

2.1.1 Phase Definition

The pre-flight phase begins with the Operations Director's decision to move the assembled space vehicle from the VAB high bay to the launch pad and ends when the space vehicle lifts off the launch pad. The phase duration is [15] days. The total interval is divided into two subphases: 1) the pad and network preparation subphase and 2) the terminal countdown subphase. The pad and network preparation subphase, [14] days, includes preparations by all mission elements to achieve operational readiness. The terminal countdown subphase, [24] hours, is a tightly controlled sequence which includes the most critical operations, such as arming and fueling, that require significantly greater recycle time if the mission is postponed.

2.1.2 Nominal Mission

The launch date is established at least [30] days in advance.

It is the first of three contiguous days that have at least [one] launch window, [2 1/2] hours or longer in duration.

Activities completed prior to the pre-flight phase include:

(1) Acceptance, mating, testing, and final system tests of the space vehicle in the VAB by the LCC,

(2) Initial deployment of remote recovery forces and tracking ships,

(3) A thorough analysis of the mission to determine the proper course of action under all foreseeable circumstances,

(4) Writing a detailed set of rules for the conduct of the mission,

(5) Equipping, staffing, and training of mission elements for conduct of the mission.

After the Operations Director has confirmed readiness of all mission elements [by simulation exercises], he authorizes movement of the space vehicle to the launch pad.

All activities during the pre-flight phase are paced by the preparation and systematic checkouts of the space vehicle. The activities of all other mission elements are adjusted to avoid disrupting the space vehicle count. The IMCC at Houston, Texas, and the LCC at Cape Kennedy, Florida, continuously monitor progress and coordinate their operations during this period.

The Launch Director at the LCC exercises control over all space vehicle readying operations. He maintains the mission count, and makes any authorized adjustments for minor holds. During the terminal countdown, he controls AMR and pad safety. He assumes control of the flight crew during the last [24] hours of the terminal countdown.

The Flight Director at the IMCC controls the remote stations (including the MSFN and the down-range AMR stations) and sequences their activities to correspond to progress at the

LCC. The IMCC monitors launch vehicle and spacecraft systems tests performed at Launch Complex #39. Specific test and countdown data sent to the IMCC are controlled by the Flight Director, who is in continuous voice contact with the LCC. Support personnel at the IMCC receive detailed performance data in their areas of interest in addition to summary and status information.

The Flight Director conducts periodic simulation exercises during this period to insure that the operational capability of the system is adequate for conduct of the mission. The simulations are scheduled by the Flight Director in consultation with the Launch and Recovery Directors.

The Recovery Director at the IMCC is responsible for the deployment of recovery forces. He adjusts their position in accordance with the launch schedule and progress at the LCC. Recovery ships are on station at least [8] hours before the scheduled launch time. The last [8] hours before launch are used to determine exact position, transmit status information, and receive updated countdown and trajectory information. Recovery forces covering the down-range launch area cover a moving ground track in the event a hold occurs.

Recovery forces near the launch area are on station and fully prepared (for a pad abort) when the LES on the space vehicle is armed. In general, the recovery support required throughout this mission is described in 2.18.

During the pre-flight phase, the Launch Director, Flight Director, and Recovery Director report to the Operations Director at designated times, and whenever operating difficulties arise that jeopardize meeting the launch schedule.

Any decisions that alter the scheduled launch date or window are made only with the concurrence of the Operations Director.

2.1.2.1 Pad and Network Preparation

Readying actions at the launch pad during the pad and network preparation subphase include 1) vehicle pressurization tests, 2) fueling system tests, 3) final installation and tests of ordnance and arming devices, 4) radio frequency interference tests, 5) flight crew suiting and loading tests, and 6) final simulation tests.

Readying operations at the IMCC, the AMR and the MSFN include 1) local site alignment tests, 2) interface tests, 3) simultaneous site tests to test network data flow, 4) computation and data flow simulated flight tests to test network tracking and data flow in coordination with RTCC computations, and 5) simulated flight tests (normal and abnormal simulated flight conditions) involving operations teams at all mission elements to establish flight controller confidence and decision capability.

Operations personnel are on-site and participating in final simulation exercises at least /‾4_/ days before launch.

2.1.2.2 Terminal Countdown

The terminal countdown subphase begins after the performance and analysis of a simulated flight test, involving all mission elements, verify readiness for the terminal countdown and subsequent flight phases of the mission. During the terminal countdown, cryogenic and combustible liquids are loaded, ordnance items are armed, fuel cells and ECS's are activated, operational RF communications modes with the space vehicle are established, and final guidance parameter revisions are inserted into onboard computers. Major decision points during the terminal countdown are 1) removal of the arming tower, /‾7_/ hours before launch, 2) insertion of flight crew, /‾5 1/2_/ hours before launch, and 3) sealing of CM cabin and arming of LES, /‾3_/ hours before launch.

[5] minutes before launch the Operations Director is given final readiness reports. He then authorizes the launch countdown to continue. The Launch Director commits the SIC launch sequences at 150 seconds before scheduled launch time. At 30 seconds before launch the SIC ignition sequencer starts, the spacecraft is transferred to internal power and the umbilicals are released during the subsequent sequencing before lift-off.

The IMCC provides up-dated trajectory parameters, weather forecasts, and ground-network status information. This information is used for the scheduling and revision of launch times. The IMCC is also responsible for comparing its computations with any similar calculations by the Apollo Guidance Computer, the LV computer, and the LCC computers, and for providing final up-dated information to these computers, [ ] seconds before launch. It sends radar acquisition data, countdown progress reports, and other needed information to all ground support facilities including recovery forces. The MSFN units receive summary information at least [1] time per hour during terminal countdown.

2.1.3 Alternate Missions and Contingencies

2.1.3.1 Emergency Malfunctions

Means will be provided for rapid evacuation of pad personnel or flight crew to the ground should emergencies arise during preparation of the space vehicle on the launch pad.

After the crew is sealed in the space vehicle immediate hazards will be circumvented through the use of the Launch Escape System. The LES may be activated by the crew, or by the Pad Safety Officer.

From initiation of the SIC firing sequence to lift-off, an automatic engine shut-down may be made. The Launch Director or his Pad Safety representative will initiate an engine shut-down within /¯ _7 seconds after the SIC fire signal, in case any /¯1_7 engine either fails to ignite or thrust buildup is abnormal. If the holdown clamps or the umbilicals fail to release within /¯3_7 seconds after the SIC fire signal, the Launch Director or his Pad Safety representative will initiate an engine shut-down. If engine shut-down is initiated by any of the above, the LES will automatically abort. An LES abort without engine shut-down will be effected by the EDS or by the crew, if any condition seriously endangers crew safety prior to lift-off.

2.1.3.2 Non-Hazardous Malfunctions

Malfunctions may occur at the launch pad, or elsewhere in the many elements of the ground system, that could cause delay in the space vehicle count. Depending on the particular malfunction, various types of delay might result. A short delay, or hold, will stop the count. Removal of the trouble will allow initiation of the count by a simple restart of the clock.

However, troubles that occur at particular times may be of such a nature that it is necessary to recycle (back-up) the count to a particular restart point. After the trouble is rectified, the count can be re-initiated from this time with only loss of an equivalent amount of pre-programmed hold time. Trouble conditions which are expected to persist for a period of time which is long in comparison to the launch window, may cause the launch to be rescheduled for a later launch window.

There are various courses of action available to compensate for malfunctions. If repair can be effected promptly, a short hold (or no hold) will handle the case. If repair cannot be effected promptly, a decision may be made either to proceed without the use of this equipment or to postpone the launch until the repair can be effected. If the malfunctions force an extended delay for which the repair time cannot be estimated, an indefinite postponement of launch will be made. Any malfunctions which can cause a delay which is significant in comparison with the length of launch window, will be reported to the Operations Director.

Any decisions to continue the count with increased risk due to equipment malfunction and/or alternate mode selection will be made by the Operations Director.

2.2 LAUNCH

2.2.1 Phase Definition

This phase extends from space vehicle lift-off to the first S-IVB cutoff, an interval of approximately 12 minutes.

2.2.2 Nominal Mission

Guidance and sequencing are under the programmed control of the launch vehicle computer and inertial reference system. At cutoff of the S-IVB, the space vehicle is stabilized in a programmed attitude hold. No spacecraft crew or ground support actions are required to achieve the Earth parking orbit. The spacecraft crew and ground personnel monitor the programmed sequence of events, the performance of space vehicle systems, and the achieved trajectory. They determine that adequate safety is provided for the spacecraft crew and populated areas. They obtain data for insertion verification at first S-IVB cutoff.

Voice contact between the spacecraft crew and the IMCC is provided for status reports and for coordination in case of deviations from the nominal. Crew displays are used for onboard real time monitoring of critical systems, timing of events, and trajectory. Crew displays of launch vehicle data are limited to those associated with specific programmed events and safety from catastrophic failure.

Telemetry and tracking data from both the launch vehicle and spacecraft are received and relayed by ground stations to the IMCC. Launch vehicle telemetry data are also sent to LCC. Updata links to the space vehicle are used only to transmit ground generated abort commands and launch vehicle destruct commands.

If necessary, the spacecraft crew can 1) override automatic event sequence timing, 2) adjust spacecraft operating settings, 3) select back-up modes, 4) cutoff the S-IVB propulsion to prevent overburn at insertion of more than [ ] fps, and 5) initiate abort sequences including selection of the appropriate guidance program for trajectory shaping.

2.2.3 Alternate Mission and Contingencies

Troubles during the launch phase which do not pose a serious threat to crew safety and do not prohibit attainment of a safe Earth orbit, shall not be cause for initiating an abort action, even if the orbit that can be obtained will preclude a lunar transfer attempt.

The S-IVB will be used to achieve a parking orbit in case of early cutoff of the S-II. The SM main engine will be used in case of early cutoff of the S-IVB. However, if the performance of the LV guidance system is unacceptable during the S-IVB flight stage, the CSM system shall be capable of performing the guidance function and placing the space vehicle in such an orbit that the primary mission could be continued. Rules for when to abort and when to attempt the Earth parking orbit will be included in the specific mission plan. If time permits, the concurrence of the Flight Director in this decision shall be obtained.

The Launch Escape System abort is the only option available during the period from lift-off to LES jettison (approximately 185 seconds after lift-off). From lift-off until clear of the Launch Umbilical Tower and out of direct visual observation, the Launch Director will initiate an LES abort without engine shutdown in case of serious space vehicle contact with the tower, explosion, automatic engine cutoff, failure of thrust to lift the vehicle clear within [ ] seconds, or early violent unprogrammed movement in space vehicle attitude. From lift-off to LES jettison the Flight Director or spacecraft Crew Commander will initiate an LES abort without engine shutdown, if the achieved trajectory, space vehicle systems, or crew health pose a serious threat to crew safety or prohibit a safe Earth orbit. From lift-off to LES jettison, the launch vehicle EDS will automatically initiate an LES abort without engine shutdown, if launch vehicle overrate in any one axis, IU power failure, or actual structural failure of the launch vehicle occurs. From lift-off to S-IC burnout, the launch vehicle EDS will automatically initiate an LES abort without engine shutdown, if thrust is lost on [2] or more engines.

From lift-off to LES jettison, the Range Safety Officer will initiate an LES abort, if he commands stage destruction and/or engine shutdown. The stage destruct enable command initiates a sequencer that 1) lights the abort indicator in the spacecraft, and 2) activates the LES firing circuits and arms the stage destruct firing circuits after a [3] second time delay. [6] seconds after the stage destruct enable command, the Range Safety Officer may send the stage destruct command. [The sequencer will be inhibited until a positive signal of LES firing is received.] The Range Safety Officer will take such action only if space vehicle performance shows a clear threat to the safety of populated areas, and [then only after consulting with the Flight Director if time permits].

After LES jettison the Flight Director, the spacecraft Crew Commander, and the Range Safety Officer may initiate an abort under the same circumstances prevailing in the case of an LES abort. The launch vehicle EDS will not cause an automatic abort, but will display critical parameters in the spacecraft and the IMCC, so that either the spacecraft Crew Commander or the Flight Director can initiate an abort.

After LES jettison, three abort options are available and the Flight Director or Crew Commander will have to select one of these options. The particular circumstances leading to the abort decision or the abort timing points already passed may preclude one or more of these options. The options are as follows: 1) At any time between LES jettison and S-II stage-off, the S-IVB engine can be used for trajectory shaping to return the CM to a single landing point. 2) From S-II ignition until insertion, the SM can be used for trajectory shaping to return the CM, during S-II burn to one of [5] landing points or during S-IVB burn to one of [2] landing points along the planned ground track. 3) A CM ballistic entry can be used. This would entail a downrange landing point that changes continuously during the S-II burn, and [6] landing points along the ground track during S-IVB burn (where aerodynamic maneuvering can be used for controlling the range within the reentry footprint).

2.3 EARTH PARKING ORBIT

2.3.1 Phase Definition

This phase covers the cruising period from first SIVB cut-off until the start of SIVB ignition sequencing for translunar injection, an interval of [90] to 300 minutes for a nominal mission.

2.3.2 Nominal Mission

Immediately after cut-off at insertion, a brief check of crew and space vehicle systems is made to verify that conditions are suitable for at least one orbit. The attained orbit is evaluated for the same criterion. Crew displays, TLM data and ground tracking are used for this purpose.

The Flight Director at the IMCC [or a Flight Controller on the Atlantic Tracking Ship in case of communications failure with the IMCC] confirms insertion to the Crew Commander via the voice communications link before loss of contact by the Atlantic Tracking Ship.

After insertion verification, the crew selects modes for cruising flight and attends to any operating troubles requiring attention. They then make preparations for a scheduled in-flight checkout.* (The EDS from this time on would not cause an automatic abort. However, the EDS parameters will be displayed to the crew.)

---

* In-flight checkout is defined as activities related to obtaining that portion of the information on space vehicle capabilities required for operational decisions which is not obtained from monitoring routine flight activities.

The first earth orbit is nominally required for determining orbital parameters to the accuracy required for computation of guidance parameters for a lunar transfer maneuver, for gaining confidence in systems performance through flight operation and in-flight checkouts, and for necessary repair and adjustment of equipment. The navigation functions and in-flight checkouts are scheduled so that they do not interfere with each other. Tracking data from the insertion ship and at least /‾one_7 other ground station must be available before the decision is made to go into the translunar trajectory. Ground tracking data from these near-space stations are the primary means for early confirmation of satisfactory orbit. The lunar transfer guidance parameters are computed at the IMCC from these ground tracking data.

Final guidance parameters for the lunar transfer maneuver are established by the IMCC and transmitted to and inserted in the SIVB-IU and the CM guidance systems. The inserted values are verified on the ground and by the crew. The Crew Commander and the IMCC collaborate in this process. The propulsion budget of the SIVB is assessed at the IMCC for acceptable level in conjunction with setting lunar transfer guidance parameters.

SIVB-IU systems are evaluated by the IMCC, supported by the Huntsville Operations Support Center when necessary, on the basis of performance data obtained prior to and during launch augmented by capability data obtained during earth orbit checkouts and contacts. Performance of SIVB-IU and CSM guidance systems is evaluated from trajectory data from SIVB-IU and from CM guidance systems, including measurement of the ΔV caused by venting, and from additional data obtained from the response of the system to attitude orientation checks. These data are compared with each other and to the ground tracking data at the IMCC. CSM navigation sightings will be used as the attitude reference for these comparisons.

The crew monitors critical CSM systems and essential stores, selects equipment modes, and controls active equipment throughout the interval for operation and energy management purposes. They monitor the SIVB propellant tankage, pressure and venting. The crew vents the SIVB before navigation sightings and IMU alignments to prevent an automatic vent during these time intervals. The crew controls changes in attitude using the SIVB-RCS for navigation sightings, precision trimming of IMU reference.

In-flight checkout data and data obtained from monitoring flight operations evaluated at the IMCC, provide the balance of information required for making the commitment decision to proceed with a lunar transfer maneuver. These data indicate 1) CSM ability to complete a successful circumlunar flight, 2) CSM and LEM back-up and reserve capabilities are adequate for an injection abort maneuver that requires /‾40_7 hours of coasting flight and supercircular reentry velocity, 3) safe SIVB-IU operating conditions and maneuver capabilities, and 4) LEM and adapter structural security. Periodic biomedical data on the crew are evaluated.

After completion of the orbit determination and the flight and ground systems assessment, the Operations Director makes a decision on the translunar injection. The lunar transfer window that requires a minimum velocity increment in the /‾second_7 earth parking orbit is preferred.

Verification of the proper insertion of the final guidance parameters into the launch vehicle and spacecraft computers and a final systems status report are transmitted to the last command site in contact with the space vehicle before the injection burn. [The crew or the ground] enables the launch vehicle guidance mode for SIVB automatic firing and control. The ground station continues radar, telemetry, and voice contact until loss of coverage.

2.3.3 Alternate Missions and Contingencies

If communication is lost before the Crew Commander receives ground confirmation of insertion, the Crew Commander will determine if conditions are acceptable for at least one earth orbit based on:

(1) voice reports of IMCC monitoring up to the end of the Bermuda contact indicating satisfactory trajectory and performance of LV systems and of CSM navigation-guidance systems,

(2) CM AGC displays of errors in velocity at cut-off indicating that deviations from the nominal trajectory are within one orbit safety criteria of [ ] fps and

(3) crew appraisal that no serious troubles exist within the space vehicle that seriously threaten safety or survival.

The Crew Commander will proceed with the Earth Orbit phase if in his judgment one orbit capability exists and at least a [3] minute tracking and communications contact with a near-earth ground terminal occurs within the next [45] minutes.

After the commitment decision for the injection burn has been made the Crew Commander or the IMCC may order a postponement of the injection (to the next Earth orbit transfer window) if any problem is detected which in either's judgment threatens the success of the injection maneuver. If this postponement is required, basic updating of the previous information will be necessary to determine whether injection is still practical.

If the pre-commitment steps have not been completed satisfactorily as scheduled during the first earth parking orbit, the commitment decision will be postponed to allow additional time for tracking, making observations or adjustments, and completing further checkout.

If circumlunar flight is not possible, the IMCC will select either a long or short duration flight in the present earth orbit, or a special cis-lunar test flight, or order termination of the mission.

During the earth orbit cruise interval, the IMCC or the Crew Commander may decide because of operating problems that the mission should be terminated using one of the planned landing areas (see 2.19). Such a decision will normally be based on troubles in the systems essential to life support or to earth return or because of crew illness. In such an instance, the decision will be coordinated between the Crew Commander and IMCC.

During the earth orbit cruise, the spacecraft Crew Commander can initiate an emergency abort at any time to effect a safe return to earth. Such action will be taken to counter acutely critical problems that threaten crew safety or minimum capability to make a manually controlled descent and landing. Under less severe emergencies, the abort will be held off until the procedures in the above paragraph can be followed, including descent into a planned landing area or at least until a ground contact is possible so that search and recovery efforts can be coordinated.

For a long duration earth orbit mission, or an elliptic (high energy) earth orbit mission, the cruise orbit shall be shaped to assure a voice and TLM ground contact at least once every [two hours] and to make use of the planned landing areas.

2.4 TRANSLUNAR INJECTION

2.4.1 Phase Definition

The injection phase begins with the start of SIVB ignition sequencing and ends with the decision to proceed with the transposition maneuver. The phase duration is [30] minutes.

2.4.2 Nominal Mission

2.4.2.1 Injection

The crew monitors the SIVB countdown to determine if [ignition or acceleration] begins at the nominal time. They monitor acceleration and velocity parameters to determine whether these are within acceptable limits. They monitor key systems for critical conditions during the maneuver. The Crew Commander determines that SIVB cut-off occurs within the pre-scheduled time increment, that attitude divergence from the nominal did not exceed limits, and that the applied ΔV, estimated by CM equipment was within the expected range. He effects a manual cut-off if the estimated ΔV increment is exceeded by [ ] fps.

Voice and telemetry data are transmitted by the space vehicle during the injection phase. [Telemetry is recorded on-board the space vehicle during the thrusting interval.] Voice is relayed to the IMCC in real time while telemetry is stored by the receiving ground station and transmitted later at IMCC direction. Real time monitoring and evaluation of the space vehicle during the injection burn, by the flight controllers at IMCC, is limited by the amount of real time data available via the voice link. There is no requirement for tracking during the injection burn.

After cut-off of the SIVB engine, the spacecraft crew makes an initial assessment of the attained trajectory from their observation of performance during the maneuver. After determining that no extraordinary actions are required, the crew sets controls for initial translunar cruising and preparation for transposition begins. [ ] minutes after SIVB cut-off, a spacecraft situation report by voice and TLM is made to IMCC. Ground tracking for orbit determination is reestablished within /¯10_7 minutes after SIVB cut-off.

2.4.2.2 Transposition Decision

The Flight Director determines whether or not the transposition maneuver can be safely effected. Tracking data and status data of the space vehicle is used by IMCC to determine whether to attempt the transposition.

The Flight Director establishes the timing and furnishes the schedule for the maneuver. It must occur 1) within a vent-free interval of the SIVB, 2) before SIVB reaction control supply tanks and electrical energy fall below predetermined minimum amounts, and 3) while in communication contact with a ground terminal. The transposition maneuver is scheduled and carried through, if the risk is acceptable, irrespective of whether the attained translunar trajectory permits continuation of a circumlunar cruise.

Ground tracking continues and computations are updated to improve existing trajectory estimates during the latter portions of this phase.

2.4.3 Alternate Missions and Contingencies

2.4.3.1 Injection Options

The Crew Commander will inhibit the SIVB firing if any condition is detected prior to ignition which, in his judgment, materially increases the risk associated with this maneuver. This criterion applies whether the decision is associated with the first or the final lunar transfer window. If ignition has not occurred by the end of a window, the Crew Commander will inhibit the SIVB firing. He will check pertinent spacecraft-displayed parameters and control settings and will prepare to report relevant information to IMCC at first contact. Thereafter, a decision at the IMCC will be made authorizing either further verification checks, or another injection attempt, or an optional mission.

If an unacceptable deviation of trajectory occurs during the translunar injection maneuver while under the control of the launch vehicle guidance system, the Crew Commander will switch control of the maneuver to the spacecraft guidance system. If the deviation persists, he will manually effect cut-off of the SIVB main engine.

If a critical condition in the SIVB-IU occurs during the SIVB burn, manual [or automatic] cut-off will be made, and the CSM will be separated from the SIVB. If a critical condition in the spacecraft occurs during the SIVB burn, manual cut-off will be made. In any of the above, the spacecraft crew will evaluate the spacecraft condition, will estimate attained trajectory, and will transmit a situation report to IMCC upon first contact.

The attained trajectory will be continued until sufficient spacecraft navigation data and earth tracking data are obtained for computing guidance parameters, and until sufficient telemetry data from both the SIVB-IU and spacecraft are obtained for assessing the capability for completing alternate missions, unless an emergency condition in the spacecraft makes immediate attempts necessary to minimize flight time to reentry. For non-emergency conditions, the Crew Commander will normally defer action until completion of the propulsion maneuver.

2.4.3.2 Transposition Decision Options

If transposition is not attempted, instructions for the alternate option to be followed will also be relayed at this time. In general, this decision would stem from an unsafe SIVB condition, and an expeditious action would be initiated to separate the SIVB and the CSM by a suitable distance as quickly as possible. This separation could be followed by a circumlunar flight or by a curtailed trajectory for earlier earth return. Except for emergency situations, the final decision as to the option to follow can be delayed until after SIVB-CSM separation to allow for additional tracking and assessment of the spacecraft situation.

2.5 TRANSPOSITION

2.5.1 Phase Definition

The transposition phase begins with the decision to proceed with transposition and ends with completion of the situation assessment after the launch vehicle stage-off. The phase duration is approximately [20 to 35] minutes.

2.5.2 Nominal Mission

The spacecraft crew and the ground jointly verify the operability and proper adjustment of SIVB-IU, LEM and CSM systems that are required for the transposition. During preparations and the maneuver, a ground station provides voice, telemetry, and tracking data for monitoring purposes. The remaining life-time of the SIVB-IU is assessed at the IMCC from telemetry data. The IMCC is supported by the Launch Control Center and the Huntsville Operations Support Center as required. Spacecraft, including LEM parameters, radiation exposure level and trajectory data are monitored at the IMCC or at the ground station providing coverage.

The crew manually initiates and controls the transposition sequence of events. After readiness is confirmed, the crew activates the equipment modes necessary for transposition. They fully vent the launch vehicle main propulsion fuel tankage, [using an orientation beneficial to trajectory corrections as indicated by initial miss distance computations after injection]. The IMCC [or the crew] commands the launch vehicle to assure the attitude which is most suitable for the transposition and docking, considering 1) lighting conditions and 2) communications contact with the ground station. The attitude hold mode with minimum deadband control is used to control the launch vehicle attitude during this time. No natural lighting constraints are required during this phase.

After obtaining a solid docking, the Crew Commander ascertains that no operational problems are present that require immediate attention. He then selects the modes required for launch vehicle stage-off.

The IMCC or [crew] effects the LEM decoupling from the SIVB. The SM RCS or [SIVB retro-rockets] provide a separation of ___feet in ___ seconds at stage-off, to reduce the hazard from SIVB explosion.

The crew makes a visual observation of launch vehicle separation, checks the CM AGC estimation of the net change of trajectory due to maneuvering, makes a general check of CSM operating conditions, and powers down unused equipment. The Crew Commander then gives a situation report to the ground and proceeds with the cruise flight phase of the mission.

Concurrently, the IMCC assesses both spacecraft and launch vehicle conditions from telemetry data and the trajectory effects from ground tracking to determine that the rate of separation is adequate for crew safety.

The IMCC determines and controls the launch vehicle trajectory to protect against the launch vehicle impacting the moon or the earth.

2.5.3 Alternate Missions and Contingencies

If the Crew Commander judges that a significantly greater hazard exists than was anticipated, he shall not dock without obtaining the consent of the IMCC. This situation can arise from an instability in SIVB holding attitude, an adapter panel not clearing away from the LEM, or abnormal contact during docking attempt.

If a critical condition in the SIVB occurs during the transposition, the crew will separate the CSM from the space vehicle using the SM RCS, and the IMCC will separate the LEM from the SIVB using the [SIVB retro-rockets]. After safe separation distances from the SIVB have been achieved by the CSM and the LEM, the IMCC will determine whether a docking between the LEM and the CSM will be attempted. [The IMCC will control LEM attitude for this maneuver.]

If a critical condition in the LEM occurs during transposition and docking, the crew will separate the CSM from the LEM using the SM RCS to achieve a safe separation distance.

If a critical condition in the CSM occurs, the crew will either 1) effect an immediate stage-off of the SIVB and/or LEM and use the SM SPS to minimize flight time to reentry or 2) complete the docking in order to utilize LEM capabilities.

2.6 LUNAR TRANSFER CRUISE

2.6.1 Phase Definition

The lunar transfer cruise begins at the end of the mission status check immediately following stage-off of the SIVB and ends with the initiation of SM propulsion for lunar orbit insertion, except for three midcourse corrections. These midcourse corrections are treated collectively in Section 7 as a separate phase. The phase duration is from [60] to [110] hours.

2.6.2 Nominal Mission

The spacecraft drifts during the major portion of the transfer cruise. The crew controls its orientation when necessary to take periodic navigational sightings or communicate with the ground. CSM equipment modes for cruising are selected to minimize use of consumables. Equipment which is not scheduled for use is put in a standby condition to conserve electrical power. The crew maintains continuous surveillance of active, critical functions, selects modes, adjusts operating controls for efficient performance of all subsystems, and transmits scheduled flight reports to the IMCC. The crew follows a rotating duty schedule designed to accommodate all scheduled activities and to rest the crew for extended duty during the active lunar phases. In addition to its monitoring function, the crew carries out planned scientific experiments, makes navigational observations, and participates in the special functions described below.

Prior to the first midcourse correction, one crewman enters the LEM 1) to participate in an in-flight checkout of the LEM systems, 2) to correct repairable failures, 3) to establish cruising modes, and 4) to energize circuits for remote IMCC and CM monitoring and control of activated LEM systems. Upon completion of these tasks, the crewman returns to the CM and makes a situation report to the IMCC and resumes his CM duties.

The IMCC has the primary responsibility for prediction of the spacecraft trajectory during this phase, scheduling of midcourse correction phases, and assessment of system capability. The ground stations, when in contact with the spacecraft, perform scheduled tracking and monitor the TLM and voice channels for transmissions from the spacecraft. The tracking data are collected at the IMCC for analysis. The ground station in contact with the spacecraft maintains a communication link between the spacecraft and the IMCC. It also relays data and commands between the spacecraft and the IMCC. Required changes in the spacecraft-to-earth communications modes are coordinated with the spacecraft by the ground stations.

Trajectory calculations based on earth tracking data are cross-checked and combined with spacecraft guidance information, including navigational sightings [and CM AGC computations] at the IMCC. The IMCC uses the spacecraft data to refine orbital parameters. Optimum correction increments for guidance maneuvers are determined.

The Flight Director, in consultation with the crew, establishes exact schedules for each midcourse correction and reschedules operations during the cruise phases whenever necessary. The schedules must allot sufficient time to each midcourse correction phase for orbit determination as described in section 7.

IMCC computes abort trajectories and the associated thrust maneuvers. This information is available for immediate transmission to the CSM. At [2] hour intervals, the abort computations are sent to the AGC on the command link to update onboard abort information. An evaluation of current and projected support capability is made of the ground stations, recovery forces and the effect of terrestial/extraterrestial environment (e.g., weather, upper-winds, solar flares). From this information, the Flight Director decides on the advisability of making any revisions in mission schedules or procedures. Periodic evaluations of vital spacecraft capabilities are made by the IMCC to determine if consumable materials are sufficient for the remainder of the mission. The IMCC periodically samples the biomedical data on the crew to determine their condition.

Preparations for lunar orbit insertion begin [3] hours before reaching the pericynthion of the translunar orbit. One hour of this time is devoted to activation and checkout of all systems which must be in a state of readiness for this maneuver or for a subsequent abort. The next 1 1/2 hours are available for repairs and any further checks and adjustments which are needed. It may be desirable to begin some of the checks before the third midcourse correction phase or as a part of that phase, especially if the third midcourse correction comes late. The SPS will be used, if possible, to make this final midcourse correction, to provide an operational verification of its status prior to deboost at the pericynthion of the translunar orbit.

During this [3] hour period, the IMCC assesses data on consumable materials aboard the spacecraft and evaluates the life-support and electrical power systems to insure that adequate capabilities exist for the remainder of the mission. Trajectory parameters are calculated at the IMCC, based on ground tracking and CSM inputs, and are transmitted to the CSM via the command up-link. The parameters are verified and stored in the CM AGC and a schedule for the insertion is set by the Flight Director.

The Operations Director's decision to proceed with lunar-orbit insertion is made and relayed to the crew at least [30] minutes before reaching the pericynthion of the translunar orbit. Approximately 15 minutes is reserved for detailed coordination between the spacecraft and the IMCC before spacecraft-earth communications are broken when the spacecraft passes behind the moon.

After the spacecraft has lost its line of sight with the earth, the crew checks the spacecraft's attitude for the maneuver, verifies mode selections, and monitors critical displays during the countdown.

2.6.3 Alternate Missions and Contingencies

The IMCC or crew will terminate the mission if the accumulated plus the predicted radiation dosage exceeds safe limits.

Loss of vital life-support or power consumables may require an abort that gives the minimum flight time to landing. Failure of a vital system(s) (e.g., CM AGC, SM RCS, or SPS) may require the use of the LEM's guidance computer, reaction control system and/or propulsion system to effect an abort.

An abort will not be made for loss of system capability that is not vital for a successful circumlunar flight and a safe earth landing. Attempts will be made to clear such difficulties. If they cannot be cleared by crew action, the mission will be curtailed to a circumlunar or cis-lunar flight terminating in a planned landing area.

If the CSM communication system fails, one crewman will enter the LEM and attempt ground contact using the LEM communication system. If the attempt is successful, the IMCC will assess the situation and decide which mission option is to be performed by the crew. If communications cannot be restored within [ ] hours, the Crew Commander will terminate the mission at a prearranged time.

The mission will be curtailed to a single pass behind the moon if the IMCC decides against lunar-orbit insertion or if the crew does not receive positive instructions from the IMCC before passing behind the moon. The Crew Commander may reverse an IMCC decision to proceed with lunar orbit insertion if, prior to SM ignition, troubles develop which, in his judgment, jeopardize crew safety. For less serious operating problems that occur after a positive decision to proceed with lunar-orbit insertion has been made, the Crew Commander may elect to carry out this maneuver utilizing back-up modes if necessary.

2.7 MIDCOURSE CORRECTION (Translunar and Transearth)

2.7.1 Phase Definition

This phase extends from start of spacecraft preparations for the powered maneuver to completion of the post-maneuver assessment. The phase duration is approximately /¯1_7 hour occurring periodically within the translunar and transearth cruise phases.

2.7.2 Nominal Mission

Each midcourse correction is scheduled as described in 2.6 for the translunar phase and 2.16 for the transearth phase. The midcourse phase is timed 1) to give continuous ground contact, 2) to afford ample time beforehand for precision calculation of desired guidance parameters, 3) to allow for activation of desired configuration, adjustment and checkout of modes and functions essential to the maneuver, and 4) to permit moderate hold for effecting minor corrections or repairs.

During the translunar cruise, the first midcourse correction is made at a scheduled time between /¯4_7 and /¯11_7 hours after transposition, and adjusts the position and time of crossing the lunar sphere of influence. The second midcourse correction is made at the lunar sphere of influence and adjusts the pericynthion altitude in the free return plane. The third midcourse correction is made /¯3_7 hours before pericynthion and is made with the objective of arriving back at the lunar sphere of influence at the proper time, in the event the lunar orbit insertion is not attempted.

During the transearth cruise, the initial midcourse correction is made approximately /¯25_7 hours after transearth injection, to adjust time of flight, inclination, and flight path angle for correct reentry phasing for the designated primary recovery area. The next midcourse correction is made approximately /¯25_7 hours after the first, to remove residual errors in reentry point miss-distance. If the projected velocity correction needed for the residual error in entry aiming point exceeds the propulsion capability of the SM RCS, an additional midcourse shall be scheduled between the second and final midcourse correction. The final midcourse correction is made /¯2_7 hours before reentry to make minor adjustments for optimizing velocity and the penetration position within the reentry corridor to achieve the planned landing site.

Spacecraft preparations for midcourse maneuvers are completed in coordination with the IMCC and the Deep Space Station providing coverage. The preparations include reception, insertion and verification of the guidance parameters provided by the IMCC, and activation, checkout and adjustment of the systems and modes essential to carrying out the maneuver. This preparation includes making navigational sightings to trim the attitude reference, establishing the planned orientation for a maneuver and selecting the designated modes.

The IMCC calculates the guidance parameters necessary for a midcourse maneuver using 1) a combination of ground tracking and onboard optical data, 2) onboard optical data only and, 3) ground tracking data only. The AGC calculates the parameters for a midcourse maneuver using optical data. The primary source of guidance parameters for the maneuvers is the combination of ground and onboard data. The difference between it and the computation using the onboard data only is transmitted to the spacecraft. This difference enables the crew to compare the AGC computation to the optimum. The AGC computation is the back-up in case of a communication failure. The comparison provides an onboard check on the operation of the CSM G&N system. The solution, using ground data only, is used for analysis of the spacecraft optical measurements and is transmitted to the spacecraft only in case of absence of optical data. This tracking-data-only solution provides a back-up in case of a failure in the spacecraft computer or the optical measurement subsystem. Verification of data sent to the spacecraft is described in 2.3.

After system verification, the Flight Director authorizes the maneuver. The Crew Commander enables the appropriate G&N guidance mode, [2] minutes before the end of engine countdown for maneuvers using the SM SPS or, at alignment of the IMU for maneuvers using the SM RCS. The AGC controls the complete firing sequence including [ullage]. The crew provides back-up capability for the AGC using manual controls to initiate ullage, engine start, and engine cut-off. The crew monitors that 1) propulsion occurs within set limits for the particular maneuver, 2) spacecraft attitude holds at the planned value, 3) the planned ΔV is achieved with acceptable error, 4) no abnormal indications are detected on critical displays or observed by the crew, and 5) cut-off is effected within a planned time.

After cut-off the Crew Commander confirms that no operating troubles occurred which require immediate attention, and makes a situation report to the IMCC. A reduced power consumption cruise configuration is established except after the last translunar and last transearth maneuvers.

Spacecraft data and ground navigational data are collected after each maneuver, and used at IMCC to define the new trajectory and calculate the next (eventually the final) midcourse maneuver. The IMCC uses TLM data transmitted during and immeiately after the maneuver to assess status of consumables, performance during the maneuver, and the mission situation.

2.7.3 Alternate Missions and Contingencies

The Crew Commander will inhibit propulsion if a trouble occurs which would jeopardize the crew or the successful completion of the maneuver, and will make a situation report to the IMCC. Based on the crew report and TLM, the Flight Director will decide whether to reschedule the maneuver or to curtail the mission.

The crew will complete a midcourse maneuver if non-emergency operating troubles occur after the start of thrusting by shifting to back-up modes if necessary. For example, the scheduled procedures will be continued if communications with the ground are disrupted during or after a scheduled maneuver. In an emergency, the Crew Commander may terminate the maneuver and coast while taking repair action, may terminate the maneuver but prepare to use the next scheduled abort window, or may attempt an immediate abort maneuver if such action is required by the emergency.

2.8 LUNAR ORBIT INSERTION

2.8.1 Phase Definition

This phase begins with the SPS pre-ignition sequencing near lunar transfer orbit's pericynthion, and ends with the post-insertion situation report made after reestablishing communications with the ground upon emerging from behind the moon. Phase duration is approximately 30 minutes including a [6] minute propulsion interval.

2.8.2 Nominal Mission

Sequencing and guidance control is automatic, under the control of the CM AGC. The flight crew is suited and restrained in the couches. They monitor the performance of the powered maneuver and 1) make operating adjustments, 2) select alternate modes for completing the phase, 3) take manual override actions, or 4) initiate an early engine cut-off or a programmed abort in case of serious operating troubles. Maneuver displays are used for monitoring the insertion. The displays are supplemented by gross visual checks of orientation using celestial bodies for reference. Ignition must start within ± [ ] seconds of the scheduled time to remain within the allocated fuel budget for a lunar landing attempt. Key performance parameters are recorded during the thrusting interval for delayed telemetry transmission to earth. These parameters are used in the IMCC's analysis of the SM's remaining operational capability.

After SPS engine cut-off, the crew checks to confirm that no serious operating problems have developed which require immediate attention. They verify that the minimum altitude of the achieved orbit is greater than [20] miles.

This verification is based on velocity vector at SM cut-off determined by the CSM guidance system. Modes and operating settings for cruising flight are established. Concurrently, navigational equipment is prepared for use. /‾Optical sightings on celestial bodies are used to obtain an estimate of the orbit sufficiently accurate to check the performance of the G&N system._7 Crew observations of system performance during the insertion are collected and summarized for transmission to the IMCC.

Contact with a deep space station is made as soon as the line-of-sight is established. This occurs approximately /‾24_7 minutes after the start of the phase. The Crew Commander makes a verbal situation report to the IMCC. Direct and stored telemetry data is transmitted to the ground for analysis of the performance and remaining capability of spacecraft systems. The schedules for lunar orbital cruise events are confirmed by the IMCC.

The ground is out of contact with the spacecraft during most of this phase, but must be ready to support any contingency action that the crew may have taken during this phase as soon as communications are reestablished. This includes instituting a search to establish communications contact at the earliest time that the spacecraft could emerge from behind the moon.

2.8.3 Alternate Missions and Contingencies

Manual initiation will be used to clear minor troubles that disrupt normal start of ullage prior to SPS ignition.

Every effort consistent with crew safety will be made to achieve a safe lunar orbit. To this end, manual guidance will be used as a back-up, if necessary, to prevent any gross attitude error. Corrective operating adjustments or selection of alternate modes will be used for troubles in essential services or non-guidance systems where possible.

Termination of ullage and SPS cut-off can be effected manually by override action as a back-up. In particular, cut-off will be effected manually, if actual ΔV exceeds programmed ΔV by [ ] ft./sec., to prevent a serious over-burn that threatens collision with the moon.

In case of a major trouble that cannot be overcome by selection of a back-up, early termination of thrust by manual cut-off will give either a safe, higher altitude orbit around the moon [or a hyperbolic orbit that allows time to activate and use the LEM guidance and propulsion for obtaining a safe earth reentry]. Initiation of an abort to an earth return trajectory by using the SM engine will be delayed except for emergency situations, i.e., threatened catastrophe to impending SPS explosion, CM fire, cabin rupture, major life support or electrical failure.

If a safe lunar orbit were achieved but there were significant uncleared operating troubles, first priority would be given to corrective actions, where possible, or trouble diagnosis. The IMCC and the DSS will assist on the basis of verbal reports from the crew and transmitted telemetry data when communications with earth are reestablished. The support would extend to assisting with special checkouts, evaluating and diagnosing conditions, recommending special repair actions or special modes, revising and optimizing mission plans and guidance parameters for early earth transfer injection. If repairs can successfully be effected within [ ] lunar orbits, a lunar landing will still be possible. Should additional orbits be needed for correcting troubles, the mission will be curtailed to a survey of the lunar surface from orbit or to early return to earth, dependent upon the situation. If the trouble pertained to the SPS and an attempt to restart the SPS for effecting a normal earth transfer injection were deemed unsafe, the LEM guidance and propulsion systems would be activated, checked out, programmed, and used for effecting the injection. In the event of loss of two-way communications with the earth from the CSM, the flight crew will occupy the LEM and attempt to establish contact. If contact were not established within [4] lunar orbits, the Crew Commander would effect an earth transfer injection for return to a planned earth-landing site.

2.9 LUNAR ORBIT CRUISE

2.9.1 Phase Definition

This phase begins with the end of the post-insertion situation report and ends with initiation of the LEM stage-off prior to leaving the lunar parking orbit for the Earth-return flight. The phase duration is from [1 1/2] to [50] hours. The total interval is divided into the following sub-phases: initial cruise [1] hour, LEM checkout and separation [ ] hours, independent CSM cruise [ ] hours, post-docking cruise [ ] hours, and LEM stage-off preparations [ ] hours. The independent CSM routine cruise sub-phase covers all independent CSM operations from LEM separation to completion of docking. The CSM-LEM interactions are covered in Phases 10 through 14.

2.9.2 Nominal Mission

2.9.2.1 Initial Cruise

The nominal parking orbit provides a constant altitude circuit of the moon at an inclination which assures passing within [2°] of the planned landing area every two hours for [48] hours. The initial cruise sub-phase lasts for approximately one hour. It is used for obtaining additional data (Earth based tracking and CSM optical measurements) on the attained orbit and confirming its acceptability for a lunar landing. During this sub-phase, CSM systems are verified for extended one man operation, and one crewman takes a brief relief and rest period. General observation of the landing area and the navigational landmarks along the descent path are made during the first fly-by, after which [one] crewman enters the LEM.

2.9.2.2 LEM Checkout and Separation

Activation, adjustments and checkout of LEM systems are completed to the extent possible prior to separate LEM flight. After relieving the CSM crewman for a rest, the second LEM crewman enters the LEM to assist in checkout and separation. After an analysis of the checkout information and separation preparations establishes the LEM capability for independent flight, the IMCC authorizes separation. Separation occurs during the second orbit while the spacecraft is within view of the Earth. Using the LEM-RCS, the LEM is separated and positioned in the same orbit as the CSM but displaced by approximately [500] feet. The separate LEM cruises near the CSM for approximately one hour. Control and operation of the LEM in independent flight is confirmed during this period. LEM and CSM navigation data and orbit elements are cross-checked. Communication channels between LEM and CSM are checked. A brief rest period for each LEM crewman, in rotation, is provided. Modest amounts of unscheduled maintenance can be performed during this interval, if needed, without altering basic mission plans and schedules. Rendezvous radar tracking by the two vehicles is initiated.

Final preparations for LEM descent are carried out after communications with the Earth are reestablished early in the third orbit. This includes: 1) final insertion and verification of guidance parameters, 2) setting timing schedules for the descent, 3) confirmation of mode selections and operating settings, 4) verification of crew readiness, and 5) extending the LEM landing legs. The IMCC authorizes proceeding with the descent at this time, after an analysis of the flight and checkout data.

2.9.2.3 Independent CSM Cruise

During the LEM descent and landing the CSM tracks the LEM, calculates the LEM nominal and abort trajectories. The CSM crewman maintains voice communications and visual contact with the LEM, when possible, and is prepared to effect an emergency rendezvous. (Independent LEM lunar operations and joint CSM and LEM operations are described in phases 10 through 14.) After the LEM has landed and it is established that the LEM is safe for the nominal lunar stay, the CSM crewman powers down all equipment that is not required for normal cruise operations. With the IMU powered down, attitude reference is maintained, when necessary, using the SCS reference system. [The SCS local vertical mode is used to maintain attitude for landmark sightings.]

CSM routine orbit operations include: 1) communication with the ground, 2) visual observation of the LEM, 3) communication with the LEM, either line of sight or relayed through the earth, 4) periodic navigational observations for orbital checks and for reference alignment, 5) collection of scientific data, 6) CSM energy management, and 7) operating adjustments, system monitoring and checks, and maintenance actions. Every [third] orbit, the CSM crewman observes a [2] hour sleep period, with telemetry and the command data receiver providing DSS monitoring and alerting respectively when the CSM is visible to Earth. Except in an emergency, resolution of troubles requiring extensive or special maintenance actions will not be attempted without specific authorization from the IMCC.

Upon reestablishing contact with Earth after each passage behind the moon, a verbal report is made by the CSM crewman to summarize status and progress, and to coordinate plans. A similar report is made to the LEM crew during each period of LEM visibility. Special reports or queries are initiated between CSM, LEM and DSS at any time during periods of mutual visibility. Concurrent with the CSM verbal report to the ground, real-time telemetry data is transmitted. This is followed by transmission of data recorded during the previous interval behind the moon. After this telemetry "dump", normal telemetry data transmission is resumed. The CSM command data channel is continuously open. Once each orbit updated CSM orbital and abort parameters (both for LEM return and for a later coordinated Earth return) are received from the ground. Ground tracking data on the CSM and LEM are obtained during periods when both vehicles are visible from the Earth.

During the last CSM orbit before LEM launch, the CSM crewman erects and aligns the IMU, tracks the LEM with the CSM rendezvous radar and confirms CSM-LEM schedules and timing with the LEM crew and the IMCC. (CSM-LEM interactions during LEM ascent and rendezvous are described in phases 13 and 14.)

2.9.2.4 Post-Docking Cruise

As soon as the CM cabin environment is stabilized for non-suited occupancy, the two LEM crewmen remove their spacesuits and observe brief personal relief and rest cycles. Thereafter, crew rotation and rest cycles are observed until LEM stage-off preparations are scheduled to commence. If three or more orbits are scheduled, each crewman observes a two hour sleep period, and if one to three orbits are available, at least a 30 minute rest period is afforded each man. Routine cruise operations continue, with periodic navigation observations and interactions with the DSS and IMCC. Extensive or special maintenance actions are performed if authorized by the IMCC. Similarly, additional collection of scientific data and lunar surface observations may be scheduled at this time.

2.9.2.5 LEM Stage-Off Preparations

The schedule for LEM stage-off and for transearth injection is coordinated between the IMCC and the flight crew no later than 1 1/4 orbits before injection. During the following non-visibility period, the attitude references are aligned and used in making a celestial navigation fix. All CSM systems needed for the LEM stage-off, and for the subsequent transearth injection maneuvers are energized and adjusted. Hatches and connections are prepared for initiating LEM stage-off from inside the CM cabin. After reestablishing communications with the DSS, systems checks are completed. Coordination is effected with the IMCC if major maintenance actions need to be performed. Final timing and parameters for the LEM stage-off and transearth injection maneuvers are inserted in the CM AGC and verified. IMCC authorization to proceed with the schedule is then transmitted. LEM stage-off is scheduled to occur near the time that the spacecraft crosses the Earth-Moon center-line. This allows sufficient time for exchange of navigation information and systems data, and for final coordination before the next loss of communication.

2.9.3 Alternate Missions and Contingencies

2.9.3.1 Initial Cruise Options and Decisions

If the achieved lunar parking orbit is safe (i.e., does not come nearer to the moon's surface than 20 n.m. at any point), it will be altered only with the concurrence of the IMCC. The Crew Commander will effect any guidance maneuver he deems necessary to alter an unsafe orbit so that its perilune will be greater than [20] n.m.

Up to [ ] additional parking orbits of the moon may be authorized by the IMCC if needed for clearing trouble without causing a curtailment in mission objectives, other than a reduction of time spent on the lunar surface. These additional orbits will be allocated as they are needed: prior to LEM activation, before LEM separation, before the LEM descent to the equiperiod orbit, or while the LEM is in the equiperiod ellipse.

Significant CSM operating troubles will be cleared, where possible, before entry into the LEM. No troubles that would be critical with one man attendance can be left uncorrected. Correction of conditions of less importance can be deferred, but IMCC-flight crew coordination is required in reaching that decision. After LEM activation, similar rules apply to LEM capabilities before separating from the CSM and before initiation of the descent maneuver.

Uncorrectable LEM malfunctions may obviate separate LEM flight or restrict separate LEM flight to the rendezvous zone for extended or short duration. If such malfunctions, in the judgment of the IMCC, significantly decrease the likelihood of successfully landing and ascending from the lunar surface the landing attempt will not be made.

If the orbital plane cannot be brought to within 2° of nominal planned inclination or to eccentricity < [ ] with an orbital period of [ ] to [ ] minutes, the IMCC may designate an alternate landing site that can be reached from the achieved or from an altered orbit. Failing this, the mission will be curtailed to omit the landing attempt, although equiperiod descent for surface survey may be authorized dependent on the situation. A maneuver to improve the orbit for landing operations will be authorized by the IMCC, if feasible, without using any fuel budgeted for transearth injection, return midcourse corrections or reserves for these maneuvers.

2.9.3.2 Options During Separate LEM Operations

During separated LEM orbital operations, the Crew Commander will defer initiation of propulsion maneuvers, if continuing the mission imposes unacceptable crew risk. Termination of separate LEM operations and expeditious rendezvous will be caused by the following: 1) crew injury or sickness, 2) inability to make voice (or code) contact with CM crewman by DSS or LEM during an entire visibility period (except during a scheduled sleep period), 3) serious environmental control or electrical power trouble, 4) excess radiation exposure, or 5) excessive rate of depletion of pressurant or propulsion reactants for SPS or SM-RCS or of O_2 or H_2 bulk supplies. LEM aborts from the lunar surface outside of a normal launch window will not be made because of CSM troubles.

2.9.3.3 CSM Aborts

The CSM can abort to an Earth return trajectory on each orbit when the entire flight crew is in the CSM. This decision must be reached sufficiently ahead of the window to permit LEM stage-off and establishment of proper modes and settings. Due to these constraints, CSM emergency aborts during this phase will be considered only for extreme emergency situations during the first two parking orbits of the initial cruise or during the first orbit after LEM docking.

At other times, back-up modes and reserve capabilities must be relied upon until separate lunar operations can be terminated (rendezvous within [3] hours) and a safe return flight to Earth made. After LEM docking, LEM capabilities may serve as special reserves for CSM systems. The LEM stage-off will be delayed until after the checkout in preparation for transearth injection to provide this back-up. The LEM capabilities that may be drawn on,if needed,by activation in the LEM include the LEM guidance and propulsion system, if these systems have not been expended or impaired during independent LEM operation. Any LEM systems or subsystems that are interchangeable with CSM equipment may be removed from the LEM and installed in the CSM.

2.9.3.4 Procedures In Event Of Communication Loss

If all CSM and LEM-Earth communications are lost for a pre-scheduled contact period, the initiation of new phases or sub-phases will be deferred. Continued loss of all Earth communications for [2] CSM orbits shall be cause for curtailment of further lunar operation except those incident to getting the entire flight crew in the CSM and getting the CSM prepared for using the preprogrammed transearth injection window [2] orbits later (a total of 4 orbits between first missed contact and start of the transearth injection phase). Loss of two-way communications with Earth by one of the two vehicles will not of itself necessitate mission curtailment.

2.10 LEM DESCENT TO PERILUNE

2.10.1 Phase Definition

This phase begins with the initiation of the LEM descent engine ignition sequence for transfer to equiperiod orbit and ends with initiation of the ignition sequence at or near perilune for the powered descent to the surface. The phase duration is 30 to 150 minutes.

2.10.2 Nominal Mission

The LEM descent to perilune phase begins with a short burn period (approximately 30 seconds) to put the spacecraft into a transfer orbit, nominally equiperiod and co-planar with the CM orbit, with perilune at 50,000 ft. altitude and in the proper position (relative to the designated landing site) for commencement of the powered descent. The propulsion event is followed by a coast period (~30 or ~150 minutes; i.e., 1/2 or 1 1/2 orbital cycles) in the new orbit up to the commencement of the powered descent. Plane changes up to 2° may be required to achieve the planned landing area. (Very small plane changes may be accommodated during Powered Descent without incurring unacceptable ΔV penalty.) An acceptable transfer orbit allows a LEM powered descent to the lunar surface near perilune in the nominal mission and provides a free return to the CSM as a contingency option.

The LEM crew enables the firing sequence for LEM descent engine after a final check on LEM IMU alignment, critical systems, the displayed thrust parameters, and time to start ignition sequence. The LEM crew then initiates the firing sequence of the descent engine. During the powered maneuver, the LEM crew monitors LEM systems performance, particularly the guidance and engine performance parameters. Both prime and back-up guidance displays are used as a cross-check to determine whether the preplanned maneuver has been performed. If either indicates successful performance, the maneuver will be continued. During the coast period, the LEM crew monitors LEM systems performance continuously. They also track the CSM with the LEM rendezvous radar, to update the abort program by determining the relative CSM-LEM trajectory and to provide an outside check on the LEM G&N system. The achieved trajectory is evaluated by the LEM crew on the basis of this tracking, and subsequently by the CM crewman and the IMCC with the additional information from CM and ground tracking, to determine whether an orbit with perilune altitude sufficiently close to 50,000 feet has been achieved and whether any certified landing site can be reached from the achieved orbit. The CM crewman uses the CSM rendezvous radar to track the LEM during the burn and the descent. The LEM orbit will be determined by the CSM within [ ] minutes after LEM engine cut-off to verify a safe perilune altitude, verify an equiperiod orbit and generate initial conditions for LEM abort. This information is transmitted to the IMCC, and to the LEM crew to aid in evaluating the performance of the LEM guidance system.

During the entire period, the ground tracks the CSM and the LEM. The IMCC, using all data available and cross-checking data from the various sources for consistency, provides a CSM ephemeris, LEM transfer orbit ephemeris and powered descent trajectory and ascent data for abort. Telemetry from both CSM and LEM, crew voice reports, and ground tracking is used to generate this information.

/̄A midcourse correction during LEM descent is not planned in the nominal mission._7 Flight path adjustments and plane changes will be incorporated into the principal propulsion events and so made at insertion into transfer orbit or in the powered descent.

The CSM systems are maintained throughout this phase in such a state of readiness that the CSM can undertake and effect rendezvous with a completely disabled LEM after advance notice of /̄ _7 hours.

There is a voice link open between the CSM and the LEM during this phase for exchange of status information, for coordinating events that require joint actions by the LEM and CSM crews, and for providing abort guidance parameters.

The LEM and CSM store, on-board, information on system operation and changes in orbit when out of contact with the ground. This information is transmitted to the ground on command.

During the latter portion of the coasting orbit, the LEM crew establishes modes for the powered descent to the lunar surface. A final update is made of the guidance parameters to be used in the maneuver, using LEM and IMCC-supplied information. The proper attitude and guidance modes are selected.

After careful evaluation of all information available to him, the Operations Director authorizes the Powered Descent and Landing at least /̄5_7 minutes before the ignition sequence initiation for the Powered Descent maneuver.

2.10.3 Alternate Missions and Contingencies

If a certified landing site is not accessible to the LEM, landing will not be attempted. If either the primary or back-up guidance system malfunctions during this phase, landing will not be attempted unless the Flight Director authorizes an increased-risk landing, after an evaluation of the G&N system capability in conjunction with the LEM crew. In these and other situations where the LEM crew or the Flight Director decides against landing, providing the orbit is safe and no emergency demanding early return to the CSM exists, the LEM will be kept in the transfer orbit until deviation therefrom is authorized by the Flight Director. After a careful evaluation of LEM and crew capability based on telemetered data and consultation with the crew, the Flight Director may direct:

(1) Continued efforts to clear the malfunction,
(2) Continuing in transfer orbit for low-level examination of landing area and vicinity,
(3) Variations of orbit for low-level examination of other accessible areas, or other scientific or mission-oriented exercises,
(4) Circularization of orbit and rendezvous and docking to CM at next opportunity.

If there is a critical system malfunction that cannot be cleared before the first opportunity to descend and land, and it can be cleared during the next two hours under option 1 above, the descent maneuver may be postponed one orbit. This will require a realignment of the guidance system and updating of trajectory parameters.

If the Descent Stage engine is not automatically cut-off precisely on time, then on attainment of the required velocity increment, the LEM crew will effect manual shut-down immediately and proceed on the assumption that the new orbit has unsafe perilune clearance. Powered Descent will not be initiated in this situation unless the cause of the failure is determined and removed, and unless an adjustment, if necessary, into a safe and satisfactory transfer orbit has been made without prejudicial propellant expenditure, and only if the Flight Director so authorizes.

If any emergency condition develops which in the judgment of the Crew Commander threatens crew safety, either immediately or within the [2] hour interval (free return path) before rendezvous with the CSM, any and all propulsion systems will be used to achieve direct ascent and early rendezvous.

The CSM must be prepared to rescue the LEM if the powered descent maneuver is not attempted and the LEM cannot perform the required trajectory changes.

If the transfer orbit does not provide safe perilune clearance, a velocity increment will be applied to alter the orbit to one which meets the safety criteria with certainty. The order of priority of propulsion systems to use for such orbital corrections is: first, Reaction Control System except for fuel needed to control attitude through docking; second, Descent Stage Engine; third, Ascent Stage Engine; fourth, all RCS fuel. The orbit, if feasible and unless otherwise ordered by the Flight Director, will be shaped to provide either a rendezvous with the CSM or a safe coasting orbit for a subsequent powered maneuver to achieve rendezvous. If such a maneuver has been necessary, no subsequent landing maneuvers or attempts shall be made until after a careful evaluation, by the Flight Director in conjunction with the crew, of the LEM and crew capabilities and the risks involved, and only after explicit authorization by the Flight Director.

In the event of loss of two-way communication with the LEM, Powered Descent will not be initiated. In this situation, the LEM will effect rendezvous and dock to the CSM at the first opportunity. If it has not done so within [2 1/2] hours of last communication contact, the CM will effect rendezvous and dock to the LEM at the first subsequent opportunity.

2.11 LEM LANDING

2.11.1 Phase Definition

This phase begins with the initiation of the ignition sequence for the Powered Descent and ends with touchdown on the lunar surface. The phase duration is approximately [8] minutes.

2.11.2 Nominal Mission

The descent trajectory, starting at 50,000 ft. altitude, has a range of approximately 180 n.m. to the landing site. The initial section of this trajectory approximates a minimum-fuel profile, whose flight path angle is very shallow. It is followed by a section designed to improve visibility to the landing site, along which the spacecraft is "flared" to a nearly vertical attitude. When the horizontal velocity is reduced nearly to zero, the spacecraft is pitched to the perfectly vertical attitude required for safe landing. A hover and horizontal translation maneuver capability is provided for accomplishing small position adjustments and visual examination of the landing spot by the crew before touchdown.

The guidance system controls the spacecraft automatically along the entire descent trajectory to landing at the designated site unless ordered otherwise en route. Manual override capability is provided for designation of a different landing site, for abort, and for control of the hover, translation, and landing sequence. During the initial section, guidance is based on flight information obtained during previous phases and on altimeter measurements. During the second section, supplemental altitude rate and range rate information is automatically incorporated. The guidance system is also capable of utilizing direct radar and optical position information on a transponder, beacon, or other distinguishable point at or near the landing spot in the final descent to touchdown. The LEM guidance package maintains, accessible to the crew, an up-to-date solution of the initial conditions for abort. Computer failure does not erase this estimate. The backup guidance system contains an abort ascent program as nearly as possible identical with that of the primary, and has the initial conditions inserted continuously and automatically.

The crew verifies and monitors settings in the LEM guidance system for the descent program, based on a preselected landing site. In addition to monitoring the descent program and general LEM systems status, the crew in the flareout and hover maneuver continually evaluates the selected landing site for its suitability. The crew can enter a new landing point into the landing program if the initial selection appears unacceptable after observation. It is essential that actual coordinates be inserted in the guidance system when any change other than final selection of the particular landing spot (within ~ 1/2 mile of hover point) is made in the intended landing site, in order that ascent parameters for abort or immediate launch may be as up-to-date and as precise as possible in the interval before an accurate post-landing determination of LEM position can be made.

Optics are provided so that the suitability of a landing site can be determined from the LEM at an altitude and capability point from which abort is still possible, with the landing site in direct sunlight from any direction relative to the line-of-sight. Means of identifying the area to which the LEM is being guided, and means of estimating the surface inclination and surface roughness (or of verifying that these quantities are within acceptable limits) are also provided. The descent guidance profile is so constructed as to afford the crew at least [1] minute of such observations on the landing spot and its immediate vicinity before the spot passes from view beneath the vehicle.

The LEM Descent Stage Engine is cut off at zero altitude by the guidance system. A parallel cut-off signal is generated by the landing gear on sensing contact and support of a predetermined fraction of LEM weight.

A voice link remains open throughout this phase between the LEM and CM for exchange of status information, coordination of procedures requiring joint actions, and provision of abort parameters.

The CM crewman tracks the LEM throughout its trajectory when within range and line-of-sight. He uses the onboard computer to evaluate the safety and accuracy of LEM trajectory and generate and have available back-up guidance and abort guidance information. This information is transmitted to the IMCC, and to the LEM when required.

The CSM systems are maintained throughout the phase in such a state of readiness that the CSM can undertake and effect rendezvous with a completely disabled LEM on [ ] hours notice.

During the entire phase, the ground tracks the CSM and LEM, and uses the tracking information plus telemetry from both vehicles and crew voice reports to monitor LEM performance and status, keep abort programs updated, and correct CSM ephemeris. The IMCC stands by to supply abort data to the LEM if it is required.

2.11.3 Alternate Missions and Contingencies

The modified or alternative missions available within the nominal mission objectives involve variations of trajectory, duration of hover, and actual landing site. The probability of such modifications is inherently so high that provisions and doctrine for them will be written into the mission plan as normal "flexibility" and the crew will implement them as needed.

Abort during this phase will be accomplished by accelerating the LEM into orbit. The "normal" abort program held by the primary and backup guidance systems will be designed to bring the LEM to rendezvous with the CSM (with additional burns as necessary after the initial abort ascent burn). The irreducible minimum acceptable abort performance is insertion of the LEM into a safe orbit in which the CSM can effect rendezvous and docking without exceeding its ΔV budget. An ultimate backup abort mode will be provided which will be independent of inertial reference, computer function, and automatic control function. It will use manual controls, an open-loop flight program, a computation device no more complex than a slide rule, and optical and radar observations of the lunar surface combined with time interval measurements, to determine and control the vehicle's altitude and velocity and assure its insertion into an acceptable orbit.

If a Descent Stage Engine malfunction occurs during the descent, abort will automatically be initiated. Non-accessibility of an acceptable landing site will require abort. Failure of either primary or backup guidance system will also call for abort. Other system failures will not be cause for abort unless in the crew's judgment or under the established mission rules the risk incurred in landing is substantially greater than that in the in-flight abort. The Flight Director may command abort at any time during the descent, but will do so without coordination with the LEM crew only in the event of an emergency requiring abort of which the crew is unaware.

If the crew inserts coordinates designating a change of landing site during the descent, and the propellants remaining are insufficient to reach the new site, the guidance system activates a warning signal. If there is no crew response within [15] seconds, the guidance system will automatically initiate abort.

Aborts will make use of all remaining propulsion capability. If the Descent Stage has sufficient ΔV remaining to justify its use, it will be operated at full throttle to burnout, then staged-off, and the remainder of the powered flight will be accomplished with the Ascent Stage Engine. The transition will be accomplished if possible by igniting the Ascent Engine just before simultaneous stage-off and cut-off of Descent Stage Engine, so as to avoid the necessity for a separate ullage thrusting and still assure getting clear of the Descent Stage. There will eventually be reached a "point-of-no-abort" (a function of altitude, velocity, Descent Stage propellant remaining, and staging time), beyond which landing is mandatory. Abort must be initiated, automatically or by the crew, before reaching this point if the LEM will not be within reach of an acceptable landing site. Once past this critical point, an alarm will be activated when the propellant quantity remaining approaches the amount required to complete a landing, if the designated landing point cannot be reached or if the LEM is under manual control. If there is no crew response within [5] seconds, the vehicle will automatically be landed immediately.

2.12 LUNAR SURFACE OPERATIONS

2.12.1 Phase Definition

This phase begins with touchdown on the lunar surface and ends with the initiation of the ignition sequence of the LEM ascent engine for lunar launch. The nominal duration is /¯24_7 hours with an additional /¯24_7 hours provided for contingencies. The phase is divided into six subphases -- Postlanding Operations, First Lunar Exploration, First Work/Sleep Period, Second Lunar Exploration, Second Work/Sleep Period, and Lunar Prelaunch.

2.12.2 Nominal Mission

LEM-earth communications are available on demand continuously. However, a voice circuit is kept open to the IMCC at all times and to the CSM during the entire communication window for coordinating scheduled events and emergency operations.

2.12.2.1 Postlanding Operations

Immediately after touchdown, the LEM crew performs a status check to verify that the LEM attitude is stable and that no damage has occurred to life support and ascent systems. If the status check reveals no immediate threat to their survival, the LEM crew reports to the IMCC and the CSM that the capability exists for a lunar stay of at least one CSM orbit.

After the status check, the LEM crew readies the LEM for an expeditious launch, prepares for the lunar stay, and visually surveys the lunar surface. The nominal time allotted for these operations is /¯2_7 hours.

To prepare the LEM for an expeditious launch, the ascent and descent stages are disconnected. Star sightings are taken and the data used to align the IMU and backup attitude reference. The LEM guidance computer computes the launch parameters and ascent program for the first lunar launch window based on landing site coordinates and CSM orbit parameters in memory (see 2.11). The results of these computations are telemetered to IMCC for verification and for transmission to the CSM. A checkout is performed by the LEM crew in conjunction with IMCC of all LEM systems required for ascent. After concurrence of IMCC, appropriate maintenance actions, if any, are taken and modes of system operation are selected. A report is made to IMCC on the completion of preparations for a launch.

The capability for a LEM lunar stay of /‾48_7 hours is to be ascertained. The physiological status of the crew is determined at IMCC from crew reports and from telemetered biomedical data. A check is also made of the quantity of expendables in the ECS, EPS, RCS, and propulsion system. Until the minimum lunar stay capability is determined, the LEM systems are maintained in modes such that a normal launch can be made. After confirmation from IMCC, the LEM systems not required for the lunar stay or for a launch are powered down.

A complete checkout is made of the PLSS and all equipments to be used for exploration of the lunar surface. The checkout of the PLSS ensures that the water, electrical power, oxygen, communication and biomedical systems are functioning normally and that the stored expendables are sufficient for /‾4_7 hours of operation without replenishment. All communications between the LEM, CSM and earth are checked operationally during the CSM orbit following touchdown.

The completion of lunar stay preparations is reported to the IMCC and to the CSM. The decision to proceed with the first lunar exploration is made by IMCC.

2.12.2.2 First Lunar Exploration

Although both LEM crew members will be able to move on the lunar surface to perform scientific experiments or to rescue a disabled explorer, in the initial lunar landing mission(s) one crewman remains in the LEM to monitor system performance and meet R&D requirements. Crew members are capable of operating independently of the LEM for a maximum of /‾4_7 hours, with a nominal operating time of /‾3_7 hours. The crew task assignments and work schedules are reviewed with IMCC prior to lunar exploration. The crewmen close their suit faceplates, depressurize the LEM cabin, and one crewman leaves the LEM.

Upon reaching the lunar surface, the crewman tests his coordination and mobility. The tasks on the lunar surface include checking for physical damage to the LEM, verifying separation of the ascent and descent stages, setting up the erectable antenna and connecting the associated cables, collecting selenographic specimens, and performing other scientific experiments within /‾1/2_7 mile of the landing site. At the completion of the first scheduled exploration period, the crewman returns to the LEM.

During the lunar exploration, the crewman in the LEM performs the following tasks:

(1) repressurizes the LEM cabin (or not, depending on the planned duration of the exploration),

(2) observes the crewman on the lunar surface and monitors his equipment and physiological status,

(3) monitors the quantity and rate-of-depletion of the expendables in the ECS, EPS, RCS, and propulsion system,

(4) periodically checks the status of LEM systems that are either operating or in standby,

(5) controls LEM communications including those used for voice reports, TV transmission, and telemetry readouts to IMCC, and communications with the CSM,

(6) receives, once each CSM orbit, a set of IMCC verified orbit parameters,

(7) participates with IMCC and the CSM in one rehearsal of emergency prelaunch operations.

During the LEM lunar stay, the CSM crewman, in conjunction with IMCC, verifies the operating condition of CSM systems, particularly the quantity and rate-of-depletion of all expendables, by monitoring the displays and performing in-flight checkout. CSM-LEM and CSM-earth communications are checked operationally during the communications windows.

IMCC calculates LEM launch parameters and ascent programs for nominal and abort modes of ascent based on landing site coordinates obtained from CSM optical sightings. These calculations are made and the data transmitted to the LEM, if required, between [10] and [30] minutes prior to launch time.

IMCC analyzes telemetry data from the LEM and CSM to determine the operating condition of all systems required for the remainder of the Apollo mission. Failures or impending failures must be detected and diagnosed to determine effects, probable cause and appropriate remedial action. IMCC alerts the crew members when conditions exist, in either the LEM or CSM, that require remedial action or deviation from the nominal mission.

2.12.2.3 First Work/Sleep Period

The duration of this subphase is nominally [7] hours.

The work/sleep schedule for the crew members [is required] to conform to the following guidelines:

(1) The minimum continuous period of sleep for any crew member will be [2] hours.

(2) Each crewman will have at least [6] hours sleep during the [24] hour lunar stay.

(3) Both LEM crew members will be awake during the lunar surface exploration.

(4) One LEM crewman will be awake during scheduled work/sleep periods.

A work/sleep schedule for this subphase which satisfies these guidelines is to allot at least /¯3_7 hours of sleep to each LEM crewman and /¯4_7 hours of sleep in the middle of the subphase to the CSM crewman.

After entering LEM, the crewman who was exploring the lunar surface records his findings, begins replenishment of his PLSS, and sleeps for the next /¯3_7 hours. The other LEM crewman closes the front hatch, repressurizes the LEM cabin, and performs tasks similar to those performed during Postlanding Operations to maintain the LEM in a condition ready for an expeditious launch.

2.12.2.4 Second Lunar Exploration

In a nominal mission, the operations performed during this subphase are similar to those already described.

At the conclusion of the second exploration, the exploring crewman disconnects the erectable antenna and associated cables. Portable equipment used solely for lunar exploration and equipment not required for ascent or rendezvous is left on the lunar surface. Selenographic specimens accumulated during lunar exploration are secured in the storage area. The ladder used for reaching the lunar surface is cast away and the forward docking hatch is secured.

2.12.2.5 Second Work/Sleep Period

In a nominal mission, the operations performed during this subphase are similar to those already described.

2.12.2.6 Lunar Prelaunch

The objective of lunar prelaunch operations is to determine and reach the best man-machine configuration to perform the ascent, rendezvous, and docking phases of the mission. The time allotted for these operations is [2] hours.

All prime and back-up systems required for ascent, rendezvous, and docking are turned on in proper sequence and checked out. The checkout is evaluated by the LEM crew, in conjunction with IMCC, to determine appropriate maintenance actions, if any, and to select modes of system operation. Star sightings are taken to obtain data for aligning the IMU and the back-up attitude reference. A final set of updated CSM orbit parameters is transmitted to the LEM from IMCC (or as a back-up, from the CSM after being verified by IMCC) and inserted in the guidance computer. The launch parameters and ascent program for the scheduled launch are computed on the LEM and telemetered to IMCC. After these computations are verified by IMCC, the operating modes for both the primary and back-up guidance systems are selected.

During the communications interval prior to launch, a final check is made between the LEM, CSM, and IMCC to determine that all is in readiness and the time of launch is synchronized. In the [2] minutes before launch, the LEM crew starts the countdown and initiates the ascent engine firing sequence.

2.12.3 Alternate Missions and Contingencies

2.12.3.1 Immediate Termination

At any time during the lunar stay, if conditions arise that make further stay unacceptably hazardous or jeopardize the ability of a successful launch from the lunar surface (e.g., fuel leak in LEM ascent engine), termination of the lunar stay will be made as rapidly as possible. An expeditious checkout

/‾ i.e., 10 min. _/ will be made and the LEM launched into parking orbit. Launch from the lunar surface will await the next normal launch window except for specific emergency conditions in the LEM. For such conditions, one or more ascent trajectories may be available depending on the orbital position of the CSM at the time of launch. The ascent program will be selected by the LEM crew on the basis of ΔV available and predicted time in parking orbit.

If the LEM status check, which is performed just after touchdown, reveals that the capability does not exist for a lunar stay of at least one CSM orbit, an immediate launch will be made to take advantage of the favorable CSM position for early rendezvous.

2.12.3.2 Launch Next Launch Window

Conditions in either the LEM or CSM could result in a decision to quickly terminate the lunar stay (e.g., degraded operation of CSM electrical power subsystem would require return to earth as soon as possible). Prelaunch operations would be performed normally or with an expeditious schedule, as in the previous option, depending on the degree of urgency.

In the event of an extended disruption in communications between IMCC and the LEM or CSM, the lunar stay will be terminated and the LEM launched during the next launch window. Under these circumstances, launch guidance operations in the LEM and CSM will utilize the last orbit parameters, launch parameters, and ascent program that were verified by IMCC.

In the event one LEM crewman becomes incapacitated, the lunar stay will be terminated. The design of the LEM will permit one crewman to perform the prelaunch operations and to take complete control of the LEM for the remainder of the mission.

2.12.3.3 Curtailed Lunar Stay

Conditions in either the LEM or CSM (e.g., greater than anticipated depletion of the oxygen supply), may result in the decision to curtail the lunar stay by one or more CSM orbits. Prelaunch operations would be performed in a normal manner.

Single failures in the LEM or CSM are not necessarily cause for termination of the lunar stay. If maintenance is possible, or if one or more alternative methods are available for completing the mission, the lunar stay may be continued if IMCC judges that the probability of crew safety is sufficiently high. If a discrepancy arises between the IMCC and crew regarding the operating condition of CSM and LEM systems, the worst case view will prevail and operational decisions will be made accordingly.

The decision policy for termination of the lunar stay must be developed from a failure-effects analysis of all LEM and CSM systems required for the remainder of the mission. A more definitive statement cannot be made at this time.

If during Postlanding Operations it is determined that only a /¯4_7 hour lunar stay capability exists, one crewman will make a curtailed exploration of the lunar surface. For a lunar stay of less than /¯4_7 hours but more than /¯2_7 hours, a curtailed exploration may be made if crew safety is not unduly compromised. This decision is made by the IMCC.

2.12.3.4 Delayed Launch

During prelaunch operations, certain conditions may cause IMCC to authorize a delay in the LEM launch (e.g., discrepancies between LEM and IMCC computations of launch parameters or ascent program). Launch may be delayed for less than the duration of the launch window, if remedial action can be accomplished in time. Otherwise, the launch will be delayed for one CSM orbital period; or if conditions exist which require the Immediate Termination Option, launch will be delayed only until remedial action is accomplished.

2.13 LEM ASCENT

2.13.1 Phase Definition

The LEM Ascent phase begins with initiation of the LEM ascent engine ignition sequence and terminates after a successful ascent with the preparations for rendezvous. The phase duration is normally /_ 2_/ hours, and a maximum of /_ 12_/ hours in emergencies.

2.13.2 Nominal Mission

The normal LEM ascent consists of a powered flight, or boost, followed by one or more segments of free orbital flight and additional thrusting events, which bring the LEM into close proximity to the CSM. A final thrusting event inserts the LEM into a co-orbit with the CSM.

The free-flight segments of the ascent must lie in orbits all points of which are safely clear (50,000 feet or more) of the lunar surface. There is no requirement that a CSM-LEM line-of-sight exist at launch or during the ascent. The ascent guidance program is required to calculate and control the ascent, minimizing propellant consumption, with the launch point as much as /_ 2_/ degrees (lunar central angle) from the CSM orbit plane and the launch as much as /_ 14_/ minutes delayed /_ or __ minutes early_/. If the LEM is not launched on schedule and/or the LEM initial position lies out of the CSM orbit plane, trajectory problems and propellant-cost penalties are incurred.

The simplest LEM ascent, in which the LEM lies in the CSM orbit plane, begins when the CSM has passed over the LEM and leads it by a specified small amount. The LEM is boosted directly into a transfer orbit, at perilune, at /_ 50,000_/ feet altitude. The transfer orbit's apolune lies on the projected CSM line of movement. The LEM launch is timed to put the LEM at apolune as the CSM arrives at the same point. A second LEM engine burn inserts the LEM into co-orbit with the CSM. If the LEM launch is delayed, the LEM is initially inserted into a low-altitude circular catch-up orbit instead of the transfer orbit. In this orbit, the position (phase) of the LEM relative to the CSM gradually advances. When the appropriate phase angle is reached, a second thrusting inserts the LEM into transfer orbit. At the apolune intercept a third burn of the LEM engine effects insertion into co-orbit with the CSM.

The dwell or phasing time in the catch-up orbit is approximately 9 times the launch delay. If launch is delayed too long, the phasing time becomes longer than the CSM orbit period. Rendezvous can then be achieved sooner by launching after the next passage overhead of the CSM. This crossover point defines a "nominal launch window" for the coplanar case. The LEM is launched only within a nominal launch window unless loss of capability of launch is imminent or an unacceptable hazard in remaining on the lunar surface has developed. A similar window and constraint will exist for any ascent geometry or mode. Since a small variation in launch time causes the rendezvous point to vary through the entire CSM orbital cycle, control of the launch time as directed by the IMCC can be used to control the general location of the rendezvous.

When the LEM at launch does not lie in the CSM orbit plane, a corrective maneuver is necessary. This can be accomplished in any of several ways. It is not possible at present to state that one is clearly preferable. The ascent plans under consideration most closely resembling the idealization above, and which retain the economy and safety, also require precise on-time launch, take a long time to complete, and are sensitive to launch errors. A second group, which deviate from perilune insertion and apolune intercept in the transfer orbits, do retain safe perilune clearance and flexibility in phasing time but incur moderate to severe propellant consumption penalties and introduce guidance complexities. A third class, using a short direct ascent, are flexible, economical, and insensitive to launch errors but, in them, the transfer orbits are not everywhere clear of the surface.

Where not affected by the uncertainties above, the operational concept, principles, and procedures are better established. The remainder of the discussion is essentially independent of the details of the ascent guidance and propulsion program.

The LEM crew monitors the launch event sequence to verify ignition at scheduled clock time and lift-off of ascent stage at the nominal time after ignition.

The LEM crew monitors trajectory and key system performance parameters to switch to a back-up system if the prime system is out of tolerance.

The CSM and the ground monitor the ascent trajectory of the LEM and stand by to assist with guidance or other advice as required. The CSM or ground supplies parameters when required for orbital corrections during the ascent, and must be able to provide back-up navigation information for the rendezvous. The CSM tracks the LEM whenever possible, and derives LEM trajectory and guidance information from the tracking data plus its own orbit parameters and data from the ground.

During the ascent, LEM, ground, and CSM data are used to calculate orbital corrections. The parameters are inserted into the LEM guidance, and the correction effected. The LEM crew acquires and tracks the CSM when in range. The LEM crew initiates rendezvous and docking maneuvers after insertion into co-orbit, and the CSM provides a stable target.

In the nominal mission the LEM crew prepares to commence rendezvous maneuvers when the LEM closes within /‾20 _7nautical miles of the CSM.

Both LEM and CSM homing and identifying beacon lights are turned on before LEM launch and remain on throughout this phase.

2.13.3 Alternate Missions and Contingencies

There is no abort in this phase. Mission success and crew safety depend absolutely upon successful launch using the Ascent Stage Engine, and successful completion of rendezvous with the CSM. Once the LEM ascent is started, all emergency life support, electrical, etc., modes will be used, if needed, to complete the ascent. There will be no reserves held back for a possible later emergency if now needed. Foreseeable alternatives and contingencies involve casualties to Guidance and Control, to Propulsion (after first burn) to Communications, or to Personnel.

Highly reliable back-up modes (which are permitted to be relatively inaccurate) are required in case of serious degradation in the prime guidance and control systems. As discussed in 2.11, LEM LANDING, an ultimate backup mode is required which can put the LEM into a safe orbit, in which the CSM can effect rendezvous and rescue, with all of the LEM's automatic computation, guidance, and control systems dead. After lift-off, any means available will be used and any degraded operation that cannot be bypassed will be accepted to achieve (in order of priority): (1) an ascent to nominal direct rendezvous; (2) an ascent to an orbit from which the LEM can later make rendezvous with an orbit transfer maneuver, or (3) an orbit where CSM can make a rescue intercept.

Should the LEM be launched outside the nominal launch window because of imminent loss of ascent capability, the CSM must presumably effect rendezvous in whatever orbit the LEM has attained (or can attain by thrusting with the RCS). If the LEM launch is at such time that phasing time required is greater than /‾9_7 hours, LEM endurance capability will be exceeded unless the CSM alters its orbit to increase the phase advance rate. Additional maneuvers by both vehicles may then be required to complete the rendezvous. Decision on the procedure will be made by the IMCC in consultation with the CM and LEM crew, and based on the mission rules and the existing LEM capability. In any case, when it becomes necessary to change the CSM orbit, it will be done only after the attained LEM orbit is determined. Both orbits will not be altered at the same time. A casualty to the Ascent Stage propulsion system after insertion into a "rescuable" orbit would have essentially the same effect as loss of LEM Guidance and Control capability. The CSM would have to adjust its orbit, using one or more orbital segments, to effect rendezvous with the LEM. If the propulsion failure occurred only a small ΔV away from insertion into a rescuable orbit, the Reaction Control System might be used to apply the final increment. The RCS may also be used to help minimize the CSM's difficulties or propellant expenditure in effecting the rescue, by making adjustments to the LEM's orbit. The LEM can use its own Guidance and Control, or data supplied by the CM, for this purpose. Mishap to crew member could influence the decision to dock, but not affect the ascent itself. If both crew members of LEM suffered mishap, CSM crew member would remotely attempt to launch the LEM and effect the orbital corrections and, if successful, complete the rendezvous maneuver and carry out docking.

The LEM launch from the lunar surface may be deferred for one or more CSM orbital cycles if there is malfunction of any potentially critical nature and repair can possibly be effected.

Total loss of communications with the LEM before launch will require deferring the launch for one CSM orbit so that efforts may be made to restore the service. If restoration is not effected, the LEM will be launched in the next window and rendezvous will be completed in the nominal manner (as closely as possible) by the LEM. If rendezvous has not been effected by the normal time after LEM launch plus one CSM orbit, the CSM will make all subsequent maneuvers and complete the rendezvous.

Some possible casualties will with near certainty cause loss of the LEM crew. Among these are Ascent Stage Engine failure before attaining orbital velocity, disablement of both crewmen before launch, mechanical failure preventing launch or causing crash during or after launch, guidance malfunction causing crash, or attainment of an "unrescuable" orbit. The IMCC will make any and all decisions, arising from these or other circumstances, concerning return of the CM to Earth without completing rendezvous with the LEM.

2.14 LUNAR ORBIT RENDEZVOUS

2.14.1 Phase Definition

The rendezvous begins when the rendezvous guidance mode is selected (LEM and CSM are [20] n.m. or less apart) and ends with completion of post-docking status check. The phase duration is approximately [60] minutes.

2.14.2 Nominal Mission

The rendezvous and docking is not constrained to occur in any particular portion of the lunar orbit. The location of the rendezvous is determined by the particular site at which the LEM was landed, the requirement for plane change in the ascent phase and the time of LEM launch. The docking mechanisms in both the LEM and CSM were activated, and the docking lights turned on, before the LEM launch. The LEM computer solves all rendezvous problems, using presupplied information and LEM rendezvous radar data obtained during this phase. The computer generates the vector ΔV required to approach the CSM. The CSM computes analogous ΔV increments based on equivalent data for the CSM for use if it should become necessary for the CSM to effect rendezvous with the LEM. The computed ΔV's are applied in a series of identical maneuvers by the LEM ascent engine or RCS to bring the LEM to close proximity with the CSM. When closing conditions for commencement of the final maneuver are achieved, the LEM crew selects the manual control mode and, using the optics, completes the approach.

In the nominal mode the docking maneuver is performed by the LEM with the CSM stabilized. For minimum residual angular rates the axis of the CSM and the line of relative motion of the vehicles are oriented perpendicular to the CSM orbit plane. The sense of the orientation, or the use of any other orientation, is established by coordination between the LEM and CM crews. The LEM crew maneuvers the LEM to align the CM and LEM docking fittings, using optics and external visual docking aids on the CM. They adjust the closing rate according to the remaining distance, while continuing to maintain the alignment and zero inertial angle rates to the CSM, using the Reaction Control System. Normally, verbal reports on progress and visual observations are exchanged by the crews in the LEM and the CM. Both the LEM and the CSM are, however, required to be able to dock without the aid of a crew in the other vehicle. [Both the LEM and CSM are depressurized and have their hatches open during docking.]

After obtaining a solid docking, the crews determine that no operational problems exist that require immediate attention. LEM systems requiring monitoring or control from the CM are set up in this mode. Personnel, equipment and specimens are then transferred from the LEM to the CSM. The LEM is left attached until after the pre-injection checkout of the CSM, in order that any LEM parts, batteries, or other systems that are required by the CSM may be transferred to the CSM.

The ground tracks both vehicles during the rendezvous and docking maneuvers if the maneuvers occur within line-of-sight of the ground. The ground monitors systems status for information purposes and to assess the remaining operational capability of the LEM.

After the docking and transfer is complete, a check is made to determine that no damage was incurred during the operation. Completion of docking and transfer, and damage incurred, if any, are reported to IMCC. The spacecraft crew then begins the pre-injection checkout.

2.14.3 Alternate Missions and Contingencies

There is no abort from this phase. Mission success and crew safety depend absolutely upon completion of rendezvous and successful transfer of LEM crew to the CM.

Contingency options available include: provision of guidance data by the CM to the LEM for completion of rendezvous; execution by the CSM of the required maneuvers for completion of rendezvous; docking by the CM to the LEM (including stabilization of the LEM by command from the CM). In the event of personnel casualty or disability, it may be necessary for a crewman of either vehicle to enter the other without assistance from within. It may also be necessary, if a hard dock is impossible to complete, to transfer personnel and equipment through space from one vehicle to the other. Approval of the IMCC is not required before undertaking this. The necessity and the adoption of this mode will be reported to IMCC as soon as possible.

[If the SM has sufficient ΔV reserve remaining to inject the additional LEM mass into the Earth Transfer Trajectory, the LEM may with IMCC approval be retained attached to the CSM until the SM stage-off just before reentry. (This is possible with a 10% fuel margin in CSM.)]

2.15 TRANSEARTH INJECTION

2.15.1 Phase Definition

This phase begins with the LEM stage-off maneuver and ends with completion of the post-injection situation report. The phase duration is approximately [1 1/2] hours.

2.15.2 Nominal Mission

Five minutes before the scheduled time for effecting LEM stage-off, which occurs in view of the earth, the spacecraft is oriented and held with the CSM in an attitude favorable for trajectory shaping and for uninterrupted earth communications during LEM separation. Final selection of control modes is made and verified per crew check list. The docking mechanism is manually tripped, and release is verified by a crew display. [Thereafter, the Crew Commander remotely activates an LEM sequencer that pulses the LEM RCS for a (5) fps ΔV in positive X-axis translation .] After separation, CSM attitude is such that LEM movement away from the CSM has an out of plane velocity vector with a velocity component that is both retrograde to the CSM flight path vector and biased toward the moon. During the first [10] seconds after separation, the crew verifies visually that docking fittings and umbilicals have cleared normally and that the relative motion of the CSM and LEM is satisfactory. CSM attitude is held until a separation of [500] feet is attained. [Tracking data, using the rendezvous radar, is obtained to estimate the LEM orbit.] A situation report is made to the IMCC, and attitude and modes for cruise are established. Rendezvous aids and functions specifically active for LEM control and for the stage-off maneuver are powered down. Telemetry data, including a bio-medical sample for each astronaut, are transmitted to IMCC for evaluation of readiness.

Navigational data are obtained by the flight crew using sightings on lunar landmarks, and tracking data are obtained by the DSS. The Crew Commander verifies that the orbit remains consistent with programmed values and the IMCC provides final injection parameters and timing. The crew continues to monitor systems required for injection and for cruise operation. They effect maintenance actions, adjustments in operational settings, and changes of modes that are required and authorized after stage-off.

After loss of communications between the CSM and earth, telemetry data recording mode is selected and the IMU is fine aligned. Crew members are suited and strapped in maneuver stations 10 minutes before start of the propulsion maneuver. Operating modes for the injection maneuver are selected and verified against crew check lists during the following 5 minutes. The CSM is then oriented for the maneuver and held in the proper attitude. Gimbal trim is adjusted, and final crew confirmation of readiness is accomplished 1 minute before scheduled start of injection. The G&N ΔV guidance and control mode is activated.

Sequencing and guidance control during pre-ignition and SPS propulsion are automatic, under the control of the CM AGC as defined previously for Lunar Orbit Insertion. The crew monitors spacecraft performance during the powered maneuver, and is prepared to 1) make operating adjustments or select alternate modes to complete the maneuver, 2) take manual override actions to assure successful completion of the injection, and 3) initiate engine cut-off manually to prevent an overburn if programmed ΔV is exceeded by more than /‾ _7 fps. Monitoring during the thrusting period is supplemented by gross visual checks of orientation using celestial bodies for reference.

Immediately after engine cut-off the flight crew checks to determine if any operating problems require immediate attention, and verifies that computer estimate of attained trajectory is within planned limits for acceptable transearth cruise. CSM systems are set for postinjection cruising flight. Crew observations on system performance during the injection are collected and summarized. Concurrently, navigational equipments are prepared for and used to obtain positional fixes for refinement of orbital parameters. Optical sightings on lunar surface landmarks, and navigational fixes on celestial bodies, are used for this purpose.

Contact with the scheduled deep space station is made as soon as the moon clears the CSM-earth line of sight. This occurs approximately /‾20_7 minutes after the start of the injection maneuver. The Crew Commander makes a verbal situation report to the IMCC. Direct and stored telemetry data is transmitted to the ground for IMCC evaluation. The IMCC assists in assessing system status, and recommending appropriate actions based on the crew's verbal reports and transmitted telemetry. The Flight Director gives concurrence for proceeding according to nominal plan for the transearth cruise or revises schedules and procedures.

2.15.3 Alternate Missions and Contingencies

If significant operating troubles arise during or subsequent to LEM stage-off while in the lunar parking orbit, the Crew Commander will determine whether to proceed into subsequent subphases using back-up modes or to defer such action for one or more orbits to permit repair attempts. In the latter instance, IMCC will assist in assessing the seriousness of the trouble, and will recommend specific actions, procedure changes, and new schedules for succeeding subphases (particularly, the injection window for effecting transearth cruise). If the LEM stage-off sequencer malfunctions when activated, the SM RCS will be manually pulsed to achieve /¯6_7 ft. of negative X-axis translation. After visual confirmation of clearance, an attitude maneuver will be performed to align the positive X-axis of the CSM opposite to the flight path vector then, a velocity impulse of /¯5_7 fps. will be applied along the negative X-axis.

The injection must start within ± /¯ _7 seconds of the scheduled time to effect the maneuver within the allocated fuel budget. If minor troubles disrupt normal start of ullage or SPS firing, manual initiation of the sequence will be used. During the thrusting period, every effort will be made by the crew to complete the injection before thrust is terminated. Manual guidance will be used as a back-up, if necessary, to prevent gross attitude error. Unbudgeted fuel reserves will be expended if needed. Corrective operating adjustments or selection of alternate modes will be made, when possible, to alleviate troubles in essential services or non-guidance systems. Early engine cut-off will only be used to prevent impending SPS explosion -- in which instance, after coordination with the IMCC, SPS fuel may have to be used through the SM RCS in a continuous thrusting mode for a long interval to correct the trajectory for effecting return to a usable reentry point.

No abort options are available during this phase. However, upon recontact with the IMCC after injection, plans can be made for shaping the trajectory during the first mid-course for minimizing time of flight or optimizing energy usage during the flight.

In the event that two-way communications with the earth cannot be established during the injection phase, the phase will be completed as scheduled, or according to programmed abort plans, to a planned landing point. One-way transmissions will be sent "blind" periodically to advise of actions taken and planned schedules.

2.16 EARTH TRANSFER CRUISE

2.16.1 Phase Definition

This phase begins upon completion of the post-injection situation report and continues until completion of SM stage-off, except during the intervals associated with midcourse corrections as previously defined in 2.7. Duration of the Earth Transfer Cruise is from /‾62 to 110_7 hours. The final /‾2_7 hours of this period are used to prepare for and complete the SM stage-off.

2.16.2 Nominal Mission

Operations during routine cruise are similar to those in the Lunar Transfer Cruise and, in general, are as described in 2.6. Ground-based tracking and spacecraft navigational observations are continued until the trajectory is determined to an accuracy adequate for guidance computation. Periodic voice reports and telemetry data, augmented by system checkouts associated with each midcourse maneuver, are used to monitor status and assess flight capabilities. Data from scientific experiments are transmitted to the DSS as scheduled.

One crew member continuously monitors CSM systems for controlling modes and attitude. After the injection situation report, two crew members remove their spacesuits and start the rotating work/rest cycle for the return flight. This cycle normally continues without interruption until /‾2_7 hours before starting the SM stage-off operation. When possible, non-critical operating troubles are cleared without disrupting sleeping schedules, by using alternative modes and spare electronic packages. However, sleep and rest periods may be dirsupted or omitted, when troubles exist in essential services, if the outage period will jeopardize crew safety or vital maneuvers. All crew members have their spacesuits on at least /‾20_7 minutes before stage-off.

In general, the non-sleeping, standby astronaut performs all authorized maintenance actions during the drifting flight intervals between guidance maneuvers. He also makes scheduled navigation and scientific observations, system checks, and observes personel relief periods. Midway between the last two planned midcourse corrections, a passive system check is made of capabilities that have been idle throughout the bulk of the mission, but will be essential for some portion of the interval between SM stage-off and earth landing. This allows ample time, in case of trouble, for coordination between the IMCC and the flight crew in maintenance actions, changes in procedures, or establishment of emergency configurations.

The IMCC provides precise orbital parameters, calculates refined guidance parameters to be used for each maneuver, and sets mission schedules. After the final midcourse correction, the Flight Director establishes the schedule for SM stage-off preparations. Adequate time is allowed, within solid coverage by the DSS, for 1) completing all preparations and effecting minor corrections or changes (1 1/2 hours), 2) performing the stage-off (5 minutes), 3) observing separation drift and estimating SM trajectory (5 minutes), and 4) verifying that previously determined trajectory parameters for reentry can be used (5 minutes). Navigation observations by the crew and ground tracking data are used at the IMCC to obtain adequate precision for establishing the reentry point and desired reentry maneuver profile.

Ground tracking coverage is essentially continuous until [20] minutes before reentry. SM stage-off is normally completed [30] minutes before reaching the reentry point.

Prior to stage-off, the crew and the IMCC monitor key status information for any indications of problems that will affect operations at and after stage-off. If none are detected, final IMCC concurrence to proceed is given [10] minutes before stage-off. The flight crew establishes equipment modes required for stage-off and planned vehicle orientation [5] minutes before stage-off. [30] seconds before stage-off, the Crew Commander makes the final confirmation of critical display values and control settings. Then he arms the SM stage-off circuit. At the end of countdown, he initiates the stage-off by activating the stage-off circuit.

The stage-off is performed with the CM X-axis aligned with the flight path vector. The SM stage-off circuit starts an SM sequencer that fires the pyrotechnics which sever CM-SM structural, service, and instrumentation connections, and cause the SM RCS to thrust all -X engines until they burn out. CM valves and switches automatically shift to internal services. The flight crew switch the communications systems to CM antennas and verifies that the CM RCS pressurizes and activates, and that the power supplies stabilize on batteries.

Crew displays are used to confirm that appropriate sequencing occurs and that stage-off is complete. After 10 seconds and confirmation of SM RCS firing, the CM is rotated for visual observation of separation rate and direction. The crew checks that no operating problems have arisen due to the stage-off, set configuration for post-stage-off flight while taking into account any known deficiencies, and makes a situation report to the IMCC.

The IMCC is able to confirm, by tracking, any change in the CM reentry point due to SM separation, and this information is sent to the crew prior to loss of DSS contact. The CM G&N system computes any such changes from onboard measurements.

This ends the stage-off subphases. In case the SM stage-off is delayed beyond loss of contact with the ground, the phase ends when the Crew Commander verifies to his own satisfaction that the SM is separated at least [ ] feet from the CM.

2.16.3 Alternate Missions and Contingencies

The effects of operating problems that arise during Earth Transfer Cruise could be limited by changing the operating modes, the number of midcourse corrections and other scheduled activities, and the amount of communication with the ground. At least a brief situation report will be transmitted at [six] hour intervals as a minimum during the cruise, and continuous voice communication would be highly desirable during midcourse maneuver phases, the SM stage-off phase, and, when coverage is available, the reentry phase.

Possibilities of an alternate mission are limited to effecting an emergency abort trajectory for minimizing the time of return flight or shaping the present trajectory by a minimum thrust budget to effect a successful reentry (in case of SPS malfunction or serious fuel depletion). These alternates will be used only at last resorts. Where possible, reliance on back-up equipment would be preferable because the altered trajectory disregards the deployment of recovery forces in the primary and secondary landing areas. The decision to initiate either of these extreme alternates will be made through crew-IMCC consultation and concurrence, unless all two-way communications with the earth have been lost. In that event, the crew will transmit information "blind" on the intended action before initiating the maneuver. During the remaining cruise, the crew will transmit information "blind" periodically, while continuously attempting to reestablish two-way voice contact with the ground. [2] hours before reentry, all CM transmitters will be activated and all modes used in an attempt to establish two-way contact with the ground and permit ground tracking of the CM by any tracking station.

For mission planning, it is assumed that, under any circumstance, the SM fuel would not be sufficient to deboost into a parking orbit from which a rescue could be effected by an earth launch and intercept, before CSM essential supplies are exhausted. Reentry with the SM attached would NOT be an acceptable emergency option.

During SM stage-off preparations, if problems are encountered that reduce capability for separate CM operations, stage-off could be delayed by either the Flight Director or the Crew Commander. Depending on the nature and severity of the problem, the IMCC could offer instructions for clearing or limiting the effect of the difficulty by use of a different mode, change of configuration, or alteration of steps in the stage-off sequence. The latter involves reducing the time allowed for ground tracking, elimination ground tracking altogether, or delaying the SM stage-off to emergency limits. Similar decisions will be made by the Crew Commander in case of loss of ground contact or when demanded by the urgency of the problem. SM stage-off would be initiated in all cases at least [10] minutes before nominal reentry to allow time for reorientation of the CM and drift of the SM to a safe separation distance before experiencing the effects of the atmosphere.

If the SM RCS firing is not confirmed at stage-off, the astronauts would delay 30 seconds and then use the CM RCS to move the CM to an orientation where the SM could be observed. Then, they would use the CM RCS to obtain sufficient separation velocity to insure that the SM will be a minimum of 1,000 ft. away from the CM at the expected reentry point.

If the primary guidance system of the CM were not operable for reentry, the flight crew and the IMCC would select a manual control strategy that optimizes the CM attitude control. They would coordinate the implementation of the selected strategy.

2.17 REENTRY AND LANDING

2.17.1 Phase Definition

This phase begins at completion of SM stage-off and ends at touchdown. Its duration is [45 to 60] minutes.

2.17.2 Nominal Mission

Upon completion of stage-off, the crew makes the changes in modes and settings to establish the configuration for reentry. In the event of a change in the desired landing point, new coordinates will be supplied by the ground before loss of communication. Such information from the ground will be received, verified, and stored in the computer. Trajectory information for updating requires the use of a standard form [position, velocity, and time] for acceptance and insertion into the computer without alteration in existing routines.

From completion of the stage-off phase, up to [10] minutes before reentry, the Crew Commander may select the most desirable mode of operations for earth observation for navigation purposes, to minimize sun heating or radiation exposure, or may allow the CM to drift (monitoring is needed to protect against IMU gimbal lock). By [10] minutes before reentry, the Crew Commander orients the SM to the attitude for reentry. He verifies that all necessary mode settings for reentry are proper by [5] minutes before reentry and at that time makes a final check of critical control and display settings. He selects the automatic reentry guidance mode for attitude control and stands by to monitor critical parameters during the maneuver.

The reentry trajectory has four parts. The first part is a dive into the atmosphere using aerodynamic lift to achieve a zero altitude rate. The onboard computer calculates a reference trajectory for the remaining parts. In the second part, the AGC flies the CM according to the calculated reference trajectory either to the edge of the atmosphere or to the proper altitude for the third part. The third part consists of either a sub-orbital skip out of the atmosphere or a constant altitude part which patches onto the fourth part, which is an equilibrium glide to the point of parachute deployment. During the initial descent, lift may be directed down if the trajectory is near the skip-out limit of the entry corridor, or it may be directed to the side if there is a large lateral range to make up. During the atmospheric portions of the flight after the initial pull-up, roll commands are generated by the AGC based on the difference between measured and predicted values of drag, and on the difference between calculated and predicted values of altitude rate for the calculated trajectory. Lateral range control is effected by calculating lateral range capability and performing roll-over maneuvers as needed to keep the touchdown point within the range capability. Trajectories generated by the G&N system are selected to be compatible with steering strategies planned for emergency manual take-over assuming such take-over could occur at an arbitrary time during the entry.

The crew verifies that .05g deceleration occurs within /‾5_/ seconds of the anticipated time, and that deceleration and heating plots stay within profile limits on the respective indicators. They observe indicated attitude to verify that it remains stable at prescribed values of pitch and yaw, and that inertial roll orientation is controlled to follow the proper flight path. The spacecraft Commander is prepared to switch to manual control in case of guidance malfunction, loss of primary orientation reference, or automatic orientation control trouble.

There are no G&N requirements for communication with or tracking of the spacecraft from the time the entry point is reached until the final descent and landing. However, communication will be attempted whenever feasible (e.g., until blackout occurs, during a skip maneuver, and throughout the final descent and landing). The CM transmits telemetry data and has a tracking channel active throughout the entry phase.

A tracking station in the vicinity of the pull-up obtains tracking data to determine 1) the time, position and altitude at which zero altitude rate occurs, 2) the velocity and flight path angle at the start of the ballistic part (at 300,000 feet altitude), 3) the position of the second entry point, and 4) whether the landing point lies within the ranging capability of the vehicle. This ship will attempt to establish communication with the CM to relay to the crew the ground's calculated time, position, and velocity at the second entry (300,000 feet). If the landing point lies near the edge of the CM's ranging capability, this fact will be relayed to the CM also. It the chosen landing point lies outside the ranging capability, the coordinates of an alternate landing point will be relayed to the CM. The command data link will be used as the prime communications link, and the voice circuit will be used as a back-up.

Depending on the ground coverage, after the end of the communications blackout, exchange of all or only some of the desired information may be effected. The spacecraft crew will use this information as a cross check against onboard derived data in determining whether any adjustments in parameters should be made for the final reentry profile. Regardless of success in communication relay with the CM, the data results at the tracking ship are sent to IMCC and the Recovery Control Center during the ballistic portion of flight. The estimates are used in deciding on any last minute changes in plans for the search and recovery phase, for alerting units as to timing and angles for aerial sightings, and for sector searches after impact.

At 25,000 feet, the forward heat shield is jettisoned by pyrotechnics followed by drogue chute deployment by mortar. At 15,000 feet the drogue chute is released and the pilot chutes are deployed by mortar. The main chutes are deployed in a reefed condition for 6 seconds and then disreefed. The HF/VHF antenna is deployed manually and the recovery beacon is turned on. The remaining RCS fuel will be burned in a manner that will not interfere with the parachutes. The main chutes are released automatically at touchdown. During this sequence the crew monitors event sequence and temporarily inhibits or manually initiates these events if, in their judgment, such action is needed to effect a safe landing.

During the glide and landing, appropriate ground elements make visual and electronic searches. If contact is established, sighting reports will be transmitted to IMCC and Recovery Control Center giving time, location, distance and direction of flight, and any other pertinent data. If telemetry or voice communication contact is made by any unit during the ballistic or glide or landing portions, a brief situation report will be relayed to IMCC and RCC. Assistance or information that the spacecraft crew can use will be provided, if available.

Search and Recovery forces adjust their positions as new predictions on the landing point are made available. The forces monitor direction-finding receivers to make position information contacts during the landing phase. Such contacts will be reported to IMCC and RCC as soon as possible to assist in defining the search area, if search is required.

2.17.3 Alternate Missions and Contingencies

If stage-off is completed on schedule but conservation of battery energy is necessary, the crew will set non-critical functions to standby or power-off (e.g., S-band communications system, air recirculation fans, etc.). Power to the IMU and computer should not be disturbed, unless absolutely necessary.

If the primary guidance system becomes inoperable, manual control and other back-up modes will be used to achieve a suborbital condition within heat and acceleration design limits. If available, computer driven displays will be used to fly the spacecraft to the primary or secondary landing site. Otherwise spacecraft attitude will be controlled to remain within acceptable acceleration and heating limits, accepting any landing point attainable without skip-out.

During the final descent, sequential steps in deploying landing aids may be manually initiated or delayed.

2.18 SEARCH AND RECOVERY

2.18.1 Phase Definition

The search and recovery phase begins, in mission time, at CM touchdown and ends when the crew is returned to a designated area. However, the phase may begin in the pre-launch phase or weeks after the scheduled touchdown of the spacecraft due to the possibility of an alternate mission including aborts curtailing or extending the nominal mission time. The distribution and planning of recovery forces must reflect this variable time of initiation.

2.18.2 General Recovery Operations

Recovery operations under the Recovery Director at the IMCC are, in general, conducted by the Department of Defense with the assistance, as required, of other government agencies. NASA supplies technical assistance in the development, evaluation, and procurement of special equipment for search, communications, pick-up and post-flight operations with the spacecraft.

The recovery philosophy uses planned and contingency landing support as in previous manned space flight. The planned landing support is situated to cover the most probable landing areas from the Pre-Flight Phase through the Reentry and Landing Phases that may result from the selection of an alternate mission. The planned support is a "dense" distribution of recovery forces provided so that the crew can be recovered from any landing point within the specified areas within NASA-designated access times for the area. The contingency support is a "loose" and flexible distribution of recovery forces situated so that all physically possible landing points can be reached within a NASA-designated time for each point. The maximum time allowable to locate and render assistance to the crew is based on 72 hours of maximum life of the post-landing batteries. Special requirements placed by the nominal and alternate mission are discussed in paragraphs below.

Before launch, a primary landing area is designated for the nominal termination of the mission. This area is selected on the basis of trajectory optimization (launch window, fuel usage), existing recovery capability, climatology, economical use of recovery forces to cover alternate and nominal mission, and the desire not to overfly populated areas.

The required planned landing support will be developed as a trade-off between the guidance capabilities of the Apollo program and the recovery force requirements. Where possible, the spacecraft will be controlled to a landing in such a way as to minimize recovery requirements. Conversely, planned recovery force deployment will be made to reduce the guidance complexity.

The primary landing area recovery capability can be implemented as the mission proceeds because the nominal mission is about a week long.

2.18.3 Special Requirements

From the time the LES is armed until /¯ _7 seconds after the launch, the launch site area will be covered. During this period, recovery must be rapid because of the hazard to recovery personnel caused by the proximity of the launch vehicle. Recovery procedures and equipment must take into account this double hazard.

From the time of launch until after orbit insertion, the launch-abort area will be covered. This area will extend across the Atlantic almost to Africa and will be wide enough to accommodate a varying launch azimuth. Recovery need not be as rapid in this area as in the launch site area.

During the period of up to 4 1/2 hours of earth orbit, a recovery capability, preferably making use of forces planned for launch coverage, will be maintained to permit at least one landing opportunity on each orbit. The Flight Director and Crew Commander will be briefed on preferred landing areas where, in addition to contingency support, there is a tracking or existing recovery capability. This planned and contingency support will be relied on in the event that a longer duration earth orbit is selected as a mission alternate.

One primary or one or more secondary areas will be required for support after translunar injection. Generally there will be a one to four-day advance notice to the recovery forces of the landing area to be used for an abort during this period. In all probability, if an abort is initiated after injection, the trajectory of the spacecraft will be shaped so that a controlled landing will be possible in either the primary or one of the secondary landing areas. Recovery forces must be capable of covering two such areas, one in the Atlantic and one in the Pacific, within sufficient time to be in position at touchdown. Once a choice of landing site has been made and the trajectory shaped to use it, the other site will not be needed.

3. OPERATIONS ORGANIZATION

(to be supplied in next draft)

APPENDIX A

This appendix to the Skeletal Operations Plan contains the Mission Profile and Event Charts for the Apollo Lunar Landing Mission. The Mission Profile lists the significant sequential mission events with their time duration relationship. The time intervals are approximate, but do indicate the time necessary for each event.

The event charts show events that occur simulatneously. The first column of the event charts lists the major events found in the Mission Profile. The second column shows the approximate time required to accomplish the event. In general, each phase shown on the chart begins at zero time. However, for phases which are orbit oriented, typical orbits are provided with an orbit reference beginning time.

1. PREFLIGHT	Time Duration
A. Pad And Network Preparations Subphase	14 days

1. Move the space vehicle to launch pad
2. Position the space vehicle LUT on pad, level and lock down
3. Position arming tower on pad
4. Perform an inspection to determine any transfer or moving damage prior to connecting active pad systems to the space vehicle
5. Activate pad ground support equipment
6. Position "normal" recovery forces, tracking ships, and the "abort" recovery forces that will be located at remote areas
7. IMCC transmits preparation status messages to MSFN and to DOD sites
8. IMCC calls for MSFN simulation exercises
9. IMCC, LCC, AMR, and down range station begin insertion measurement system checkout
10. Conduct calibration checks of bio-medical and space vehicle displays to the IMCC
11. Insert initial conditions and trajectory data into the guidance computers

Time Duration

12. Perform comprehensive preliminary "all systems" simulated launch test
13. Perform RF interference tests
14. Perform space vehicle sensor calibrations
15. Transmit final operational procedures, rules, etc. to MSFN
16. Verify recovery network and control center operational simulation
17. Condition and install all space vehicle carry on equipment
18. Perform pyrotechnic arming
19. MSFN fully mission operational
20. Load and verify performance of the space vehicle high pressure gas system
21. Verify proper installation and performance capabilities of fuel cells
22. Confirm fuel venting and replenishing systems performance capability
23. IMCC assumes control of MSFN and communication network
24. Conduct "closeout" at pad
25. Perform with LCC, IMCC, MSFN and other principal elements a complete flight simulation for final verification of readiness of space vehicle, launch facilities, MSFN and IMCC

B. Terminal Countdown Subphase — 24 hrs

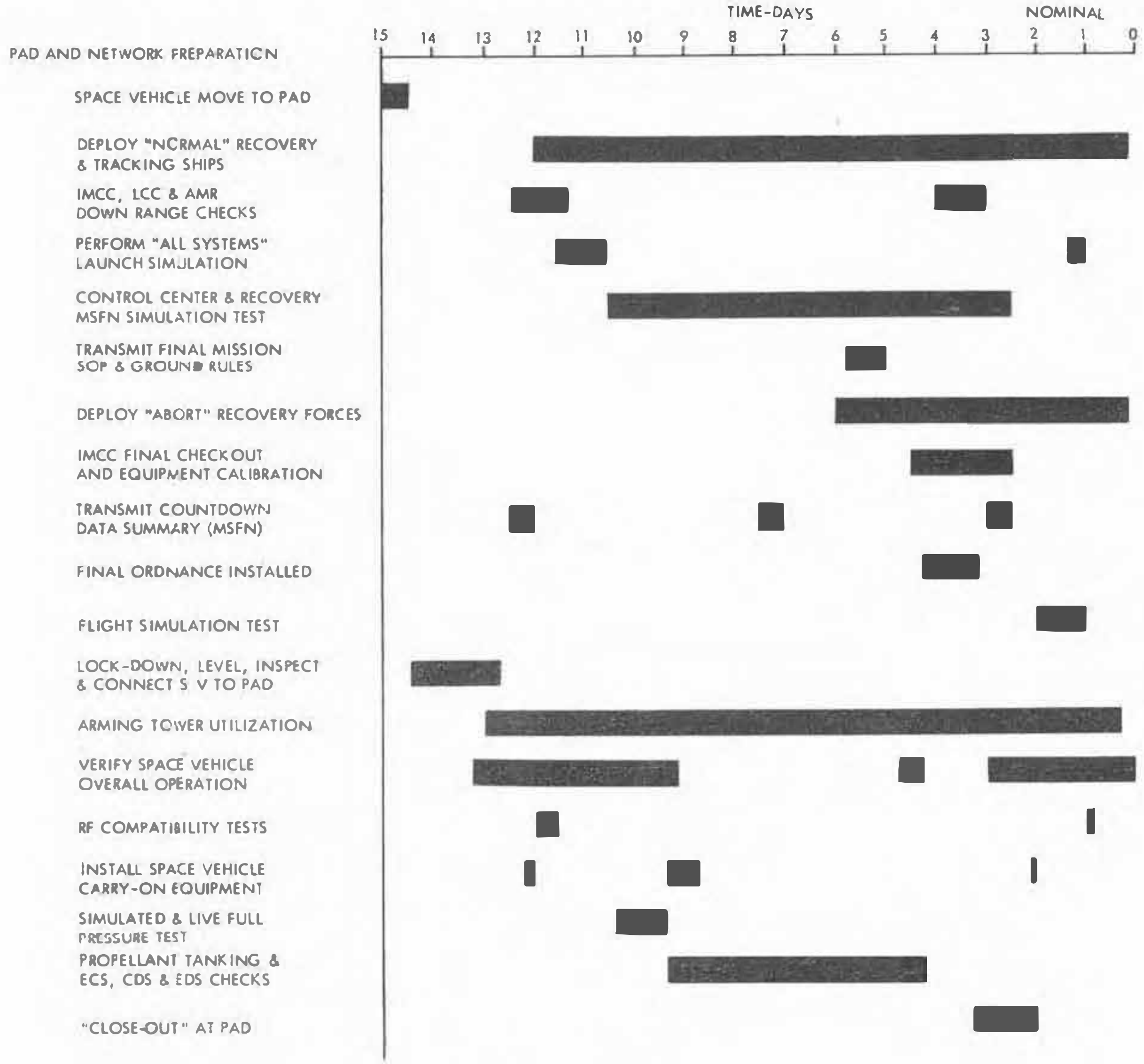
1. Begin terminal countdown using countdown clock to synchronize all future mission operations
2. Time synchronization verified by IMCC
3. Complete final computation of orbit parameters, trajectories, launch window, and radar acquisition data
4. Position "abort" recovery forces located in immediate areas
5. Verify IMCC final operational checkouts and calibration:
    a. High speed interface checks
    b. Teletype poll
    c. Radar slew tests
    d. Mission traffic rules
    e. GMT-time synchronization

Time
Duration

- f. Voice communication, loop tests
- g. Trajectory run
- h. Guidance tests
- i. Bermuda interface checks
- j. IMCC-LCC voice checks
- k. Remote site status checks
- l. Telemetry summary message

6. Perform space vehicle fuel system precooling and loading preparations
   - a. SIVB liquid oxygen
   - b. SII liquid oxygen
   - c. SIC liquid oxygen
   - d. SIVB liquid hydrogen
   - e. SII liquid hydrogen

7. Remove arming tower
8. Remove CM and LEM "carry on" equipment
9. Clear all critical personnel from launch area and perform final preparation for cryogenic loading
10. Load cryogenic propellant
11. Begin 100% fuel load replenishing operation
12. Load pneumatics to flight pressure
13. Insert crew
14. Perform final range safety command checks
15. Confirm all stations <u>go</u> status from IMCC
16. Verify pre SIC engine ignition sequence
17. Initiate space vehicle fuel cells
18. Start SIC engine ignition sequencer
19. Verify SIC center engine ignition and confirm firing of remaining engines
20. Release space vehicle pad hold down arms
21. Verify space vehicle lift-off



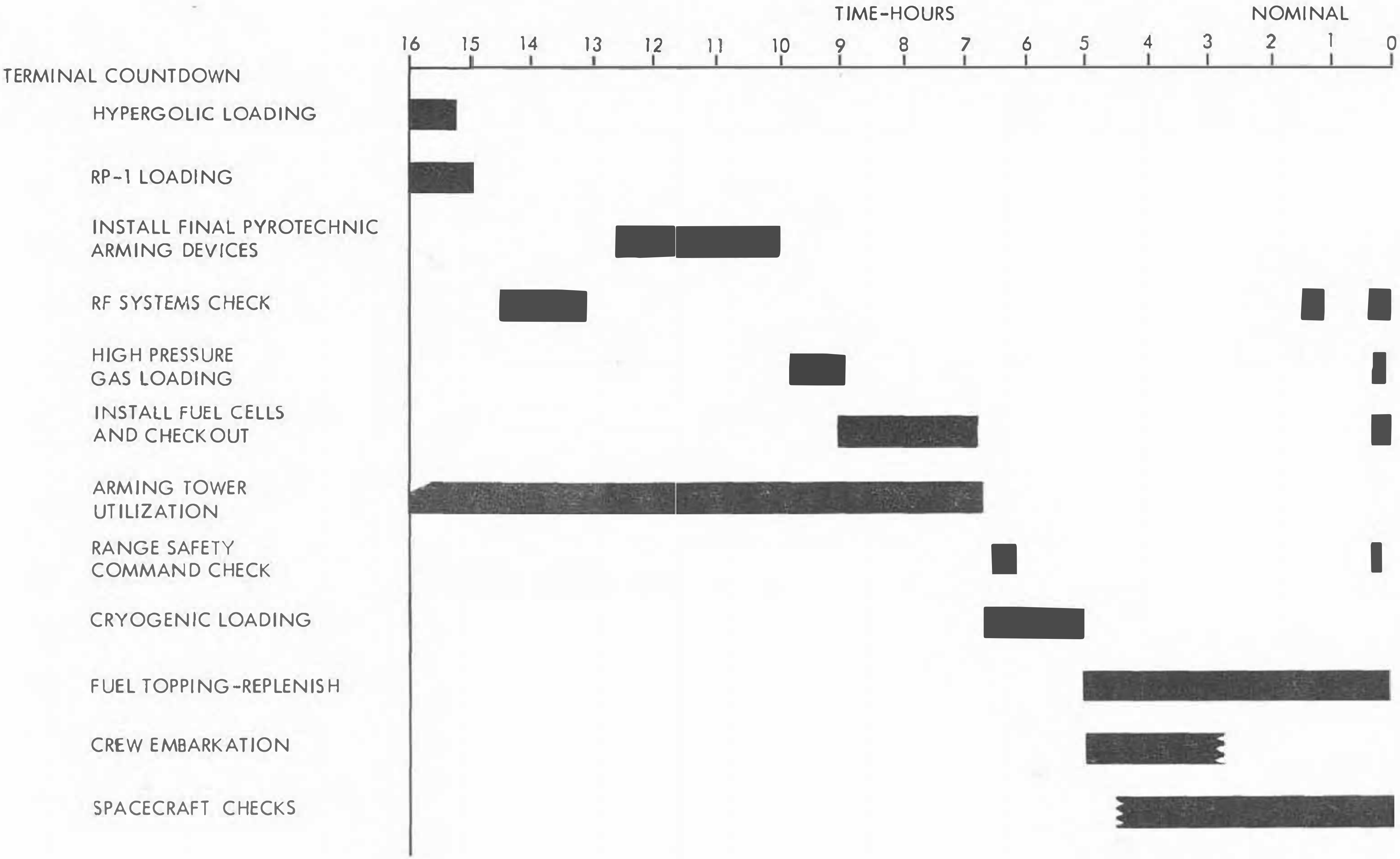
1 PRE-FLIGHT

LEGEND

■ TIME REQUIRED FOR MISSION EVENT

▩ VARIABLE TIME REQUIREMENT

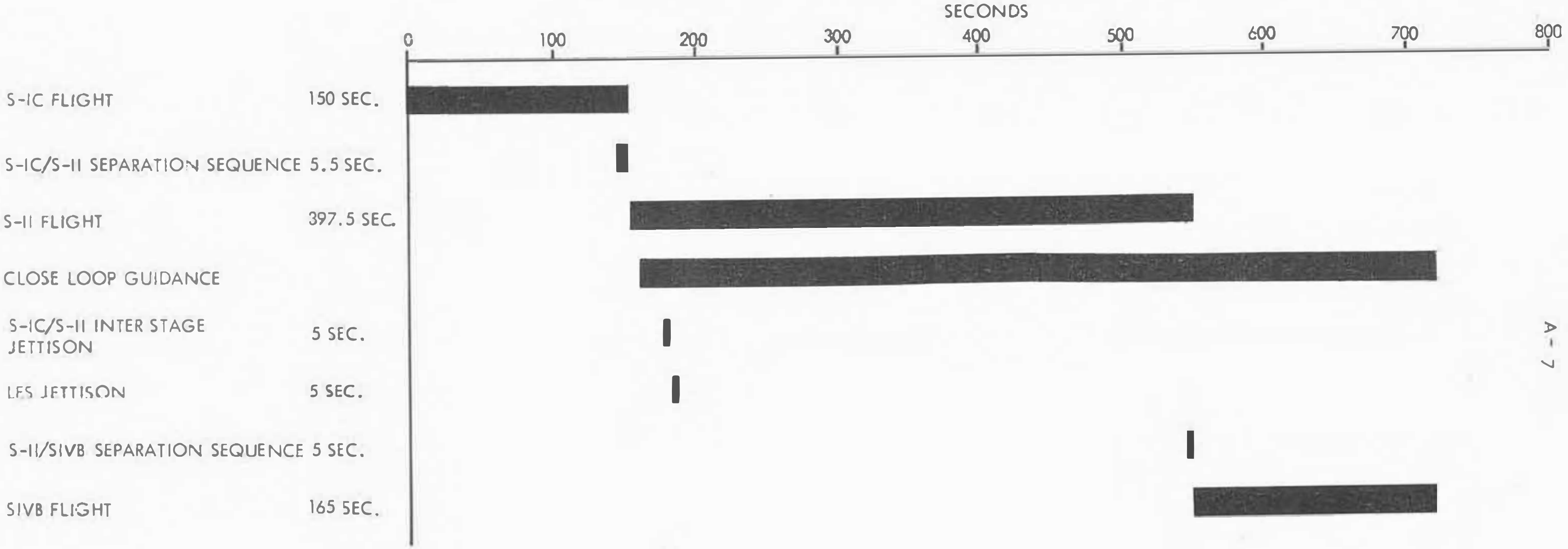
⬚— EVENT MAY OCCUR OVER A TIME INTERVAL


TIME-HOURS
NOMINAL
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
TERMINAL COUNTDOWN
HYPERGOLIC LOADING
RP-1 LOADING
INSTALL FINAL PYROTECHNIC ARMING DEVICES
RF SYSTEMS CHECK
HIGH PRESSURE GAS LOADING
INSTALL FUEL CELLS AND CHECKOUT
ARMING TOWER UTILIZATION
RANGE SAFETY COMMAND CHECK
CRYOGENIC LOADING
FUEL TOPPING-REPLENISH
CREW EMBARKATION
SPACECRAFT CHECKS

1 **PRE-FLIGHT**

2. LAUNCH PHASE (12 minutes)

	Time Duration
A. SIC Flight	150.5 sec
1. Lift-off	
2. Flight stage SIC	150.0 sec
a. Vertical rise and execution of roll program	
b. Commence gravity turn	
c. Occurrence of maximum dynamic pressure	
3. SIC/SII separation sequence	5.0 sec
a. Center F-1 engine shut-down initiated	
b. Center F-1 engine out	
c. Outboard F-1 engines shut-down initiated and SII ullage initiated	
d. Outboard engines reach 10% thrust and first-stage separation initiated	
e. SIC retro-rockets fire	0.5 sec
B. SII Flight	397.5 sec
1. J-II engines start signal initiated	
2. Begin J-II chill-down	1.0 sec
3. J-II start tank opens	
4. Begin J-II thrust build-up	
5. 90% thrust level reached	4.8 sec
6. Commence closed-loop guidance	
7. Forward portion of SIC/SII interstage jettisoned	2.0 sec
8. LES jettison	5.0 sec
9. Disable automatic abort	
10. Begin SII/SIVB separation sequence	5.0 sec
a. Center J-II engine shut-down initiated	
b. Center J-II engine out	
c. Outboard J-II engines shut-down initiated	
d. Ullage thrust initiated	
e. Separation initiated	
f. Retro-rocket thrust initiated	
C. SIVB Flight	165.0 sec
1. SIVB roll control system activated	
2. SIVB engine start sequence initiated	
3. Start tank discharge valve opens	
4. Main stage signal initiated	
5. Ullage off	
6. 90% thrust level reached by J-II engines	4.8 sec
7. SIVB first cut-off	


SECONDS
0
100
200
300
400
500
600
700
800
S-IC FLIGHT 150 SEC.
S-IC/S-II SEPARATION SEQUENCE 5.5 SEC.
S-II FLIGHT 397.5 SEC.
CLOSE LOOP GUIDANCE
S-IC/S-II INTER STAGE JETTISON 5 SEC.
LES JETTISON 5 SEC.
S-II/SIVB SEPARATION SEQUENCE 5 SEC.
SIVB FLIGHT 165 SEC.

2. LAUNCH

3. EARTH PARKING ORBIT (90 to 300 minutes)

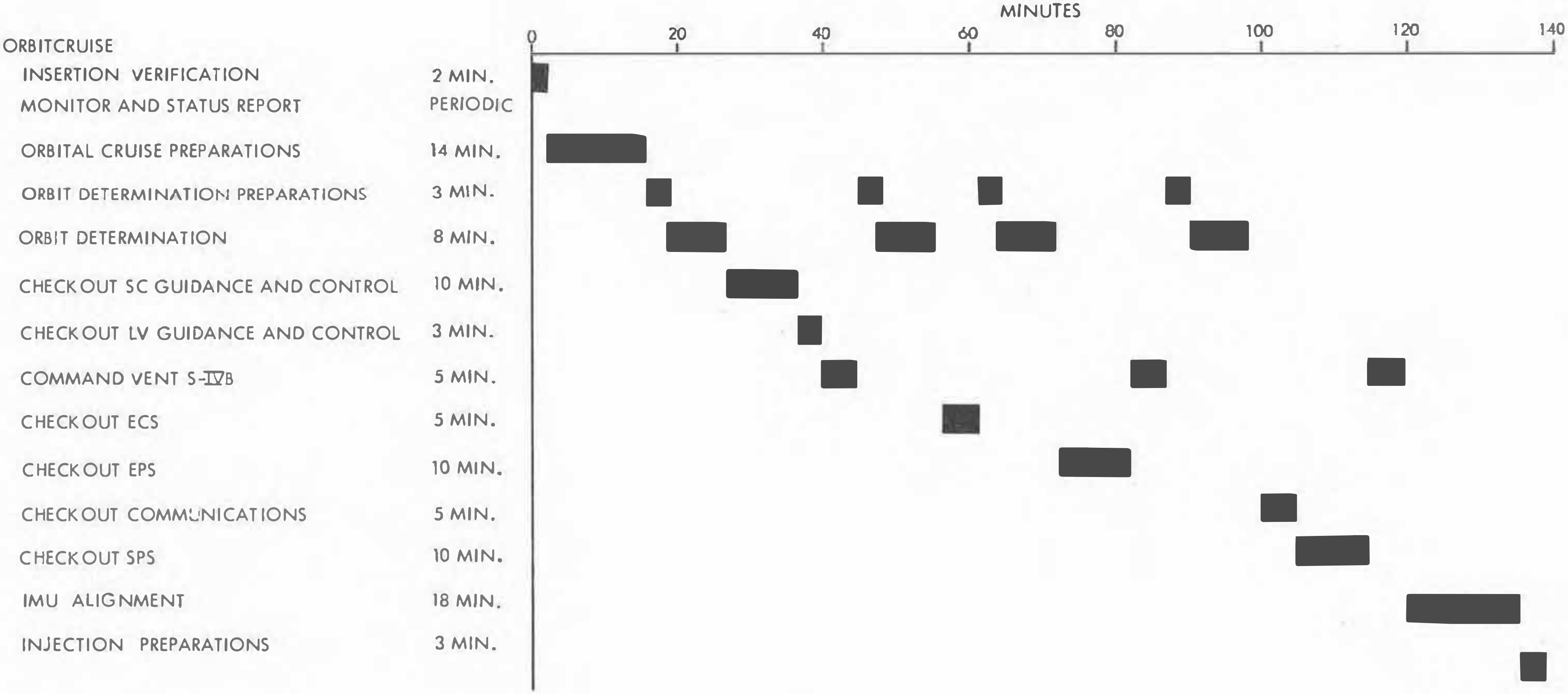
	Time Duration
A. Orbit Cruise	90-300 min
1. Insertion achieved	2 min
a. SIVB main engine cut-off	
b. Insertion into safe orbit determined by crew	
c. Verification of insertion received from IMCC	
d. Position mission sequencer to "safe"	
2. Monitoring and status reporting	Periodic
a. Monitor LV EDS	
b. Monitor CSM MDS	
c. Monitor LEM EDS	
d. Systems status report to IMCC	
3. Orbit cruise preparations	14 min
a. Adjust crew systems for orbit cruise	
b. Perform IFTS check	
c. Set up ECS for orbit cruise	
d. Prepare tape recorder for recording data during periods of no ground contact	
e. Check and monitor ECS parameters	
f. Check and monitor EPS parameters	
g. Check and monitor SM RCS (four subsystems)	
h. Perform biomedical checks	
4. Prepare for orbit determination	3 min
a. Navigator positioned at G&N station	
b. Activate and checkout optics, map viewer and AGC panel	
c. Check G&N system status	
d. Check SIVB RCS status	
e. Switch attitude control from SIVB to spacecraft	
5. Orbit determination	8 min
a. Adjust attitude via hand control for landmark sighting	
b. Set deadband to minimum position	
c. Select landmark area on map viewer	
d. Enter orbital navigation sighting program into AGC	
e. Zero optics	
f. Select optics mode (direct)	
g. Sight through telescope	
h. Roll to landmark	
i. Center landmark in optics	
j. Disable automatic attitude deadband	

Time Duration

- k. Center landmark using minimum impulse control stick
- l. Mark sighting (enter angle and time into AGC)
- m. Recenter landmark
- n. Mark sighting (enter angle and time into AGC)
- o. Request position and velocity solution from AGC
- p. Transmit onboard computer values to IMCC
- q. Receive IMCC verification of acceptable on-board values for orbital determination
- r. Secure G&N station
- s. Switch attitude control from spacecraft to SIVB
- t. Select G&N monitor mode

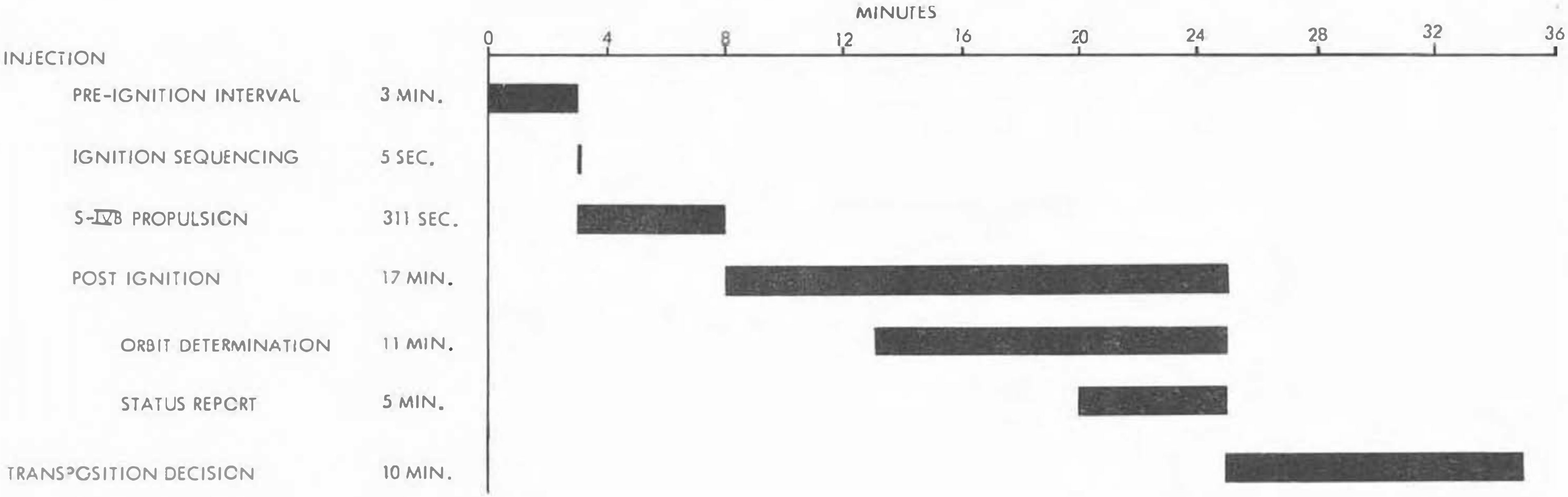
6. Checkout of spacecraft guidance and control systems (in addition to normal status reports) — 10 min
   - a. Check IMU against SCS reference
   - b. Exercise and check all SCS modes
   - c. Exercise and check all G&N modes
   - d. Exercise and check all attitude controls (thrust levels, pulse rate, deadbands, gain, etc.)
   - e. Exercise and check all manual controls (note reaction and indicators)
   - f. Coordinate and confirm all checkouts with the IMCC
7. Checkout of launch vehicle guidance and control systems — 3 min
   - a. Exercise and check all crew control modes
   - b. Coordinate and confirm all checkouts with the IMCC
   - c. Receive checkout summary from the IMCC
8. Command vent the SIVB — 5 min
   - a. Read pressure in SIVB fuel tank
   - b. Read pressure in SIVB LOX tank
   - c. Depress and hold command vent button
   - d. Monitor pressure drop in SIVB fuel tank
   - e. Monitor pressure drop in SIVB LOX tank
   - f. Release command vent button
9. Prepare for orbit determination (Same as 4) — 3 min
10. Orbit determination (Same as 5) — 8 min
11. Checkout ECS — 5 min

	Time Duration
12. Prepare for orbit determination (Same as 4, except d. and e.)	3 min
d. Check SM-RCS status	
e. Disable SIVB attitude control	
13. Orbit determination (Same as 5)	8 min
14. Checkout of EPS	10 min
15. Command vent SIVB (Same as 8)	5 min
16. Prepare for orbit determination (Same as 4)	3 min
17. Orbit determination (Same as 5)	8 min
18. Checkout of communications	5 min
19. Checkout of SPS	10 min
20. Command vent SIVB (Same as 8)	5 min
21. IMU fine align preparations (Same as 4)	3 min
22. IMU fine align	15 min
a. Program AGC	
b. Zero optics	
c. Prepare optics for IMU fine alignment	
d. Set CDU for IMU fine alignment	
e. Adjust attitude via hand control for navigation sighting	
f. Set deadband to minimum position	
g. Locate star and landmark in telescope	
h. Center star and landmark in telescope	
i. Disable automatic attitude deadband	
j. Use minimum impulse control to center star and landmark or second star in sextant	
k. Center and mark (AGC reads angle & time)	
l. Enter star code into AGC (star code listed on maps viewer)	
m. Enable AGC fine alignment program	
n. Secure G&N station	
23. Injection preparations	3 min
a. Final injection guidance parameters sent to the LV by the IMCC	
b. Final injection guidance parameters sent to the spacecraft by the IMCC	
c. Final injection guidance parameters verified by crew and inserted into the AGC	
d. Time to ignition set and verified	
e. Crew systems positioned for the injection maneuver	



3. EARTH PARKING ORBIT

4. TRANSLUNAR INJECTION (35 minutes)	Time Duration
A. Injection	25 min
1. Pre-ignition interval	3 min
a. Visual check of displays	
b. Manually vent SIVB	
c. Verify attitude of SC and hold for ignition	
d. Verify SC main engine control position - null hold for ignition	
e. Start ullage rockets	
2. Ignition sequencing	5 sec
a. Ignition signal	
b. Ullage thrust developed	
c. Main engine valves open	
d. Enable thrust vector control	
e. Engine thrust -- 90%	
3. SIVB propulsion	311 sec
a. Terminate ullage thrust	
b. Full engine thrust developed	
c. Verify attitude and thrust vector control	
d. Close main engine fuel valves	
e. Thrust tail-off	
4. Post-ignition	17 min
a. Power down main engine equipment	
b. Enable attitude hold	
c. Perform SC subsystem checks	
d. Perform celestial navigation sightings (Same as 3.A.12. and 3.A.5. except steps o, p, q.)	
e. Establish voice and TLM communications link with IMCC	
f. Translunar injection voice and TLM status report to IMCC	
g. Resume ground tracking	
B. Transposition Decision	10 min
1. Flight Director determines safety of transposition maneuver	5 min
2. Flight Director establishes timing and furnishes transposition schedule - must occur	5 min
a. Within vent-free interval of SIVB	
b. Before SIVB RCS and electrical energy falls below minimum limits	
c. During ground communication period	



4. TRANSLUNAR INJECTION

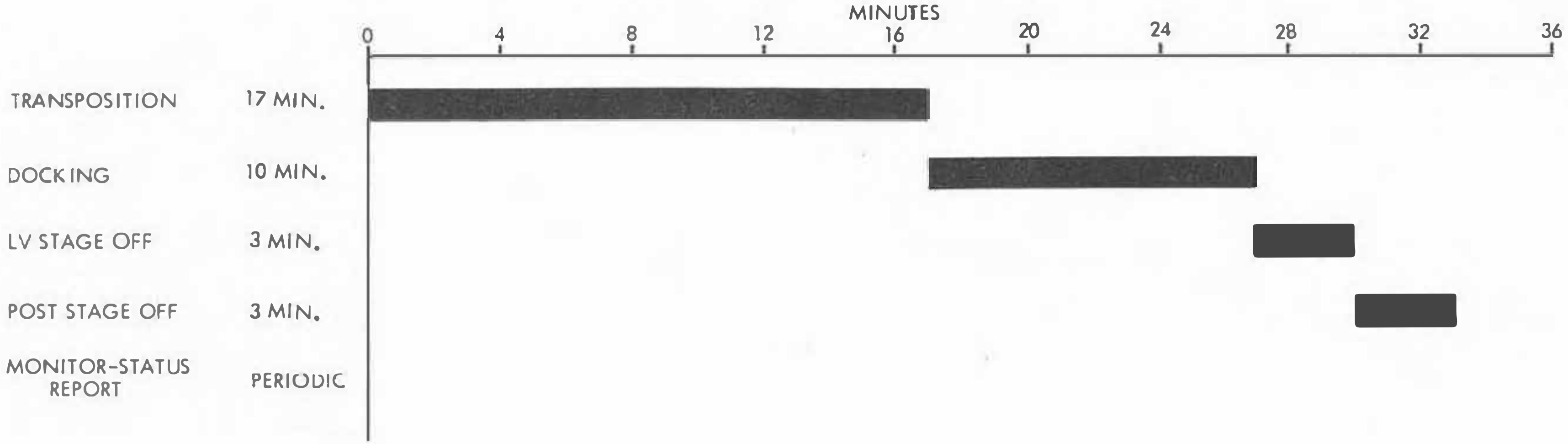
5. TRANSPOSITION AND DOCKING (20 to 35 minutes)

Time Duration

A. Transposition and Docking — 27 min

1. Transposition — 17 min
    - a. LV vent-manual command [5 to 12 minutes]
    - b. IMCC commands LV attitude hold (minimum deadband, minimum cycle limits)
    - c. SC-LV control circuits disconnected
    - d. Adapter separation firing circuits armed
    - e. Crew Commander positions couch to docking position
    - f. Select G&N attitude hold mode
    - g. Set deadband to minimum position
    - h. Adapter separation fired
    - i. Initiate SM RCS thrust (along +X axis) for separation
    - j. Perform 180° turn with SM RCS
    - k. Check visually to ensure adapter panels have cleared immediate area
    - l. CSM apex cover opened
    - m. CSM alignment probe extended
    - n. CSM latching mechanisms extended
2. Docking — 10 min
    - a. Visually check relative motion of the LEM/SIVB
    - b. Control SM RCS thrusting with translational control stick to close with LEM/SIVB
    - c. Visually center CSM alignment probe on LEM/SIVB X axis
    - d. Close CSM to LEM/SIVB with closing velocity of 1 fps (transverse velocity less than 0.5 fps)
    - e. CSM alignment probe centered and engaged in LEM alignment and attenuation cone
    - f. Final closing effected
    - g. Latching mechanisms engaged
    - h. Select G&N monitor mode
    - i. CSM/LEM interface cables connected
    - j. Report completed docking to IMCC

	Time Duration
B. <u>Launch Vehicle Jettison</u>	6 min
1. LV stage-off	3 min
a. Arm stage-off firing circuits [IMCC command or crew action]	
b. Select G&N attitude hold mode	
c. Fire stage-off circuits	
d. Stage-off effected by SM RCS thrusting	
e. Crew confirms stage-off with IMCC	
f. IMCC commands LV attitude to best orientation	
g. Crew [visual sighting] reports safe separation distance	
2. Post stage-off	3 min
a. Deploy high gain antenna	
b. Perform CSM status check	
c. Perform LEM status check	
d. Report net change of trajectory due to maneuvering and venting	
e. Prepare for translunar cruise	
3. Monitoring and status reporting	Periodic
a. Monitor LV EDS	
b. Monitor CSM MDS	
c. Monitor LEM EDS	
d. System status report to IMCC	



5. TRANSPOSITION AND DOCKING

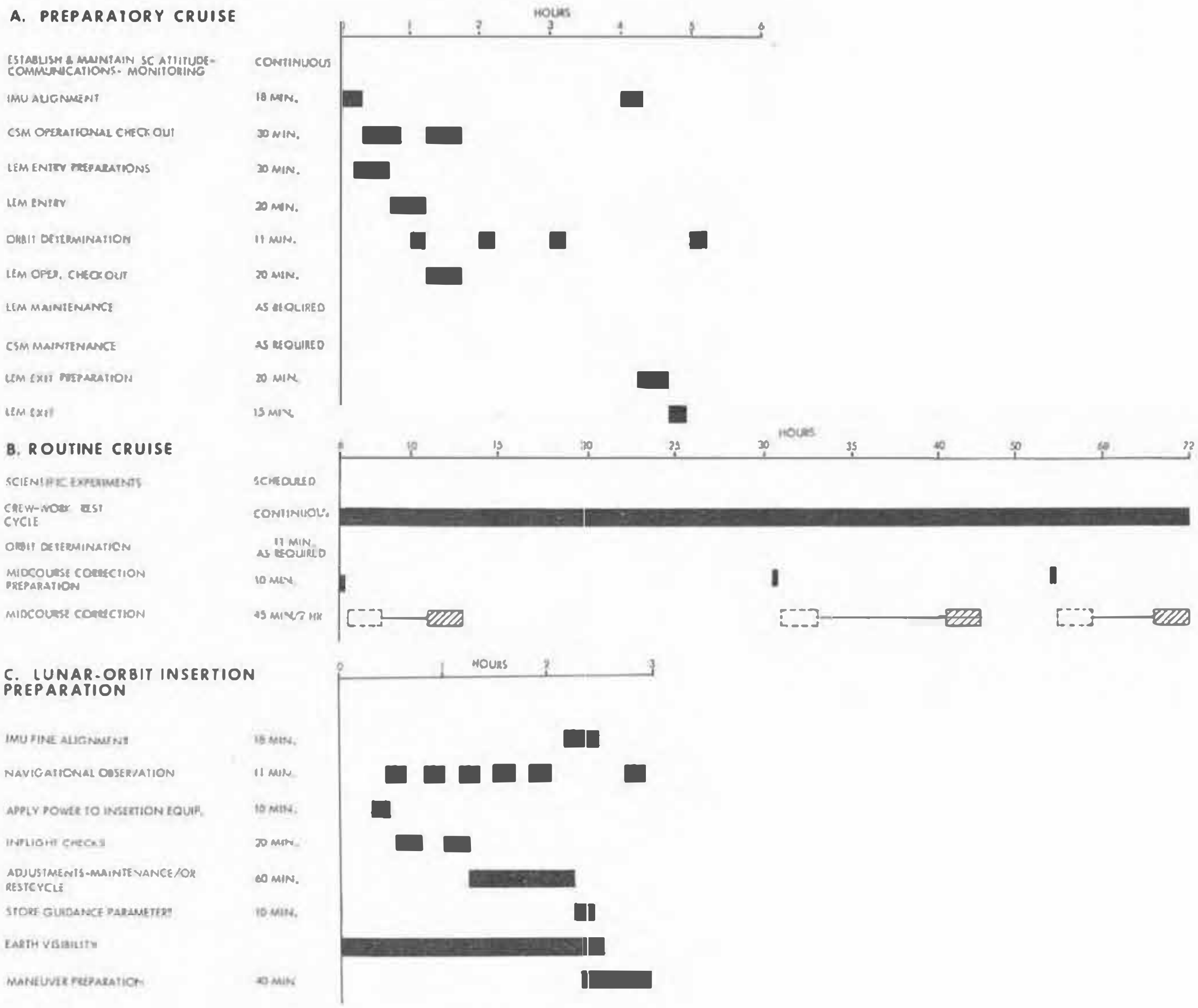
6. LUNAR TRANSFER CRUISE (60 - 110 hours)

	Time Duration
A. Preparatory Cruise	6 hrs
1. Position SC attitude for optimum	Continuous
a. Ground communication	
b. Radiation protection	
c. Navigation observations	
2. Monitor CSM systems throughout phase	Continuous
3. Obtain and maintain communication link	Periodic
a. Voice-CM to IMCC	
b. R-Ṙ tracking	
c. CSM telemetry	
d. CSM up-data	
4. Perform CM-IMU alignment (Same as 3.A.12. and 3.A.22.)	18 min
5. Conduct CSM operational checkout	30 min
6. Perform LEM-entry preparations	30 min
a. Attach and checkout PLSS with space suit	
b. Enter and close off pressurized boarding passageway	
c. Open CM docking hatch	
d. Open LEM docking hatch	
e. Check chamber pressure and leakage rate	
7. LEM entry	20 min
a. Activate LEM lighting and intercom	
b. Activate primary checkout services	
c. Adjust primary services for stable operation	
d. Verify primary service operation	
8. Terminate CSM operational checks	
9. Orbit determination (Same as 3.A.12. and 3.A.5. except steps o, p, q.)	11 min
10. Conduct LEM operational checkout	20 min
a. Report to IMCC operational discontinuities	
11. Complete remaining CSM operational checkouts prior to next navigational observation	30 min
12. Begin LEM-IMCC approved maintenance procedures	As required
13. Orbit determination (Same as 6.A.9.)	11 min
14. Begin CSM-IMCC approved maintenance procedures	As required
15. Orbit determination (Same as 6.A.9.)	11 min
16. Perform CSM-IMU alignment (Same as 6.A.4.)	18 min

	Time Duration
17. Prepare to exit LEM	20 min
a. Power down non-essential LEM equipment	
b. Select designated modes or other systems and adjust for optimum performance	
c. Activate CM-LEM remote monitor and control equipment	
d. Establish final coordination with CM before withdrawal	
18. Return to CM	15 min
a. Seal LEM and CM docking hatches	
b. Bring boarding passageway to CM cabin pressure	
c. Reenter CM cabin	
d. Remove PLSS and prepare for recharge	
19. Orbit determination (Same as 6.A.9.)	11 min
B. <u>Routine Cruise</u>	<u>72 hrs</u>
1. Midcourse correction preparation	10 min
a. Based on previous subphase navigational observations, determine orbital elements to adequate accuracy	
b. Store orbital parameters in CM AGC	
c. Schedule midcourse correction	
d. Store midcourse correction parameters in CM AGC	
e. Store preferred abort parameters in CM AGC	
2. Monitor LEM and CM systems throughout phase	Continuous
3. Two crew members remove space suits and perform work/rest cycles	
4. Orbit determination and R-$\dot{R}$ tracking only if further refinement of orbital elements is needed	11 min
5. Conduct periodic scheduled CSM TLM and voice transmission	Periodic
6. Updata channel information available on voice request	Periodic
7. Conduct scientific experiments	Periodic
8. This subphase is suspended at designated times in order to perform midcourse corrections. The subphase is resumed after completion of all but the final midcourse correction	Periodic

C. Lunar Orbit Insertion Preparation

		Time Duration
1.	Conduct navigational observation every 15 minutes until end of phase. (Same as 6.A.9.)	2 min
2.	Maintain R-$\dot{R}$ tracking until SC passes behind moon	
3.	Apply power to equipment necessary for lunar insertion and abort options	10 min
4.	Conduct in-flight check to verify operability and to evaluate endurance - transmit TLM to IMCC	20 min
5.	Perform IMCC approved operating adjustments and maintenance procedures or rest cycle	60 min
6.	Store guidance parameters necessary for lunar insertion and contingency abort operations in CM-AGC	10 min
7.	Report to IMCC readiness for lunar insertion on schedule	
8.	IMCC authorizes SC to proceed with insertion as scheduled	
9.	Verify loss of communication when CM-earth-moon eclipse occurs	
	a. Power down S-band communication	
	b. Activate TLM recording mode	
10.	Perform CM-IMU alignment (Same as 6.A.4.)	18 min
11.	Verify crew readiness for major-propulsion maneuver	20 min
	a. Stow loose CM equipment	
	b. Obtain proper SC orientation for lunar insertion	
	c. Select minimum deadband limits	
	d. Prepare TLM recorder	



6. LUNAR TRANSFER CRUISE

7. MIDCOURSE CORRECTION (60 to 72 minutes)

Time Duration

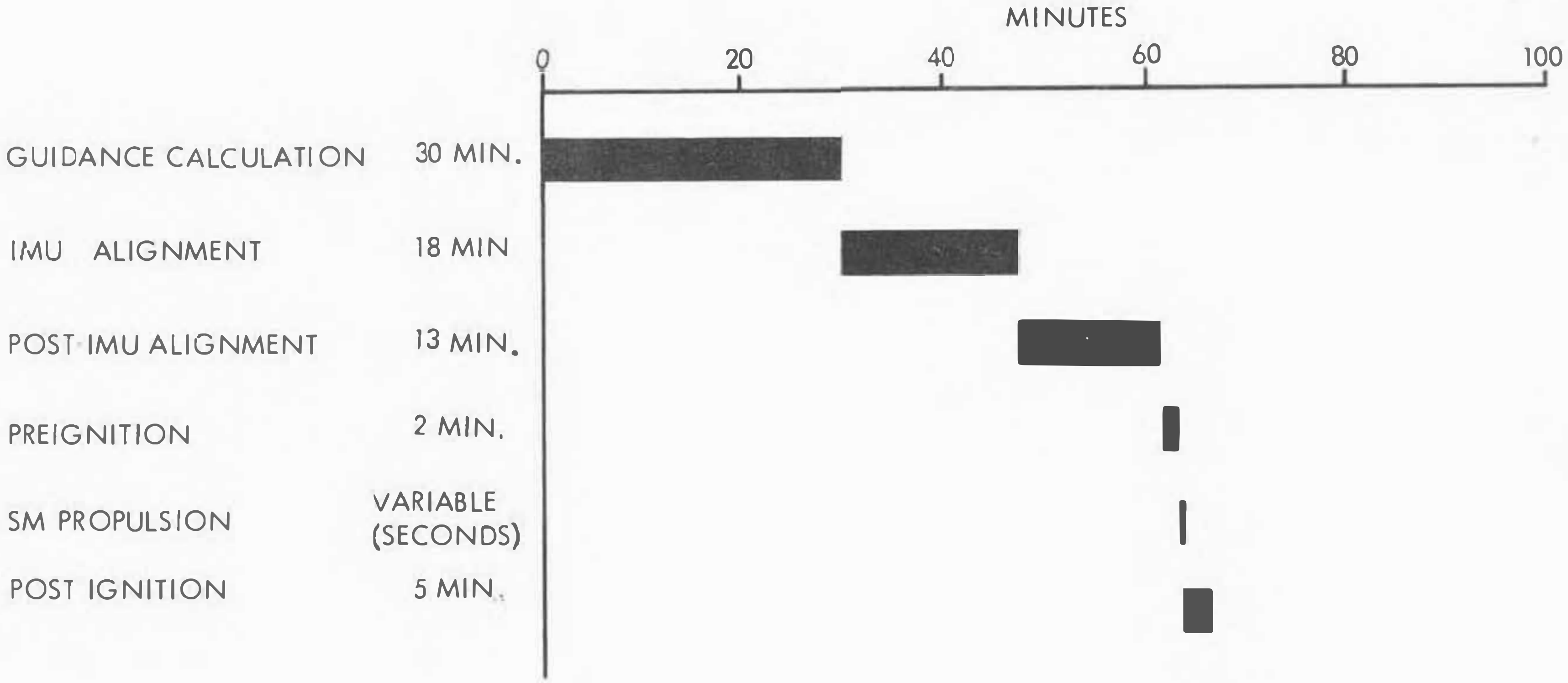
A. Guidance Calculations — 60 min

1. Pre-IMU alignment and guidance calculation — 30 min
   - a. Verify ground communication link as in Section 6.A.3
   - b. Begin static checkout of SM main engine
   - c. Obtain from IMCC
     - 1) Required ΔV increment
     - 2) Start time
     - 3) Duration of burn
     - 4) Position and velocity
     - 5) Attitude
     - 6) Contingency abort information
   - d. Enable AGC for computation of guidance parameters using IMCC start time
   - e. Compare IMCC and SC guidance parameters
   - f. Begin static checkout of SM RCS
   - g. Switch IMU to operate
2. IMU alignment (Same as 6.A.4) — 18 min
3. Post IMU alignment — 13 min
   (If CM RCS propulsion system is used, delete steps b.c.d.f. and k)
   - a. AGC compute center of gravity
   - b. Generate command engine gimbal angles
   - c. Switch control mode to G&N ΔV
   - d. Manually position engine gimbals (pitch and yaw) - AS-GPD
   - e. Synchronize AGCU-AGAP to G&N system
   - f. Switch control mode to G&N attitude control
   - g. Monitor SC attitude using FDAI
   - h. Stow loose gear
   - i. Perform final check
   - j. Manually insert ΔV increment (ΔV display panel)
   - k. Manually insert "thrust tail-off" (ΔV display panel)

B. Propulsion Maneuver — 7 min

1. Pre-ignition — 2 min
   (If CM RCS propulsion system is used, delete steps c.f. and g.)
   - a. For SPS operation switch mode select to G&N ΔV mode

	Time Duration
b. For RCS operation switch mode select to G&N attitude control	
c. Monitor gimbal trim -- AS/GPD	
d. Communicate <u>go</u> status to ground	
e. Monitor <u>attitude</u> using FDAI and time to thrust	
f. Arm propulsion system	
g. Ullage thrust initiated by AGC	
2. SM propulsion	Variable - (seconds)
a. AGC initiates ignition	
b. AGC terminates ullage	
c. Ignition full thrust	
d. Monitor attitude and thrust vector	
e. Monitor trajectory controlled by AGC	
f. AGC generates engine cut-off signal	
g. Automatic gimbal motor power down	
2.1 SM RCS propulsion	
a. AGC initiates X translational thrust	
b. AGC terminates RCS thrust	
3. Post-ignition	5 min
a. Verify engine cut-off	
b. Verify ΔV achieved	
c. Change mode select switch to G&N attitude control or SCS attitude control depending on next phase	
d. Verify that no operating troubles have occurred - situation report to IMCC	



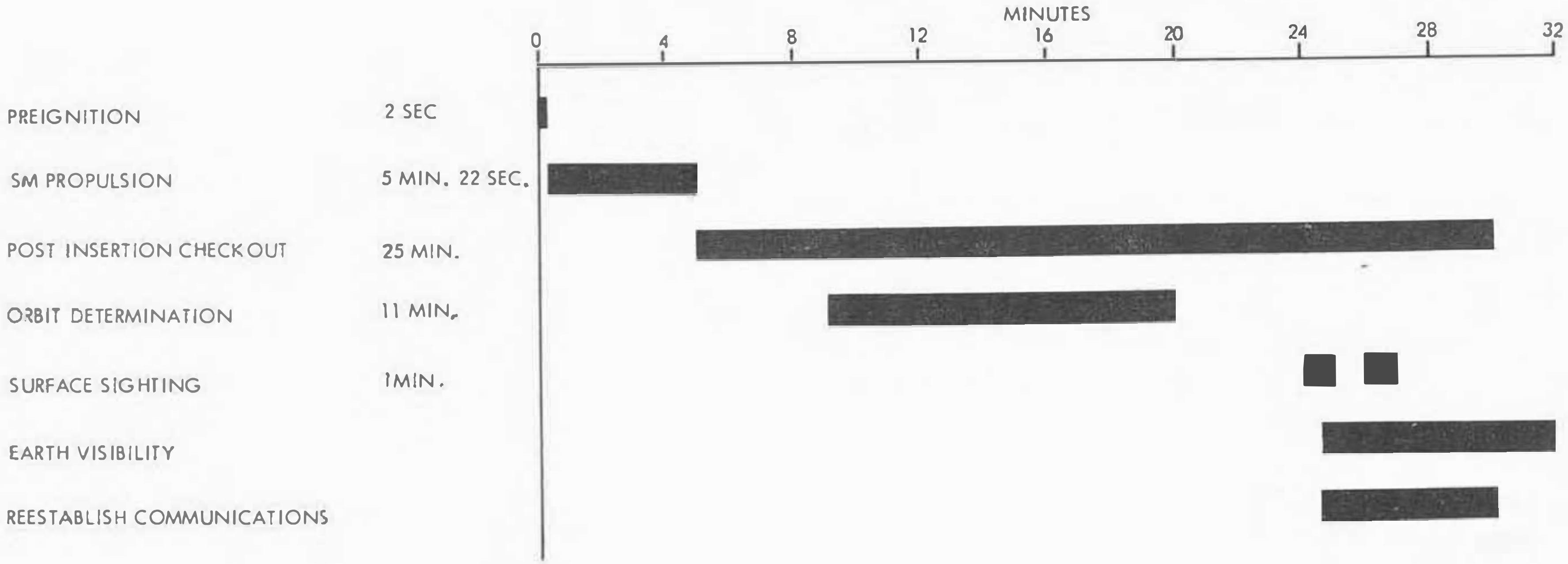
7. MIDCOURSE CORRECTION

8. LUNAR ORBIT INSERTION (30 minutes)

	Time Duration
A. Insertion Maneuver	30 min
1. Pre-ignition sequencing	2 sec
2. SM Propulsion	322 sec
3. Post-insertion checkout	25 min

A. Insertion Maneuver — 30 min

1. Pre-ignition sequencing — 2 sec
   a. SM RCS ullage thrust is developed (X translation)
   b. SM engine start signal is automatically generated
2. SM Propulsion — 322 sec
   a. Ignition - full thrust is developed
   b. SM RCS ullage thrust is terminated
   c. SC attitude and thrust vectors are controlled for trajectory shaping
   d. Engine cut-off signal is automatically generated; pressurization valves are closed
   e. Thrust tail-off. Gimbal motors are powered down. An attitude hold is effected
3. Post-insertion checkout — 25 min
   a. The crew confirms that no serious operating problems exist, and the achieved trajectory shows a safe perilune
   b. CSM operating modes and settings are established for initial cruising flight. A performance status summary is complied
   c. Conduct periodic lunar altitude measurements and surface sightings
   d. Conduct celestial navigation sightings
   e. Activate S-band communication - voice, TLM, and ground R-$\dot{R}$ tracking
   f. End of CM-Lunar-Earth eclipse
   g. Reestablish communication link. A situation report is made to the ground and coordination is effected. After a 3 minute direct sample of CSM-TLM data has been received at the ground terminal, the eclipse TLM is transmitted
   h. Phase is terminated



8. LUNAR ORBIT INSERTION

9. LUNAR ORBIT CRUISE (1 1/2 to 50 hours)

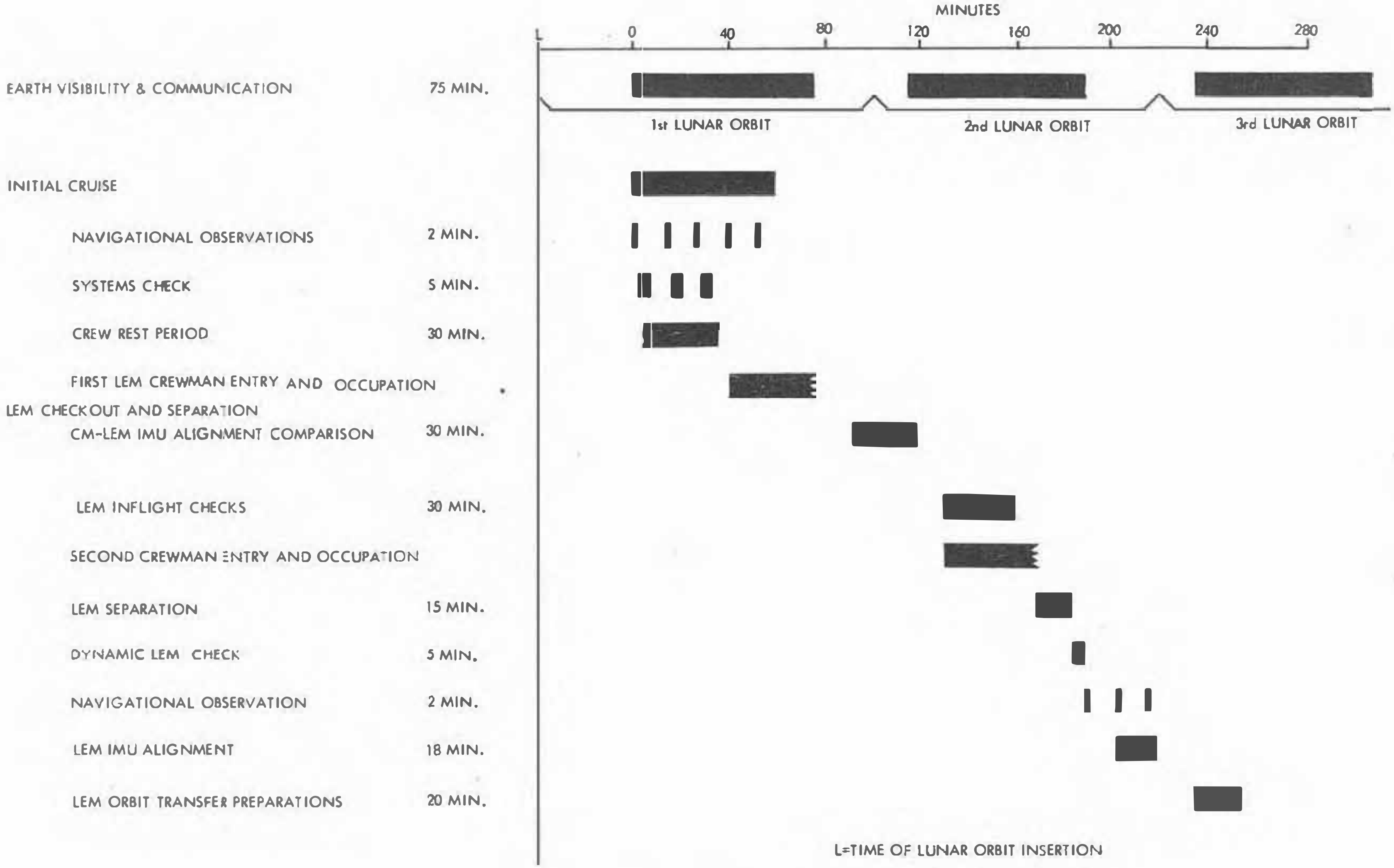
		Time Duration
A.	Initial Cruise	60 min
1.	Conduct navigational observations every 10 min. until orbit determination confidence is achieved	2 min
2.	Position SC for optimum attitude (same as 6.A.1.)	Continuous
3.	One crewman monitors CSM and pertinent LEM systems continuously throughout phase	Continuous
4.	CSM systems are sequentially checked between navigational observations to confirm operability for extended one man attendance	15 min
5.	IMCC confirms that orbit is acceptable for the lunar landing phases	10 min
6.	Conduct IMCC approved CM maintenance as required	
7.	Begin crew member rest period	
8.	Ground tracking, TLM, voice channels, and updata channels are available on request throughout the phase	Periodic
9.	One crewman enters LEM and begins LEM activation after the first fly-by of the landing area	
10.	The moon obstructs CM-earth line-of-sight and blocks communications. Non-essential systems are powered down	47 min
B.	LEM Checkout and Separation	190 min
1.	CSM systems are continuously monitored	Continuous
2.	LEM systems are adjusted for manned operations	15 min
3.	Conduct periodic altitude measurements to the lunar surface from both CM and LEM	2 min
4.	Compare CM and LEM IMU alignment data	30 min
5.	Activate S-band communication systems in both the CM and LEM (same as 6.A.3.)	
6.	Updata channel is available upon request	Periodic
7.	The moon clears the CM-earth line-of-sight	

		Time Duration
8.	LEM in-flight operational checks	30 min
9.	Second LEM crewman enters LEM	
10.	Conduct periodic navigational observations from the LEM using lunar surface landmarks	2 min
11.	Landing area observations are made from the LEM during the second fly-by	
12.	LEM checkouts are completed and the crew confirms operability	
13.	IMCC authorizes CSM-LEM separation to proceed	6 min
a.	SM RCS is used to orient and hold the vehicles with minimum deadband	
b.	LEM RCS is used to achieve separation	
14.	Conduct dynamic LEM checks and confirm operability	3/5 min
a.	Transmit 3 min. sample of CM and LEM TLM	
15.	The moon obstructs the line-of-sight to the earth and blocks communications. Non-essential systems are powered-down	47 min
a.	The CM-LEM voice channel and rendezvous radar communications are used for monitoring each other's status	
b.	Other CM-LEM communication channels are activated and their operation is verified sequentially	
16.	Conduct periodic LEM navigational observations	2 min
17.	Conduct LEM IMU alignment	18 min
18.	CM and LEM systems and attitude are controlled independently to:	Continuous
a.	Maintain mutual communications	
b.	Make visual lunar observations	
c.	Obtain planned scientific data	
19.	The moon clears the CM-LEM-earth line-of-sight. Reestablish and verify communications (same as 8.A.3.g.)	
20.	IMCC-generated final revised parameters for LEM equiperiod transfer maneuver are stored in the LEM AGC and in the CM AGC for advisory monitoring	
21.	LEM crew prepares for propulsion maneuver	5 min

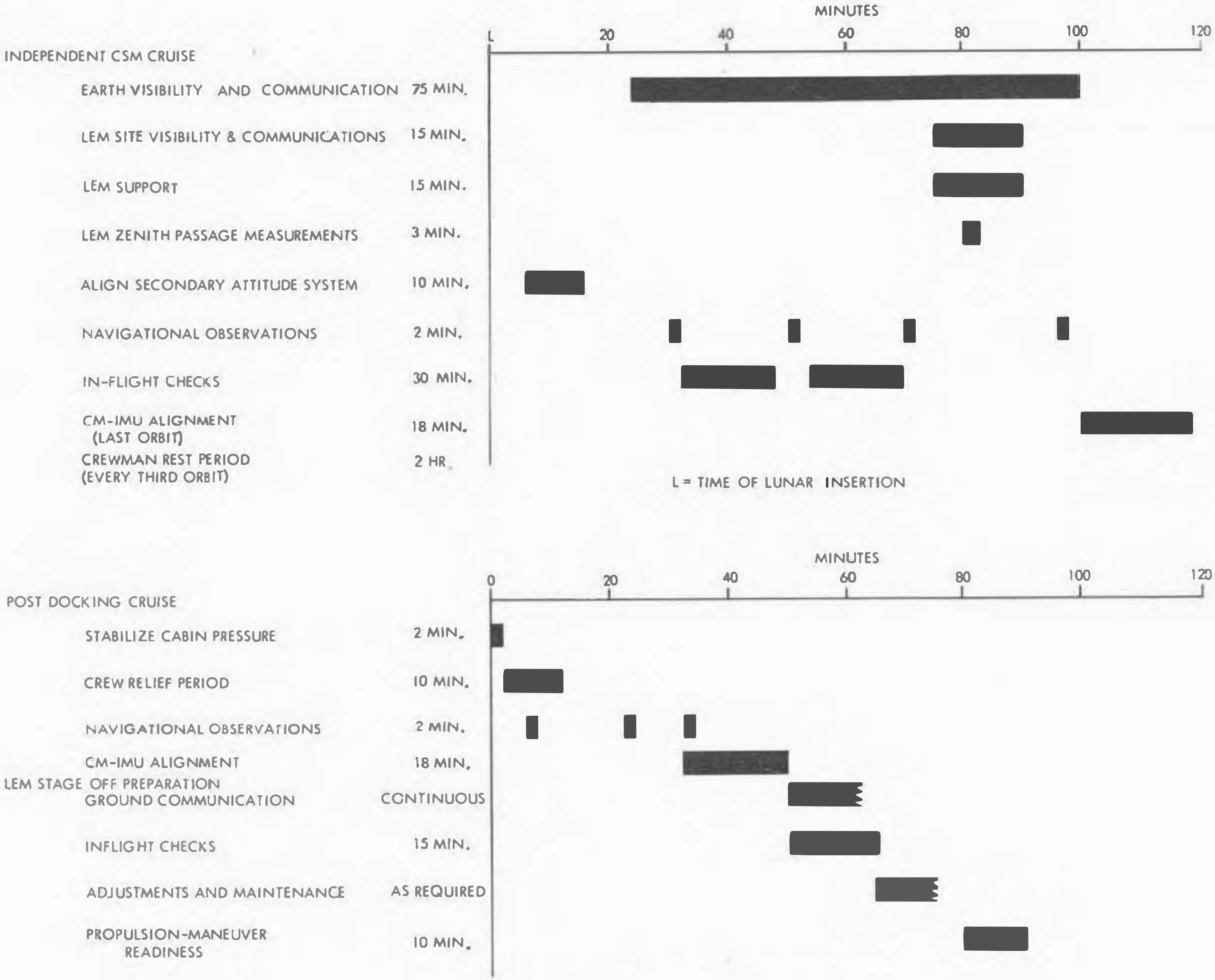
		Time Duration
22.	Verify that PLSS units are available for emergency use	5 min
23.	IMCC receives final readiness report from CM and LEM	
24.	IMCC-authorizes lunar descent	
25.	Orient LEM to begin descent	2 min
26.	Orient CM for LEM tracking and observation	2 min
27.	Adjust and verify LEM gimbal trim	2 min
28.	Final clock synchronization one minute before end of subphase	
C.	<u>Independent CSM Cruise</u>	<u>24 hrs</u>
1.	Power down CSM equipment not required for normal cruise operations (IMU, etc.)	
2.	Monitor CSM system performance except during a. Scheduled rest periods b. Scheduled navigational observations c. LEM support functions	Continuous
3.	Position spacecraft for optimum attitude (same as 6.A.1.)	Continuous
4.	Align secondary attitude system	10 min
5.	Perform in-flight systems check and IMCC-approved adjustments and maintenance as required	30 min
6.	Activate ground communication one minute prior to earth visibility. Upon contact transmit and receive a. Voice situation report b. 3 minute real time TLM c. Recorded TLM since last contact d. Ground tracking -- 10 minutes e. Updata orbital elements and abort parameters	
7.	Periodic navigational observations using lunar surface landmarks	2 min
8.	Activate LEM-CM communication system one minute before LEM-CM mutual visibility a. Voice channel -- coordination, exchange of mission data, and progress reports b. Rendezvous tracking	

	Time Duration
9. CM-LEM mutual visibility	15 min
a. Conduct visual observation	
b. Communication contact	
1) General Status	
2) Contingency launch planning	
3) Timing information	
4) Pertinent operations exchange	
c. Conduct optical measurement at zenith passage	
10. Power down LEM-CSM communication equipment upon loss of contact	
11. Power down CSM-earth communication equipment upon loss of communications due to CM-moon earth eclipse	
12. Start new orbit	
13. Conduct IMU alignment (same as 6.A.4.) during the last orbit prior to LEM ascent	18 min
14. Rest period every 3rd orbit	2 hrs
D. Post Docking Cruise	50 min
1. Establish routine cruise modes	
2. Monitor and control as in 6.A.2.	
3. Stabilize cabin pressure for non-suited occupancy	2 min
4. Two crew men remove space suits and begin 5 minute personal relief periods	10 min
5. Conduct navigational observations using lunar surface altitude and landmarks	2 min
6. Conduct in-flight systems checkout	On demand
7. Establish communication contact prior to earth-CM-moon eclipse	5 min
a. Voice situation report	
b. 3 minute real time TLM	
c. Recorded TLM until end of period	
d. R-Ṙ ground tracking until end of visibility	
8. Power down communication equipment	
9. Conduct celestial navigational observation. Conduct CM IMU alignment, (Same as 6.A.4.) during last orbit before LEM stage-off.	2/18 min
10. Begin first crew member rest cycle period	30 min

		Time Duration
11.	Begin second crew member rest cycle period	30 min
12.	Activate ground communication one minute prior to earth visibility. Upon contact transmit or receive (Same as 9.C.6.)	5 min
13.	Conduct navigational observation using lunar surface altitude and landmarks	2 min
14.	Activate R-$\dot{R}$ equipment for 10 minute sample while transiting the earth-moon center line	10 min
15.	End second crew member rest cycle	
16.	Conduct navigational observation using lunar surface altitude and landmarks	2 min
17.	Begin third crew member rest cycle period	30 min
18.	Repeat phase as number of lunar orbits require	
E.	<u>LEM Stage-Off Preparations</u>	<u>30 min</u>
1.	Checkout and verify operability of systems needed for transearth injection maneuver	5 min
2.	Conduct in-flight checks	15 min
3.	Transmit in-flight check TLM to ground	
4.	Crew-IMCC evaluation of any operating adjustments or maintenance to be performed before injection.	10 min
5.	Perform IMCC approved adjustments or maintenance	As required
6.	Set and verify guidance parameters	5 min
7.	Final crew confirmation of readiness for propulsion maneuver	2 min
8.	Phase terminated	



9. LUNAR ORBIT CRUISE



9. LUNAR ORBIT CRUISE (CON'T.)

10. LEM DESCENT TO PERILUNE (30 to 150 min.)

Time Duration

A. Propulsion Maneuver — 0.5 min

NOTE: A detailed description of the LEM descent propulsion procedure is attached as an addendum to phase 10.

1. LEM crewman initiates ignition sequence
2. Propulsion interval
   a. LEM crew monitors system performance
   b. CSM tracks LEM with rendezvous radar
   c. CSM calculates LEM trajectory and abort parameters -- transmitted to IMCC and LEM
   d. Ground DSS tracks CSM and LEM
   e. IMCC provides CSM ephemeris, LEM descent trajectory and ascent data for abort
   f. Maintain voice link between LEM and CSM
3. Propulsion termination

B. Coast to Perilune — 30/150 min

1. Post thrusting activities
   a. Evaluate achieved orbit for safety; determine perilune altitude
   b. LEM crew monitors system performance
   c. LEM radar tracks CSM to update abort program
   d. Determine orbit parameters
   e. Verify accessibility of certified landing site.
2. Final preparations for powered descent
   a. LEM crew establishes modes for powered descent to lunar surface
   b. Perform final update of guidance parameters for descent maneuver
   c. Flight Director authorizes descent and landing
   d. LEM crew executes propulsion procedure
   e. LEM crew [enables] ignition sequence
   f. LEM crew initiates ignition

ADDENDUM

SEQUENCE FOR LEM DESCENT PROPULSION

1. Pre-Ignition Sequence
   a. Set up guidance and control
      (1) Determine and insert (or verify inserted values best data on present LEM orbit parameters and coordinates
      (2) Determine and insert (or verify) best data on present CM orbit parameters and coordinates
      (3) Select program (set up in computer)
         (a) Origin (state or condition at beginning of maneuver): Parking orbit (Essentially same as CM's), Transfer orbit, or other orbit
         (b) Destination (state the maneuver is intended to attain): Transfer orbit, commencement of powered descent burn, return to parking orbit (rendezvous), other orbit.
         (c) Options, where available: Time of execution, orbital pass of execution, other
         (d) Other required data insertions:
            1. Mode selection (if available)
            2. Landing site coordinates
            3. Attitude control
               a. Attitude for commencement of maneuver
               b. Time of assumption of attitude for commencement
               c. Whether attitude assumption to be automatic (on enablement of ignition sequence or other signal, or by program initiated by such signal) or manual with automatic "hold" until commencement of burn
               d. Attitude program during thrusting: "hold" constant (for short-duration impulse type burn as for orbit conversion or small change) or relate to thrust vector (for long burns involving large velocity changes, as for powered descent)
               e. Attitude control logic (use of main engine gimbals and RCS) is built into the computer
            4. Corrected mass of vehicle
            5. Propulsion variations: ISP, propellant temperature, others?

(4) Align IMU
    (a) Will be done in nominal mission /¯ _7 minutes before conversion to transfer orbit; and in transfer orbit before commencement of powered descent if more than /¯ _7 minutes are spent in Transfer Orbit.
    (b) May be omitted before emergency or non-nominal thrust events.
(5) The following characteristics are built into the descent program fixed memory and are not inserted each time
    (a) Type of transfer orbit (Equiperiod or Hohmann)
    (b) Powered descent trajectory logic and sequence: Minimum fuel, gravity turn, proportional navigation, letdown
    (c) Thrust program
    (d) Abort ascent program
b. Set up propulsion
    (1) Verify critical parameters (propellant quantity, pressure, temperatures, controls, etc.)
    (2) Enable ignition sequence
        (a) Verify attitude correct and holding
c. Initiate ignition sequence

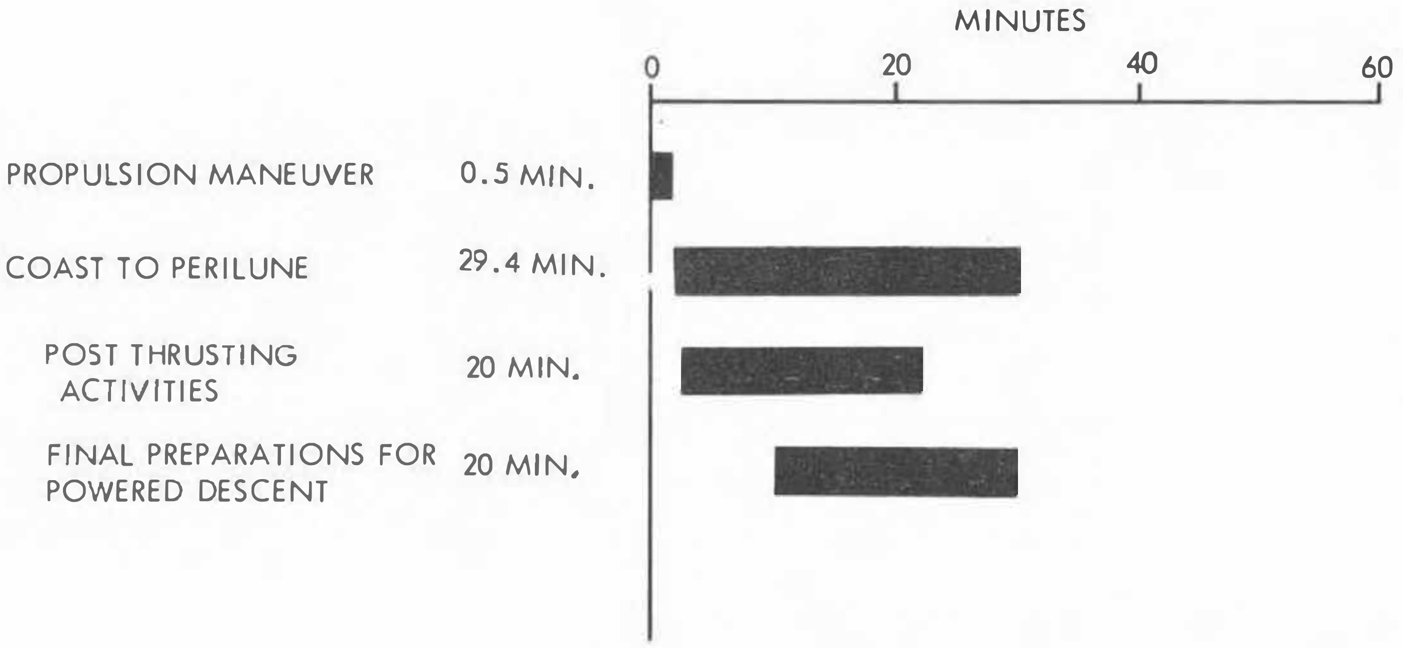
2. Ignition Sequence
    a. Ullage jets cut in (T - /¯ _7)
    b. Ullage thrust develops and continues
    c. Descent stage pump valves open; pumps start, main engine valves open
    d. Main engine ignition: T + 0

3. Propulsion Interval
    a. Full thrust developed by T + /¯ _7
        (1) Responds properly to throttle commands
    b. Ullage jets cut off by T + /¯ _7
    c. Ullage thrust terminated by T + /¯ _7
    d. Propellant accumulators recharged by T + /¯ _7
    e. Monitor and verify attitude (1) held, or (2) matched to thrust vector, as set up in G&C system
    f. ΔV, velocity, altitude, position, follow prescribed program; thrust vector controlled to regulate this
    g. Interval ends at achievement of (1) required V or (2) required V and position

4. Propulsion Termination
    a. Initiated by:
        (1) G&C sensing attainment of required V or ΔV, or
        (2) Sensing of touchdown and support of LEM weight by lunar surface
        (3) Command of pilot (in case of abort, emergency, change of mission, or failure of automatic control)

   - b. Pumps shut off; main valves shut
   - c. Thrust reduced to zero by ___ sec. after command

5. Post-Thrusting Activities
   - a. Survey for damage to vehicle
   - b. Verify safety of present situation and probable duration or condition of safety
     - (1) Perilune clearance if in orbit
     - (2) Stability, etc., if on surface
   - c. Assume attitude(s) required for navigational observations, tracking, communications, and thermal balance



10 LEM DESCENT TO PERILUNE

11. LEM LANDING (8 minutes)

Time Duration

A. Powered Descent, First Section

4 min

1. LEM crew initiates ignition sequence (see note 10.A.)
2. LEM propulsion
   - a. Crew monitors descent program and general system status throughout propulsion maneuver
   - b. Most of horizontal velocity is removed
3. LEM guidance will maintain updated abort parameters throughout phase

B. Powered Descent, Second Section

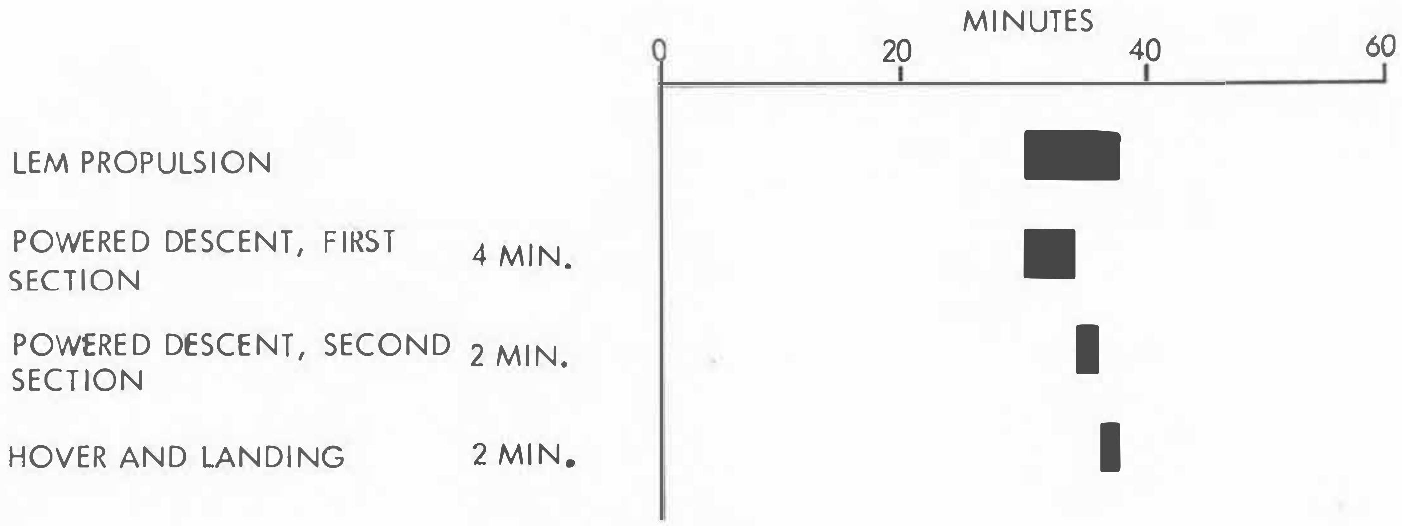
2 min

1. Begin increasing weighting of supplementary radar/optical data on surface and landing site
2. LEM guidance pitches LEM toward vertical position
3. Begin optical evaluation of landing site

C. Hover and Landing

2 min

1. Horizontal and vertical velocity brought to zero
2. Verify landing site
3. Begin final descent, with position adjustments
4. Touchdown
5. Propulsion termination
   - a. Using zero lunar surface altitude as a control parameter the guidance system generates engine cut-off



11 LEM DESCENT

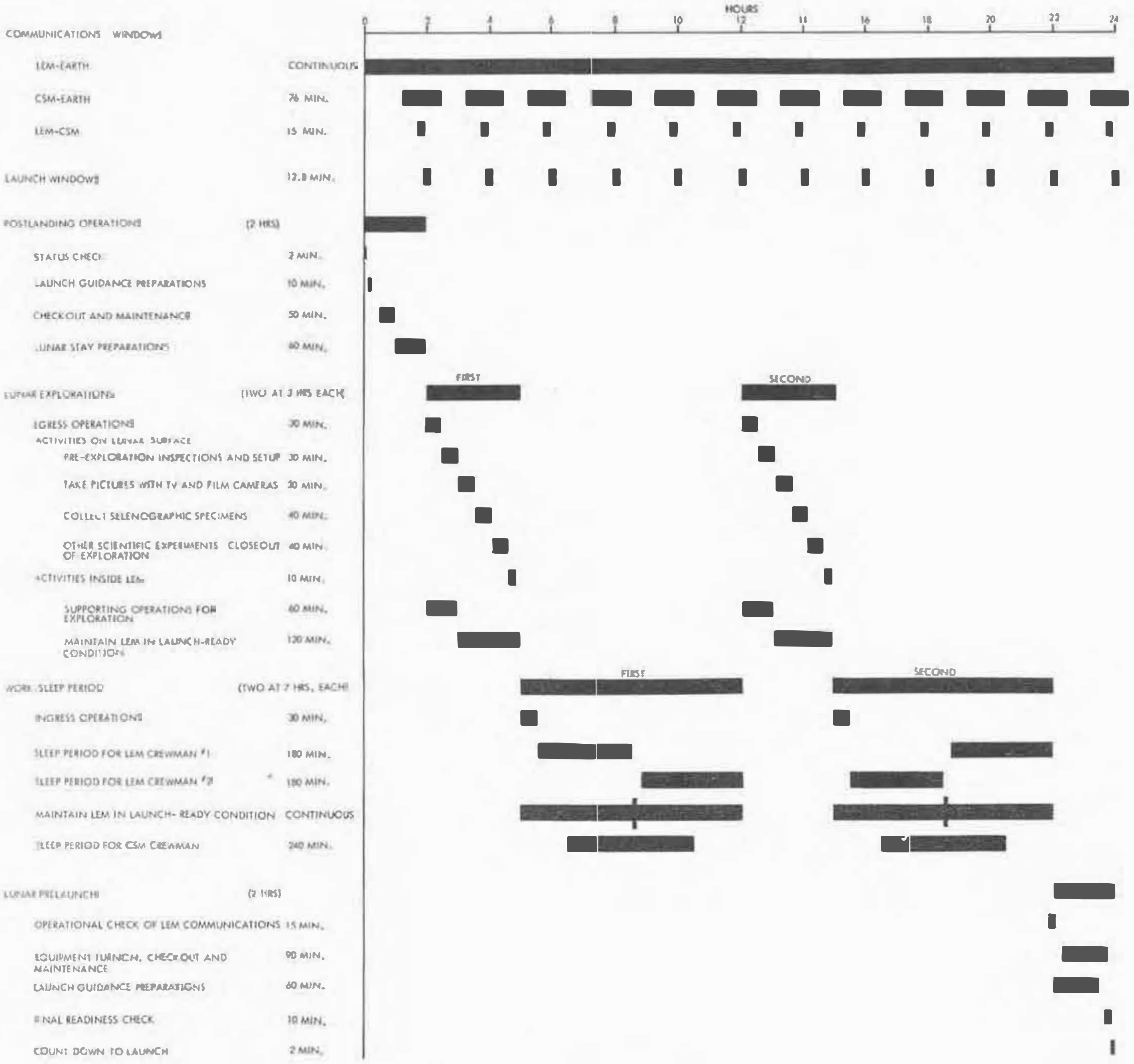
12. LUNAR SURFACE OPERATIONS (24 hours)	Time Duration
A. <u>Postlanding Operations</u>	2 hrs
1. Short status check	
a. Determine that nothing has occurred to life support and ascent systems that precludes remaining on the surface for at least one CSM orbit (i.e., approximately 2 hours)	2 min
2. Launch guidance preparations	10 min
a. Separate ascent and descent stages	
b. Star sightings and IMU alignment	
c. Compute launch parameters and ascent trajectory for next launch window	
d. Voice report and telemetry readout to IMCC on completion of a,b, and c.	
3. Checkout and maintenance of ascent systems	50 min
a. Conduct checkout of all systems required for ascent	
b. Determine maximum available lunar stay time	
c. During a., transmit telemetry data and voice reports	
d. Perform IMCC approved adjustments and maintenance	
4. Lunar Stay Preparations	60 min
a. Checkout PLSS and scientific instruments	
b. Visual survey of lunar surface	
c. Operational check of LEM-CSM communications	
d. Turn off or place in standby equipment not essential for lunar stay or expedited launch	
e. Review with IMCC crew task assignments and work schedules for lunar exploration	
f. Review emergency prelaunch operations	
B. <u>Lunar Exploration</u> (Two at 3 hours each)	
1. Egress operations	30 min
a. Depressurize LEM cabin, open forward hatch, and secure ladder	
b. Egress of one crewman to lunar surface	
2. Activites on lunar surface	
a. Pre-exploration inspections and setup	30 min
1) Establish voice contact with LEM	
2) Examine surface characteristics of landing site	
3) Test physical coordination and mobility	
4) Inspect exterior of LEM for damage	
5) Verify separation of ascent-descent stages	
6) Deploy directional TV antenna and connect cables	

	Time Duration
b. Take picutres with TV and film cameras	30 min
c. Collect selenographic specimens	40 min
d. Perform other planned scientific experiments within /¯1/2_7 mile of LEM	40 min
e. Closeout of exploration	10 min
1) Disconnect television antenna and associated cables	
2) Wherein possible leave scientific instruments and portable equipment on lunar surface	
3) Return to LEM and climb ladder to forward hatch	
3. Activities of crewman inside LEM	
a. Supporting operations for exploration	60 min
1) Repressurize LEM cabin	
2) Establish voice contact with crewman on lunar surface, observe his activities, and report status to IMCC	
3) Control all LEM communication to IMCC and CSM	
b. Maintain LEM in condition for expeditious launch	
1) Monitor onboard displays and perform checkout of systems that are operating or in standby	
2) Receive IMCC verified orbit parameters	

C. <u>Work/Sleep Period</u> (Two at 7 hours each)

1. Ingress operations	30 min
a. Depressurize LEM cabin	
b. Exploring crewman enters LEM	
c. Repressurize LEM cabin	
d. Begin replenishing PLSS of exploring crewman	
2. Exploring crewman sleeps	180 min
3. Other crewman maintains LEM in a condition ready for an expeditious launch. Crew members reverse roles 2 and 3 for second half of this period	
4. CSM crewman sleeps	240 min

	Time Duration
D. Lunar Prelaunch	2 hrs
1. Operational check of LEM-CSM and LEM-IMCC communications	15 min
2. Equipment turn on, checkout and maintenance	90 min
a. Turn on, in proper sequence, the LEM prime and back-up systems required for ascent, rendezvous, and docking	
b. Conduct checkout of all systems	
c. During a., transmit telemetry data and voice reports	
d. Perform IMCC approved adjustments and maintenance	
3. Launch guidance preparations	60 min
a. Synchronize LEM clock	
b. Star sightings and IMU alignment (including warm up)	
c. Receive updated orbit parameters	
d. Verify landing site coordinates	
e. Compute launch parameters and ascent program for scheduled launch window	
f. Voice report and telemetry readout to IMCC	
g. Receive verification from IMCC on computations in c. and e.	
h. Align rendezvous radar for CSM acquisition	10 min
4. Final readiness check between LEM, CSM, and IMCC	
a. Receive confirmation of CSM readiness from IMCC	
b. Establish LEM-CSM communications	
c. Acquire and track CSM with rendezvous radar	
d. Synchronize time of launch	
5. Countdown to launch	2 min



12. LUNAR SURFACE OPERATIONS

13. LEM ASCENT (82 to 172 minutes)

Time Duration

NOTE: A detailed description of the sequence for LEM ascent propulsion is an addendum attached to Phase 13.

A. Powered Ascent — 6 min

1. LEM crew monitors event sequence and initiates and verifies ignition at scheduled time
2. CM and LEM tracks each other, when in range and line-of-sight is open, with rendezvous radar
3. Ground and CSM monitor trajectory and provide guidance parameters as required

B. First Orbital Segment — 30-60 min

(If launch is exactly on time and no plane change is required, insertion is directly into transfer orbit; skip to "C" below).

1. LEM crew monitors event sequence and verifies ΔV and cut-off at correct time
2. Verify safe orbit
3. LEM, CM, IMCC computes attained orbit parameters, compute guidance data for next maneuver
4. Prepare for propulsion event for conversion to transfer orbit when proper phasing and/or plane relationships have been attained

C. Second Orbital Segment — 30-90 min

1. LEM crew monitors event sequence and initiates and verifies ignition at scheduled time
2. LEM crew verifies ΔV and cut-off at correct time
3. Verify that new orbit is safe and has 80-mile apolune
4. LEM, CM, IMCC computes attained orbit parameters
5. Prepare for midcourse correction (if required)
   a. IMCC provides guidance parameters for midcourse correction

D. Midcourse Correction — 30 sec

1. LEM crew monitors and verifies event sequence and initiates and verifies ignition at scheduled time

	Time Duration
2. LEM crew verifies ΔV and cut-off at correct time	
3. LEM-CSM-IMCC calculate new orbit parameters	
4. CM, IMCC supply guidance parameters for rendezvous orbit	
E. Insertion Into Rendezvous Orbit	30 sec
1. LEM crew monitors and verifies that thrusting maneuver proceeds as scheduled and proper ΔV is attained	
F. Preparation For Final Closing And Docking	15 min
1. Track CSM for relative orbit data	
2. Calculate closing maneuver	

ADDENDUM

SEQUENCE FOR LEM ASCENT PROPULSION

1. Pre-Ignition Sequence
   - a. Set up guidance and control
     - (1) Determine and insert (or verify) best data on present LEM parameters
       - (a) Orbit parameters if in orbit
       - (b) Position and time
     - (2) Determine and insert (or verify) best data on present CM parameters
       - (a) Orbit parameters
       - (b) Position and time
     - (3) Select program
       - (a) Origin (state or position at beginning of maneuver): surface, catch-up orbit, transfer orbit, rendezvous orbit, emergency (abort ascent) orbit or other
       - (b) Destination (the state the maneuver is intended to achieve): Catch-up orbit transfer orbit rendezvous orbit, rendezvous, emergency (abort ascent) orbit, or other
       - (c) Options where allowed: Time of execution, CM pass of execution, other
       - (d) Other required data insertions: attitude for commencement of maneuver, attitude hold or control program, time of assumption of attitude, whether attitude assumption to be automatic (on enablement of ignition sequence or other signal) or manual; corrections to mass of vehicle, corrections for propulsion variations (propellant temp; others?)
     - (4) Align IMU
       - (a) Will be done before ascent from surface except in emergency
       - (b) May be omitted in subsequent thrust events depending on time and data available
   - b. Set up propulsion
     - (1) Verify system parameters (propellant quantity, pressure, temperature, controls, corrections for variations, etc.)
     - (2) Enable ignition sequence: close switches bringing power to essential systems not powered except during thrusting and to controls for these systems
       - (a) Attitude for commencement of thrust should have been assumed and should be being held by this time, verify

- c. Initiate ignition sequence

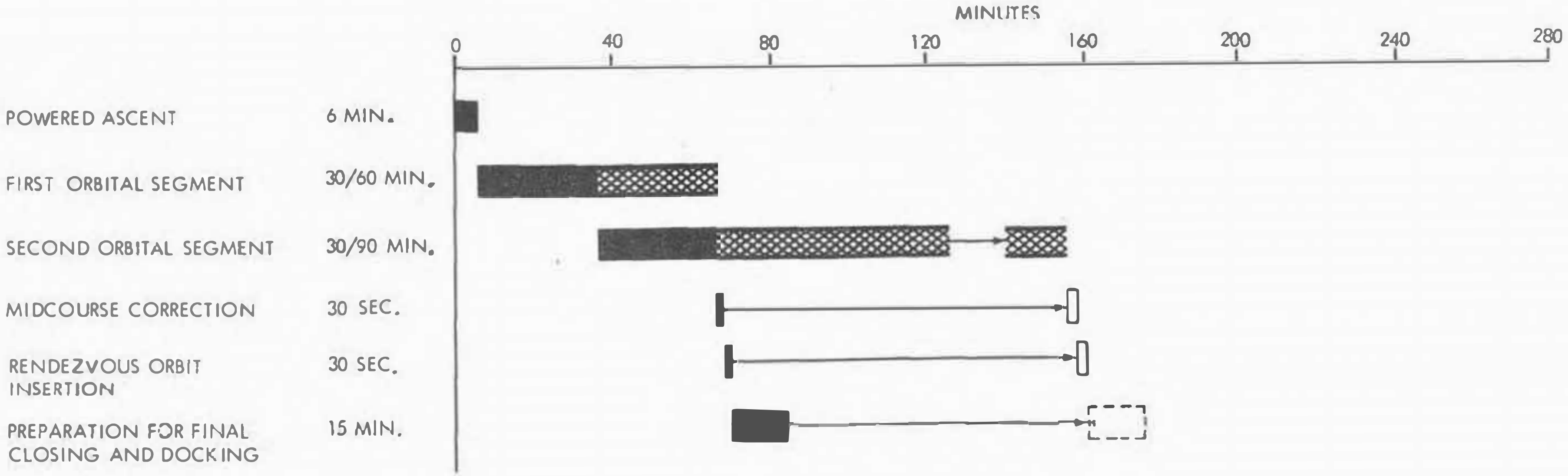
2. Ignition Sequence (Automatic program scheduled to result in 90% of required thrust at calculated or inserted in G&C system)
   - a. Ullage jets fire (not required for ascent from surface)
   - b. Ullage thrust develops and continues
   - c. Ascent stage pump valves open; pumps start, main engine valves open
   - d. Main engine ignition; thrust builds up 90% full thrust (~3150 lb.) at T = 0

3. Propulsion Interval
   - a. Full thrust (3500 lb.) developed by T + /‾ _7 sec.
   - b. Ullage jets cut-off by T + /‾ _7
   - c. Ullage thrust terminated by T + /‾ _7
   - d. Propellant accumulators recharged by T + /‾ _7
   - e. Crew monitor and verify attitude (controlled entirely by RCS) held at proper value or controlled according to program or thrust vector requirements; control manually if automatic performance (primary and back-up) outside limits
   - f. Crew monitor critical flight parameters: ΔV, V, altitude, position. Verify (and assure, by manual switch-over) shift to back-up mode if primary deverges from limits) Assume manual control if required
   - g. Interval ends at achievement of required V or ΔV and altitude
   - h. The irreducible minimum of performance in ascent from the surface is achievement of a safe orbit. All trade-offs and optimizations are dominated by this requirement: thus, any attainable orbit parameters are acceptable if <u>not</u> - accepting them (e.g., insisting on, or trying for a better orbit) somehow prejudices that objective

4. Propulsion Termination
   - a. Initiated by:
     - (1) G&C, sensing attainment of required V or ΔV or
     - (2) Command of pilot (in case of resort of manual back-up mode, or of failure of automatic cut-off)
   - b. Pumps shut off, main valves shut

c. Thrust reduced to zero by /‾ _7 sec. after command
d. Attitude continues held at last value or is shifted automatically to programmed value

5. Post-Thrusting Activities
   a. Survey for damage to vehicle
   b. Ascertain safety of orbit (Clear perilune)
      (1) From primary guidance system read-out
      (2) From back-up guidance system read-out
      (3) From CM tracking data if available
   c. Commence preparation for next thrust step



13 LEM ASCENT

14. LUNAR ORBIT RENDEZVOUS (60 minutes)

	Time Duration
A. Rendezvous	25 min

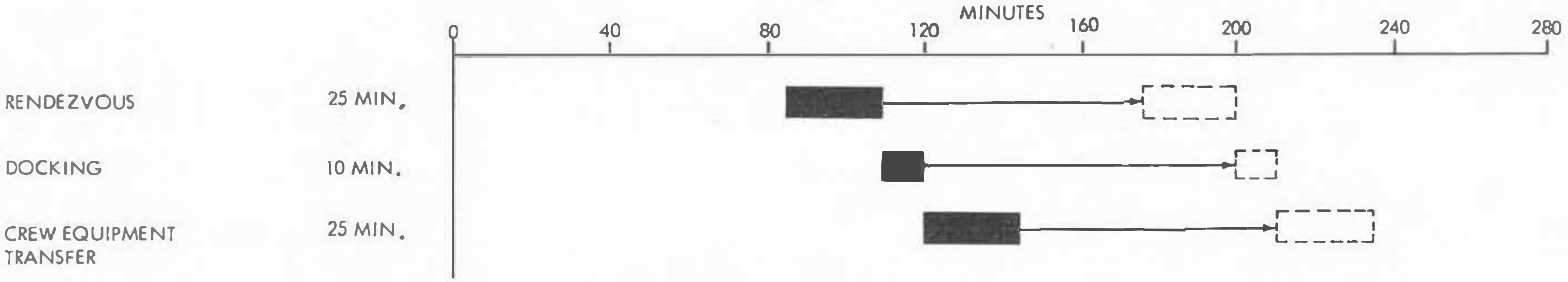
1. LEM-AGC provides ΔV required for LEM to approach the CSM
2. CSM-AGC calculates ΔV required for CSM to approach the LEM if it is necessary for the CSM to actively rendezvous with LEM
3. CM and ground calculate and provide rendezvous guidance data to LEM as feasible and required
4. Ground sites monitor LEM-CSM systems throughout phase (as mutual visibility permits)
5. Ground sites track both vehicles throughout phase (as mutual visibility permits)

B. Docking	10 min

1. CM-LEM coordinate docking attitude
2. Position and align LEM
3. Maintain zero inertial angle rates
4. Using LEM-RCS, close to final docking
5. Report docking status to IMCC

C. Crew and Equipment Transfer	25 min

1. Begin transfer of first LEM crewman, equipment and lunar samples to CSM
2. Establish remote LEM monitoring and control in CSM
3. Begin transfer of second LEM crewman and equipment to CSM
4. Conduct check to determine if damage was incurred during operation
5. Make situation report to IMCC
6. Begin pre-injection checkout



14 LUNAR ORBIT RENDEZVOUS

15. TRANSEARTH INJECTION (90 minutes)

		Time Duration
A.	LEM Stage-off	7 min
1.	Attain attitude for stage-off and hold using minimum dead-band limits	5 min
2.	Confirm correct operation mode for LEM stage-off	2 min
3.	LEM separation sequencer armed	1 min
4.	Docking latch is tripped and its release is verified by a crew display	10 sec
5.	LEM RCS is initiated by sequencer and provides a positive ΔV of 5 fps	5 sec
6.	Separation of docking and umbilical fittings is verified	5 sec
7.	CSM attitude is held until a 500 ft. separation is attained. LEM separation is observed visually during the first 50 ft. pullaway	100 sec
B.	Post Stage-off Cruise	65 min
1.	Make situation report to IMCC	2 min
2.	Select the cruise attitude control mode	1 min
3.	Power down all equipment associated with LEM or LEM stage-off and other non-essential equipment	1 min
4.	Establish SC attitude and ground communication as in 6.A.1.,2.	Continuous
5.	Conduct navigation observations, using lunar surface landmarks and altitude, to verify orbital data	2 min
6.	Transmit a 3-min. sample of real time TLM data and crew biomedical data	3 min
7.	The crew confers with IMCC on revision of operational settings and maintenance	10/25 min
8.	Orbital parameters are verified; the final parameters for transearth injection are generated and stored in the CM AGC	10 min
9.	Timing is synchronized with IMCC	
10.	IMCC receives final crew confirmation of readiness and authorizes the crew to proceed with transearth injection	5 min
11.	CM-Moon-Earth eclipse	
12.	Power down communication systems	
13.	Conduct IMU alignment (Same as 6.A.4.)	18 min

Time Duration

14. Final preparation for propulsion maneuver 10 min
    a. All movable CM equipment is stowed
    b. Crew puts on space suits and is positioned for the injection maneuver
    c. Obtain orientation for injection, hold until ignition
    d. Gimbal trim is adjusted and verified
    e. Minimum dead-band limits are selected
    f. Crew makes final confirmation of monitoring systems and control modes
    g. TLM recording equipment is activated

C. Pre-Ignition Sequencing 2 min

1. Ullage is initiated by AGC
2. SM engine start signal is automatically generated
3. The gimbal motors reach their normal operating speed and solonoid valves open for pressurization of propellants

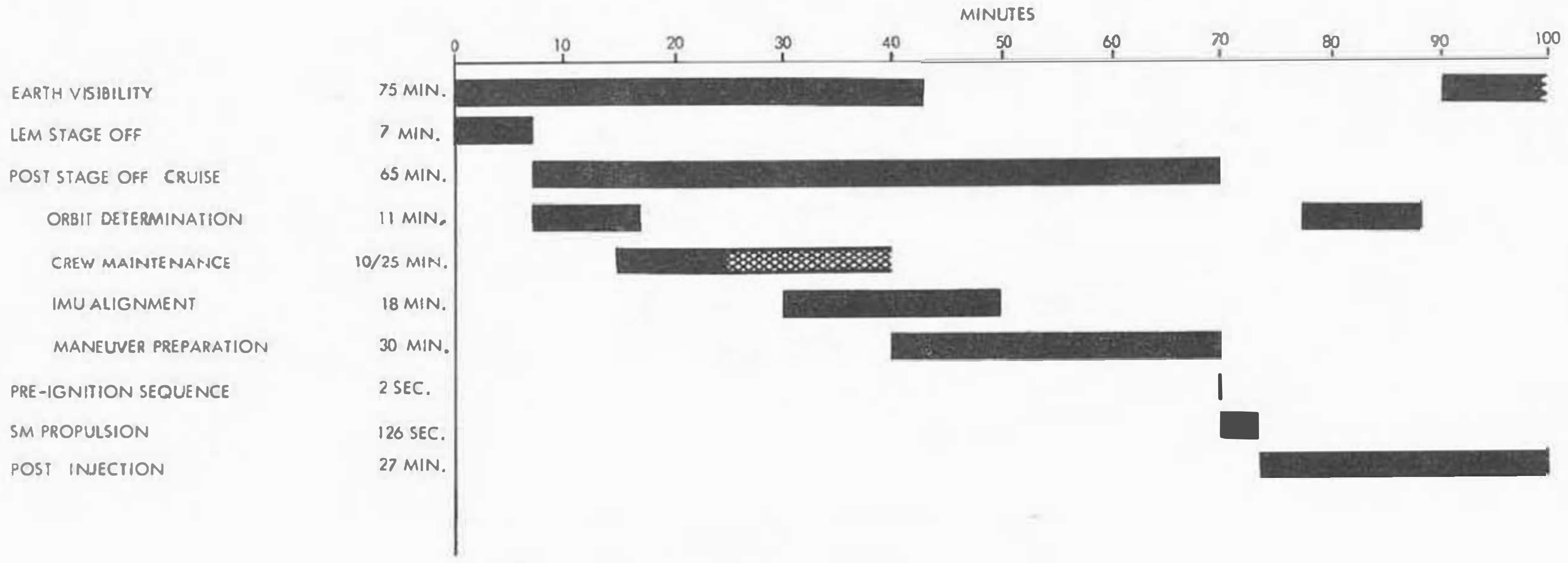
D. SM Propulsion 126 sec

1. Ignition
2. Full thrust is developed
3. SM RCS ullage thrust is terminated automatically
4. SC attitude and thrust vector are controlled for trajectory shaping
5. Engine cut-off signal is generated automatically
6. The pressurization valves are closed
7. Thrust tail-off
8. Gimbal motors are powered down
9. An attitude hold is effected

E. Post-Injection 27 min

1. The crew confirms that no serious operating problems require immediate attention 1 min
2. Establish CSM operating modes for initial cruising flight 2 min
3. Compile a performance summary 5 min
4. Conduct lunar altitude measurements

		Time Duration
5.	Conduct a celestial navigation observation	2 min
6.	Activate normal communications systems	2 min
7.	The moon clears the CM-earth line-of-sight. Communications are reestablished	
8.	Make a situation report to the ground and coordination is effected	2 min
9.	Transmit 3 min. real time CSM-TLM	3 min
10.	Transmit recorded TLM for injection maneuver after Step 9 has been received by IMCC	
11.	The phase is terminated	

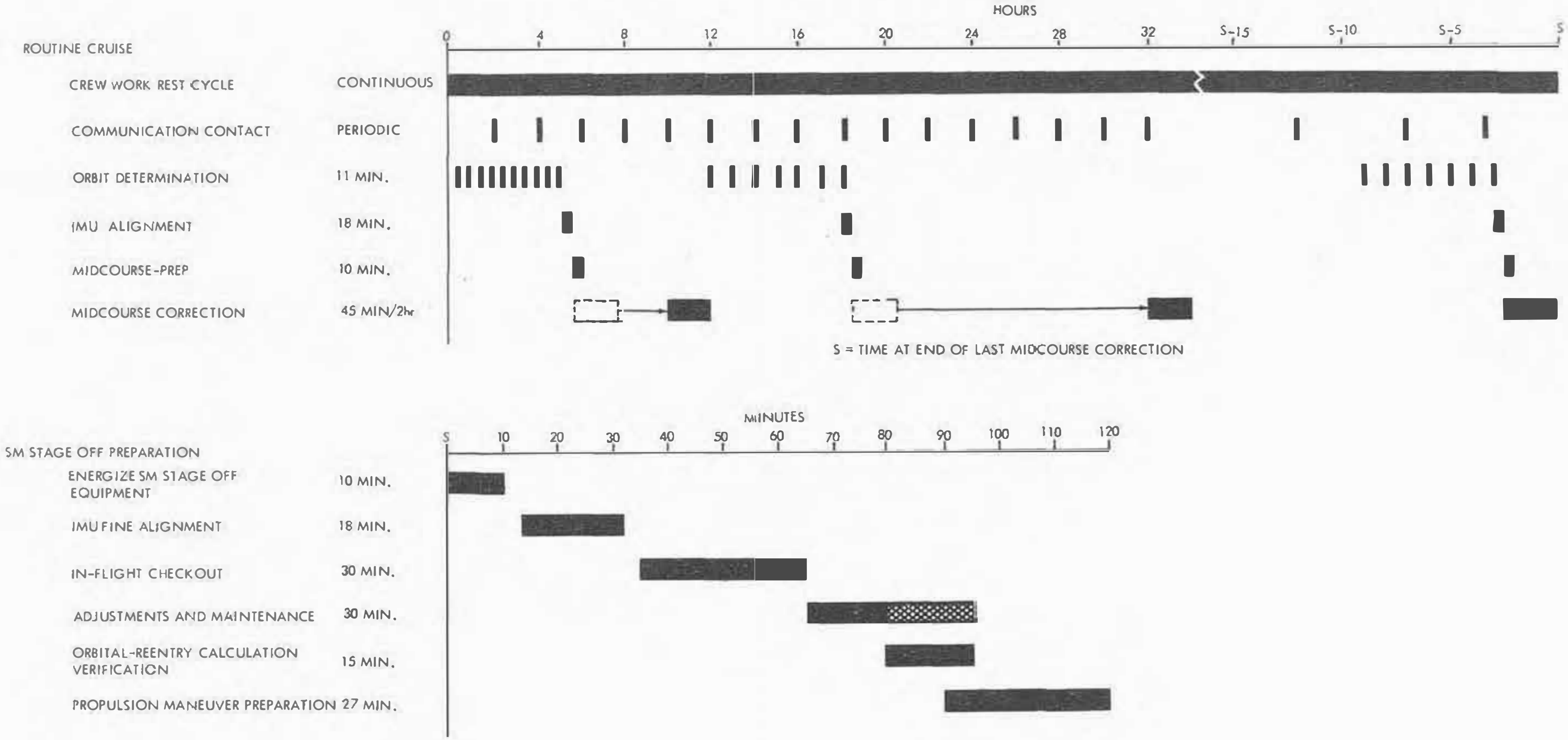


15 TRANS EARTH INJECTION

16. EARTH TRANSFER CRUISE (62 to 110 hours)

	Time Duration
A. Routine Cruise	60/108 hrs
1. Establish normal SC altitude, systems monitoring and control, and communications as described in 6.A.1.,2.,3.	Continuous
2. Begin rotating duty schedule. Two crew members normally out of spacesuits	Continuous
3. Establish communications contact schedule (contact at least every two hours)	Periodic
4. Perform navigational observations once each half-hour for five hours to determine orbit parameters to sufficient accuracy for first midcourse maneuver. In subsequent midcourse maneuvers, one observation each hour for five to ten hours depending on ground correlation	2 min
5. Conduct CM IMU alignment (same as 6.A.4.)	18 min
6. Perform midcourse correction preparation procedures as described in 6.B.1.	10 min
7. Perform midcourse correction maneuver -- Section 7	45 min to 2 hrs
8. The subphase is repeated after each midcourse maneuver except after final midcourse correction	
B. SM Stage-Off Preparations	2 hrs
1. Maintain normal SC attitude, systems monitoring, and ground communications described in 6.A.1.,2.,3.	Continuous
2. End crew work rest cycle	
3. Activate CSM systems necessary for SM stage-off and reentry	10 min
4. Perform CM IMU alignment	18 min
5. Perform in-flight checks to verify operability of equipment used during SM stage-off -- TLM available for IMCC analysis	30 min
6. Power down non-essential equipment	2 min
7. IMCC determines any revision of operating adjustments and any needed maintenance	10 min

	Time Duration
8. Crew performs IMCC-approved adjustments or maintenance	As required
9. Calculate, refine and store orbital parameters for propulsion maneuver	15 min
a. Determine orbital parameters at SC for precise calculation of (Same as 6.A.9.) 1) Reentry point 2) Time of reentry	
b. Obtain IMCC orbital and maneuver parameters via updata communication channel	2 min
c. Store IMCC and SC parameters in CM AGC	
d. Reentry parameters are revised as appropriate. Store in CM AGC	5 min
e. Normal and contingency landing area objectives coordinated between IMCC and crew	3 min
f. Data insertion verified	
10. Perform IMU alignment if desired (same as 6.A.4.)	18 min
11. Preparation for propulsion maneuver	25 min
a. Stow all movable CM equipment	
b. All crew members in space suits	
c. Set CSM systems, to stage-off operating mode, monitor operating parameters	
d. Orient SC for stage-off maneuver, hold within minimum dead-band limits	
12. Final crew readiness confirmation	2 min
a. CM systems on reentry power supplies	
b. Transfer communication to antenna on CM	
c. Power down non-essential SM equipment	
d. Activate stage-off maneuver sequencer	
e. Shut down two fuel cells	
13. Crew Commander makes contact report and selects control modes for	1 min
a. Pyrotechnic rupture of the CM-SM structural connections - verify	
b. SM continuous retrograde thrust using SM RCS (-X translation) -- verify	
c. Pressurization of CM RCS -- verify	

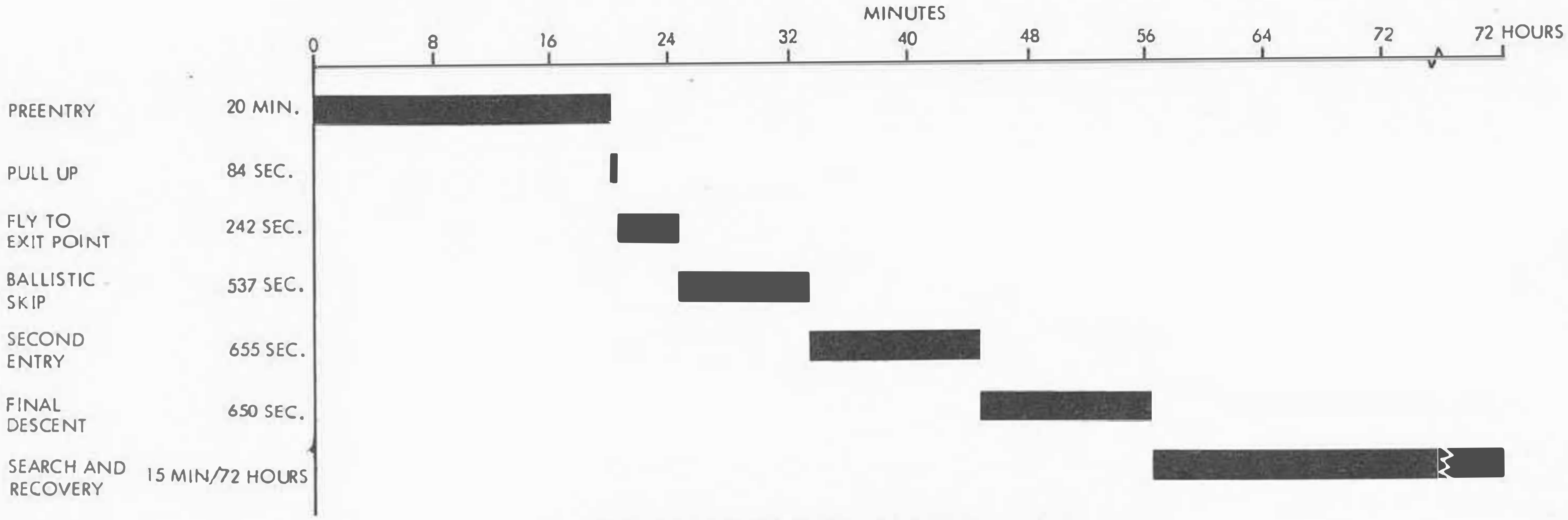


16. EARTH TRANSFER CRUISE

17. REENTRY AND LANDING (45 to 60 minutes)

	Time Duration
A. Reentry	45/60 min
1. Pre-Entry, from SM jettison to entry point	20 min
a. Update navigation parameters from ground	
b. Predict time to landing point	
c. Check of all systems	
d. Assume attitude for entry 10 minutes before entry	
e. Select automatic entry mode 5 minutes before entry	
2. Entry point (0.05g acceleration at about 300 kft.). Pitch, yaw control disabled, roll-yaw coupling initiated	
3. Initial pull-up (from entry point to first horizontal flight)	84 sec
a. Control constant roll angle determined by location in entry corridor	
b. Compute reference trajectory for exit phase	
4. Fly to exit (h = 0 to 300 kft.)	242 sec
a. Automatic guidance flies the computed reference trajectory to exit point for a controlled skip. If no skip is to be executed, a constant altitude phase is substituted	
5. Ballistic skip or constant altitude phase	537 sec
a. Predict second entry point and time, and estimate landing point and time	
b. Reestablish communication and tracking	
6. Second entry (300 kft.)	655 sec
a. Automatic guidance flies an equilibrium glide trajectory	
7. Final descent. Starts at 25,000 ft.	650 sec
a. At 25,000 ft. forward heat shield is jettisoned followed by drogue-chute deployment	
b. Main chutes are deployed reefed at 15,000 ft., and are fully opened at 13,000 ft.	
c. CM RCS fuel burned	
d. Recovery communications and beacon are activated	
e. Touchdown, main chute jettisoned	

NOTE: Time Durations are for a typical 5000 mile reentry trajectory.



NOTE: TIME DURATIONS ARE FOR A TYPICAL 5000 MILE TRAJECTORY

17. REENTRY AND LANDING

18. SEARCH AND RECOVERY (8 to 72 hours)

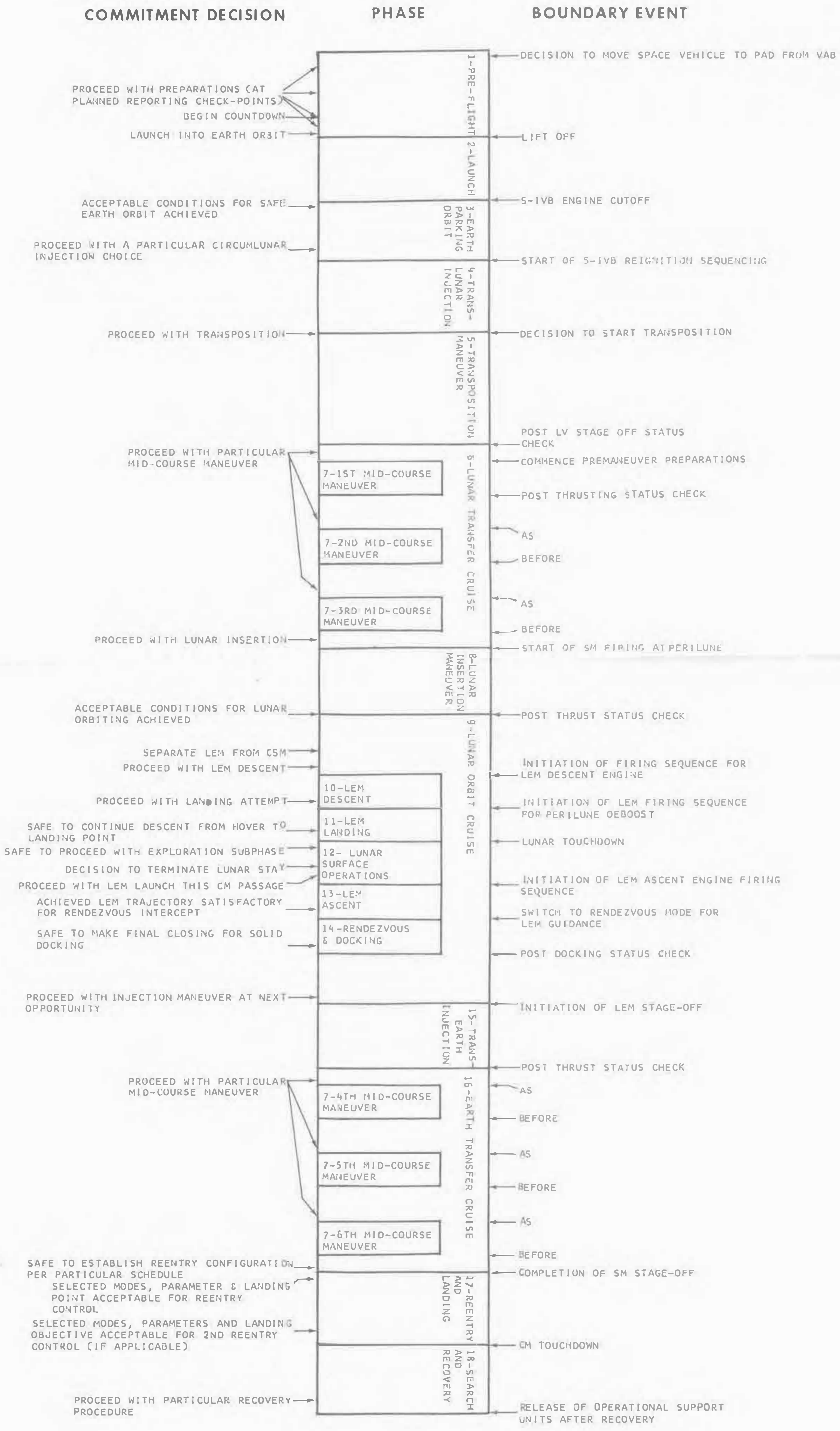
	Time Duration
A. Touchdown	
1. Recovery aids automatically activated. HF antenna is extended	
2. Crew broadcasts touchdown site information to Recovery Forces	
B. Location In Planned Landing Areas	8 hrs
1. Recovery forces determine location of touchdown from information supplied by IMCC or crew broadcast	
2. Advance para-medics and para-rescue personnel dropped to render medical assistance and attach flotation aids, if on water	
3. Crew retrieval forces arrive and ferry the crew to the Recovery Ship or Station	
4. Spacecraft retrieval forces arrive and bring the CM into a secure location. Scientific samples recovered	
C. Search And Recovery In Contingency Areas	72 hrs
1. Search patterns commenced based on last known CM position transmitted from IMCC	
2. Location of touchdown by reconnaissance forces and crew retrieval forces directed to site	
3. Crew is retrieved and delivered to point of nearest regular transportation for relay to a Recovery Station	
4. Spacecraft retrieved	

APPENDIX B

Abbreviations used in this document are alphabetically listed and defined in this Appendix.

AGAP	Altitude Gyro, Accelerometer Package
AGCU	Altitude Gyro Coupler Unit
AGC	Apollo Guidance Computer
AMR	Atlantic Missile Range
CDU	Coupling and Display Unit
CM	Command Module
CSM	Command Service Module
DOD	Department of Defense
DSS	Deep Space Site
ECS	Environmental Control System
EDS	Emergency Detection System
EPS	Electrical Power System
FD	Flight Director
FDAI	Flight Director Attitude Indicator
fps	feet per second
G & C	Guidance and Control
G & N	Guidance and Navigation
GOSS	Ground Operations Support System
GSFC	Goddard Space Flight Center
HF	High Frequency (3-30 Megacycles)
IFTS	In Flight Test System
IMCC	Integrated Mission Control Center
IMU	Inertial Measurement Unit
IU	Instrument Unit
LC	Launch Center
LCC	Launch Control Center
LEM	Lunar Excursion Module

LES	Launch Escape System
LOR	Lunar Orbit Rendezvous
LUT	Launch Umbilical Tower
LV	Launch Vehicle
MDS	Malfunction Detection System
MSFN	Manned Space Flight Network
n.m.	Nautical Mile
OD	Operations Director
PLSS	Portable Life Support System
R & D	Research and Development
RCC	Recovery Control Center
RCS	Reaction Control System
RTCC	Real Time Computer Complex
S-band	1550-5200 Megacycles
SC	Spacecraft
SCS	Stabilization and Control System
SM	Service Module
SPS	Service Propulsion System
SV	Space Vehicle
S-IC	First Stage Launch Vehicle
S-II	Second Stage Launch Vehicle
S-IVB	Third Stage Launch Vehicle
TLM	Telemetry
V	Velocity
ΔV	Change in velocity
VAB	Vertical Assembly Bldg.
VHF	Very-High Frequency (30-300 megacycles)



APOLLO LOR MISSION PHASES
AND COMMITMENT DECISION
RELATIONSHIPS

FIGURE 1

FIGURE 2

POSSIBLE CONTINGENCY OPTIONS AVAILABLE DURING THE APOLLO MISSION REFERENCED TO SIGNIFICANT MISSION EVENTS

☐ LES PAD ABORT

☐ HOLD, RECYCLE, OR RESCHEDULE

☐ INDEFINITE POSTPONMENT

☐ LAUNCH ESCAPE SYSTEM ABORT
a-LOCAL AREA
b-HIGH Q
c-HIGH ALTITUDE

☐ USE S-IVB THRUST FOR INSERTION INTO SAFE EARTH PARKING ORBIT; DEMONSTRATE TRANSPOSITION, SEPARATE LEM FLIGHT, LONG DURATION MISSION; USE SM THRUST FOR HIGH ENERGY CM RE-ENTRY OR FOR DEBOOST TO ACHIEVE OPTIMUM RECOVERY POINT

☐ USE SM THRUST FOR CSM INSERTION FOR MULTI-ORBITS FOLLOWED BY SM DEBOOST FOR CM-RE-ENTRY AT AN OPTIMUM POINT FOR RECOVERY

☐ USE S-IVB OR SM THRUST FOR CSM INSERTION FOR SINGLE ORBIT; SM DEBOOST FOR CM RE-ENTRY AT OPTIMUM POINT FOR RECOVERY

☐ CSM ABORT WITH SM THRUST USED TO SHAPE CM BALLISTIC RETURN
a-SHORTEN TRAJECTORY
b-LENGTHEN TRAJECTORY

☐ CM ABORT FOR BALLISTIC RETURN
a-NO LIFT MANEUVER
b-WITH LIFT MANEUVER

☐ CM ABORT USING LIFT MANEUVER; MAXIMUM ATMOSPHERIC BRAKING FOR EARLIEST RE-ENTRY

☐ S-IVB CUT OFF FOR MARGINAL ORBIT; MAKE TRANSPOSITION ① OR SM DEBOOST; CM RE-ENTRY TO OPTIMUM RECOVERY-POINT

☐ TERMINATE FLIGHT BY AN IMMEDIATE SM DEBOOST FOR AN EMERGENCY CM RE-ENTRY AND LANDING
a-WITH LIFT MANEUVER TO IMPROVE TIME TO RECOVERY
b-WITH NO LIFT MANEUVER

☐ **TERMINATE FLIGHT BY SM DEBOOST** AT AN OPTIMUM POINT IN **PRESENT ORBIT FOR CM** RE-ENTRY AND LANDING AT **PRIMARY OR SECONDARY RECOVERY POINT**

☐ TERMINATE THRUST IF IN POWERED FLIGHT; USE S-IVB OR LEM (AFTER APPROPRIATE DOCKING MANEUVER) FOR DEBOOST FOR A CM RE-ENTRY

☐ DELAY INJECTION TO LATER ORBIT; MAKE ADDITIONAL CHECKS AND REPAIRS AS NECESSARY BEFORE PROCEEDING WITH NOMINAL MISSION

☐ PROCEED WITH A LIMITED LUNAR MISSION ③
a-ORBIT MOON BUT NO LUNAR LANDING
b-CIRCUMLUNAR FLIGHT ONLY

☐ INJECT IN HIGHER VELOCITY EARTH ORBIT (CIRCULAR, OR ELLIPTIC) USING S-IVB AND/OR SM ② THRUST; MAKE MULTIPLE OR SINGLE REVOLUTION(S) FOLLOWED BY SM DEBOOST FOR NOMINAL APOLLO-TYPE RE-ENTRY AND RECOVERY

☐ MAKE MULTI-ORBIT MISSION IN NOMINAL PARKING ORBIT AND USE SM DEBOOST FOR CM RE-ENTRY AT AN OPTIMUM POINT FOR RECOVERY

☐ IF A SPECIAL TRACKING BEACON WERE TO BE INCLUDED IN LEM: USE S-IVB AND/OR SM THRUST (WITH TRANSPOSITION AS APPROPRIATE) TO PLACE LEM IN A LONG-LIFE EARTH ORBIT FOR STORAGE AND USE BY A SUBSEQUENT MISSION; THEN USE SM THRUST FOR OPTIMUM RETURN OF CM TO LANDING

☐ CSM ABORT WITH SM THRUST USED TO DEBOOST FOR EMERGENCY CM RE-ENTRY AND LANDING

☐ TERMINATE THRUST AND DETERMINE ELLIPTIC EARTH ORBIT; DEMONSTRATE CSM TRANSPOSITION AND POSSIBLY SEPARATED LEM FLIGHT; USE SM THRUST FOR OBTAINING SUITABLE TRAJECTORY FOR SINGLE OR MULTIPLE REVOLUTIONS AND FOR A DEBOOST AFFORDING A NOMINAL APOLLO-TYPE RE-ENTRY AND RECOVERY

☐ TERMINATE THRUST; DETERMINE ORBIT AND USE SM THRUST TO ACHIEVE A TRAJECTORY FOR CIRCUMLUNAR FLIGHT FOLLOWED BY CM RE-ENTRY AND LANDING

☐ TERMINATE THRUST AND STAGE-OFF LV/LEM; DETERMINE TRAJECTORY; USE SM THRUST FOR MINIMUM FLIGHT TIME TO EMERGENCY CM RE-ENTRY AND LANDING

☐ TERMINATE THRUST; DETERMINE ORBIT; USE LEM THRUST (WITH APPROPRIATE TRANSPOSITION) FOR OBTAINING OPTIMUM FLIGHT ELLIPSE FOR CM RE-ENTRY AND LANDING

☐ TERMINATE THRUST AND DETERMINE TRAJECTORY; MAKE TRANSPOSITION, AND STAGE-OFF LV; USE SM (OR LEM, ④) THRUST TO ATTAIN LUNAR TRANSFER TRAJECTORY FOR:
(a) ORBIT MOON, NOT LAND
(b) CIRCUMLUNAR FLIGHT ONLY

☐ DETERMINE STATE OF SC AND LV; GO AHEAD WITH TRANSPOSITION; STAGE-OFF LV; DETERMINE ORBIT; ATTEMPT REPAIRS; THEN DECIDE ON CONTINUING OR CURTAILING MISSION

☐ MAKE EMERGENCY LV SEPARATION; AT SAFE DISTANCE, DETERMINE CSM STATE AND ORBIT; THEN DECIDE ON SPECIFIC OPTION FOR CURTAILMENT OF MISSION

☐ DETERMINE ORBIT AND ATTEMPT TRANSPOSITION; THEN TERMINATE FLIGHT BY USE OF SM THRUST TO ACHIEVE A RETURN ELLIPSE FOR EARLIEST CM RE-ENTRY AT A POINT ALLOWING DESCENT TO A PRIMARY OR SECONDARY RECOVERY POINT ⑤

☐ STAGE-OFF (LV AND) LEM; TERMINATE FLIGHT BY USE OF SM PROPULSION TO ACHIEVE MINIMUM FLIGHT TIME ELLIPSE FOR EMERGENCY CM RE-ENTRY AND LANDING ⑤

☐ ALTER NUMBER AND/OR SCHEDULING OF MID-COURSE CORRECTIONS TO ALLOW SPECIAL DIAGNOSTIC CHECKS AND REPAIRS, TO OPTIMIZE TRANSFER TRAJECTORY, OR TO CONSERVE PROPULSION FUEL

☐ CONTINUE ON LIMITED LUNAR MISSION WITH LEM ⑤
a-ORBIT MOON (BY SM OR LEM THRUST)
1-DEMONSTRATE SEPARATE LEM OPERATION
(a) DESCENT ORBIT BUT NO LANDING
(b) NO ORBIT CHANGES, REMAIN IN RENDEZVOUS ZONE
2-OPERATE LEM WITHOUT DECOUPLING UNTIL JETTISONED
b-CIRCUMLUNAR FLIGHT ONLY
1-DEMONSTRATE SEPARATE LEM OPERATION AND DOCKING BUT IN RENDEZVOUS ZONE ONLY
2-OPERATE LEM WITHOUT DECOUPLING, DELAY STAGE-OFF UNTIL FIRST HOME-BOUND MID-COURSE CORRECTION

☐ CONTINUE ON LIMITED LUNAR MISSION WITHOUT LEM
a-DEMONSTRATE CSM TRANSPOSITION BEFORE ABANDONING LEM, THEN:
1- CSM ORBIT MOON
2- CSM CIRCUMLUNAR FLIGHT ONLY
b-WITHOUT DOCKING WITH LEM
1- CSM ORBIT MOON
2- CSM CIRCUMLUNAR FLIGHT ONLY

☐ MAKE CIRCUMLUNAR FLIGHT WITH ONLY SMALL ΔV CORRECTIONS, TO GIVE RE-ENTRY FOR LANDING AT A PRIMARY RECOVERY POINT

☐ TERMINATE BY A CIRCUMLUNAR FLIGHT; USE SM THRUST FOR MINIMUM FLIGHT TIME ELLIPSE ⑤

☐ **TERMINATE FLIGHT BY USE OF LEM THRUST TO ACHIEVE** OPTIMUM TRAJECTORY FOR CM RE-ENTRY AND LANDING:
a-BY CIRCUMLUNAR FLIGHT
b-WITHOUT PASSING MOON

☐ TERMINATE INSERTION ATTEMPT; REVERSE ORIENTATION AND IMMEDIATELY USE SM THRUST FOR EMERGENCY ABORT TO E-TRANSFER CRUISE

☐ TERMINATE THRUST; CIRCUIT MOON IN ATTAINED ORBIT TO DETERMINE PARAMETERS AND/OR EFFECT REPAIRS; MAKE E-TRANSFER INJECTION USING SM (OR LEM) THRUST FOR NORMAL OR MINIMAL RETURN CRUISE, AS APPROPRIATE

☐ DETERMINE ORBIT; CORRECT GROSS TRAJECTORY ERROR, OR CHANGE PLANE BEFORE STARTING LEM CHECKOUT, OR SELECT NEW LANDING SITE THAT IS CONSISTENT WITH ACHIEVED ORBIT

☐ MAKE MULTIPLE **MOON ORBITS WITHOUT** LEM SEPARATION, **THEN COMMENCE CSM** RETURN FLIGHT ⑤

☐ **TERMINATE LUNAR OPERATIONS BY ABANDONING LEM AND USING SM** THRUST TO START THE RETURN TO EARTH AT FIRST INJECTION **OPPORTUNITY**

☐ TERMINATE LUNAR OPERATIONS BY USING LEM THRUST FOR INJECTION INTO EARTH-TRANSFER TRAJECTORY AND FOR MID-COURSE CORRECTIONS

☐ EXTEND LEM CHECKOUT EVENT FOR ADDITIONAL ORBIT(S) TO MAKE FURTHER TESTS OR EFFECT REPAIRS BEFORE PROCEEDING WITH THE NOMINAL MISSION

☐ COMPLETE LEM DESCENT AND ASCENT FOR RENDEZVOUS; OR MINIMIZE FURTHER INDEPENDENT LEM OPERATIONS BY RENDEZVOUS AND DOCKING; MAKE SCHEDULED CSM RETURN FLIGHT ⑤

☐ DEMONSTRATE SEPARATE LEM OPERATION FOR MULTIPLE ORBITS IN THE RENDEZVOUS ZONE; DOCK AND COMPLETE NORMAL RETURN TO EARTH ⑤

☐ LEM DELAY DEBOOST FOR ONE OR MORE TRANSFER ORBITS FOR MORE CHECKS OR REPAIRS BEFORE LANDING

☐ MINIMIZE FURTHER LUNAR OPERATIONS BY RETURN OF CREW TO CM AT EARLIEST OPPORTUNITY; EFFECT ANY POSSIBLE CM REPAIRS BY USE OF LEM PARTS BEFORE ABANDONMENT; START EARTH RETURN AT FIRST PRACTICABLE INJECTION OPPORTUNITY ⑤

☐ MAKE LEM EMERGENCY ASCENT FOR EARLIEST RENDEZVOUS AND DOCKING; MAKE A SCHEDULED CSM RETURN FOR NOMINAL LANDING POINT

☐ MAKE EMERGENCY LEM ASCENT IMMEDIATELY

☐ SHORTEN EXPLORATION PERIOD; ADVANCE SCHEDULE FOR ASCENT

☐ MINIMIZE EXPLORATION OR TERMINATE IMMEDIATELY; MAKE AN EXPEDITED CHECKOUT AND BE READY FOR ASCENT (AN EMERGENCY ASCENT IF TROUBLE WARRANTS) ON NEXT NORMAL LAUNCH OPPORTUNITY

☐ CSM ABANDON DISABLED LEM ONLY IF ALL POSSIBLE REPAIR ACTION FAILS TO GIVE THE MINIMUM CAPABILITY ESSENTIAL FOR ASCENT TO AN ORBIT ACCEPTABLE FOR A RESCUE INTERCEPT

☐ EXTEND THE EXPLORATION PERIOD

☐ LEM TERMINATE LUNAR OPERATIONS AS RAPIDLY AS POSSIBLE; EXPEDITE CHECKOUT AND MAKE EMERGENCY ASCENT TO A CATCH-UP ORBIT; AT PROPER PHASING, MAKE ORBIT TRANSFER FOR NORMAL RENDEZVOUS AND DOCKING

☐ POSTPONE ASCENT TO LATER ORBIT OF CSM TO PERMIT FURTHER CHECKS OR REPAIRS, OR TO OBTAIN REDUCED TIME TO RENDEZVOUS

☐ MAKE RENDEZVOUS AND EFFECT CREW TRANSFER WITHOUT DOCKING; COMPLETE REMAINDER OF THE NOMINAL MISSION

☐ DETERMINE ATTAINED LEM ORBIT; USE ANY REMAINING LEM PROPULSION, IF PRACTICABLE, TO BETTER SHAPE THE ORBIT FOR A RESCUE INTERCEPT, AND USE SM THRUST TO EFFECT RENDEZVOUS; TRANSFER CREW AND COMPLETE REMAINDER OF MISSION TO A DESIGNATED RECOVERY POINT

☐ CSM ABANDON LEM ONLY IF DISABLED BEYOND CHANCE OF REPAIR OR IF LEM PROPULSION IS EXHAUSTED BUT ATTAINED ORBIT MAKES RESCUE INTERCEPT IMPOSSIBLE

☐ ADVANCE INJECTION TO EARLIER ORBIT TRANSFER OPPORTUNITY AND EXPEDITE PREPARATIONS; PROCEED WITH A MINIMUM TIME RETURN FLIGHT

☐ LIGHTEN PAYLOAD BY ABANDONING SCIENTIFIC SAMPLES AND OTHER NON-ESSENTIAL WEIGHT; PROCEED WITH MINIMUM THRUST BUDGET RETURN FLIGHT

☐ USE ANY REMAINING LEM FUEL TO OBTAIN A MORE OPTIMUM ORBIT FOR THE CSM BEFORE PROCEEDING WITH REST OF NOMINAL MISSION

☐ DELAY INJECTION TO LATER ORBIT FOR FURTHER CHECKOUTS AND REPAIRS; PROCEED WITH NOMINAL RETURN FLIGHT

☐ NO OPTION, USE BACK-UPS AND OVERRIDES TO OBTAIN SUITABLE TRAJECTORY BEFORE TERMINATING THRUST; EXPEND RESERVE FUEL IF NECESSARY

☐ ALTER NUMBER AND SCHEDULING FOR MID-COURSE CORRECTIONS TO IMPROVE THE PATH ACCURACY AT RE-ENTRY WINDOW, TO OPTIMIZE TIME TO RE-ENTRY, TO REDUCE ATTITUDE OR PROPULSION REQUIREMENTS, AND/OR TO ALLOW FOR SPECIAL CHECKS AND REPAIRS

☐ USE REMAINING SM FUEL THROUGH SM/RCS TO SHAPE TRAJECTORY FOR A SURVIVABLE RE-ENTRY

☐ DELAY THE SM STAGE-OFF TO CONSERVE CM RESERVES ⑥

☐ CHANGE THE SCHEDULED CM MANEUVER PROFILE AND THE EXPECTED TOUCHDOWN POINT TO MAXIMIZE THE LIKELIHOOD OF A SAFE AND SUCCESSFUL LANDING

☐ NO OPTIONS POSSIBLE, CONTINUE NOMINAL MISSION; USE MODES ⑦ BELIEVED MOST RELIABLE

☐ CHANGE GUIDANCE MODE OR MANEUVER PROFILE AND EXPECTED TOUCHDOWN POINT; MANUALLY INITIATE LANDING SYSTEM DEPLOYMENTS

☐ ALTER SEARCH AND RECOVERY PLANS AND DEPLOYMENT
a—MOVE UNITS OF RECOVERY FORCE
b—USE STANDBY RESCUE UNITS OF COOPERATING ORGANIZATIONS
c—ORGANIZE SEARCH WITH AVAILABLE UNITS OF OPPORTUNITY IN GENERAL AREA OF THE LANDING

☐ CREW ABANDON CAPSULE

☐ DESIGNATE A SPECIFIC TYPE UNIT OR MODE FOR RECOVERY PICKUP:
a—RECOVER CREW WITHOUT SAVING CAPSULE
b—DROP MEDICS AND SUPPLIES FOR DELAYED RECOVERY
c—MAKE RECOVERY BY AIR WITHOUT LANDING

NOTE:
① AFTER DOCKING, A SUB-OPTION MIGHT BE TO USE SM OR LEM PROPULSION TO ACHIEVE A MORE OPTIMUM ORBIT AND THEN DEMONSTRATE A MULTI-ORBIT PERFORMANCE.

NOTE:
② COULD INCLUDE A SUB-OPTION OF DOCKING FOLLOWED BY LEM USE TO ACHIEVE A NEW ORBIT OR TO DEMONSTRATE SEPARATE OPERATION.
③ COULD PERHAPS USE LEM THRUST HERE TO HELP MAKE LUNAR MISSION POSSIBLE.

NOTE:
④ COULD PERHAPS USE LEM THRUST HERE TO MAKE A CIRCUMLUNAR FLIGHT POSSIBLE IF VELOCITY IS NEAR THRESHOLD FOR SM CAPABILITY.

NOTE: ⑤ COULD USE LEM THRUST, GUIDANCE AND NAVITION, OR COMMUNICATIONS FOR TRACKING, COMMAND DATA OR VOICE, UNDER CERTAIN TROUBLE CONDITIONS OF CSMTO ASSIST IN OPERATIONS PROVIDED THE EMERGENCY ARRANGEMENT IS ANTICIPATED OR DETERMINED EARLY ENOUGH AFFORD THE TIME FOR ACTIVATION AND CHECKOUT

NOTE:
⑥ COULD EXTEND TO USING SM REACTION CONTROL TO GET CM ORIENTED TO RE-ENTRY ATTITUDE BEFORE SEPARATION IN AN EMERGENCY CM CONDITION IF SM RCS GIVES LATERAL CLEARANCE AFTER STAGING
⑦ IN EXTREME, USE MANUAL CONTROL TO KEEP WITHIN MAXIMUM DECELERATION LIMIT AND CONSTANT ANGLE OF ATTACK