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NASA APPROVED SPECIFICATION

THIS SPECIFICATION IS A CONTRACT SPECIFICATION AND IS SUBJECT TO CONFIGURATION MANAGEMENT CHANGE CONTROL PROCEDURES.

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GFE
GUIDANCE, NAVIGATION, AND CONTROL PERFORMANCE AND INTERFACE SPECIFICATION BLOCK II (U)

2 October 1965

Contract NAS9-150

Approved by

Dale D. Myers

Dale D. Myers, Vice President
Apollo Program Manager

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GFE
GUIDANCE, NAVIGATION, AND CONTROL
PERFORMANCE AND INTERFACE
SPECIFICATION
BLOCK II

1.0 SCOPE

1.1 Scope. - This specification defines performance and interface requirements of the Guidance, Navigation, and Control (GN&C) subsystem in all areas where the characteristics and capabilities of that subsystem place any design constraints on the Command and Service Module (CSM) or any of its other subsystems.

Performance characteristics of the Launch Vehicle and other items of Government Furnished Equipment (GFE) with which the design of the GN&C subsystem shall be compatible are also specified.

1.2 Objective. - The objective of this specification is to provide the base line requirements for the GN&C subsystem supporting the CSM - Block II and its associated subsystems.

2.0 APPLICABLE DOCUMENTS

The following documents, of exact issue shown form a part of this specification to the extent specified herein and/or in the referenced Interface Control Documents (ICD's).

2.1 Project Documents. - The asterisk (*) adjacent to a document number indicates that further review and mutual agreement is required prior to incorporation of the document into this specification.

SPECIFICATIONS

Military

MIL-I-26600(2) 9 May 1960	Interference Control Requirements, Aeronautical Equipment (As amended by MSC-ASPO-EMI-10A)

National Aeronautics and Space Administration (NASA)

MSFC 10M01071 6 March 1961	Environmental Protection When Using Electrical Equipment Within the Areas of Saturn Complexes Where Hazardous Areas Exist, Procedure for
MSC-ASPO-EMI-10A	Addendum to MIL-I-26600(2)

[redacted]

MSFC-PROC-158A 12 April 1962	Soldering Electrical Connectors (High Reliability) Procedure for (As amended by MSC-ASPO-S-5B, dated 10 February 1964
*MSC (TBD)**	Design Reference Mission I, Apollo Mission Planning Task Force

North American Aviation, Inc./Space and Information Systems Division (NAA/S&ID)

SID 64-1344 Revised 22 February 1965	CSM Technical Specification - Block II
SID 64-1345 Revised 22 February 1965	CSM Master End Item Specification - Block II

Massachusetts Institute of Technology/Instrumentation Laboratory (MIT/Inst. Lab.)

*MIT/Inst. Lab. (TBD)	Apollo Guidance, Navigation, and Control Technical Specification - Block II
*PS 2015000 (TBD)	Apollo Guidance and Navigation Equipment Master End Item Specification - Block II

DRAWINGS

Not Applicable

STANDARDS

Military

MS-33586A 16 December 1958	Metals; Definitions of dissimilar

OTHER PUBLICATIONS

MH01-01348-416 16 July 1965	Guidance and Navigation Environmental Requirements
MH01-01356-416 16 July 1965	Weights

**To be determined.

[redacted]

2.2 Precedence. - The orders of precedence in the instance of conflicting requirements shall be as follows for NAA/S&ID and MIT respectively:

NAA/S&ID

a. The Contract, NAS9-150

b. SID 64-1344, CSM Technical Specification - Block II

c. This Specification

d. SID 64-1345, CSM Master End Item Specification - Block II

e. Other documents referenced herein

MIT/Inst. Lab.

a. The Contract, NAS9-4810

b. MIT/Inst. Lab. Apollo Guidance, Navigation and Control Technical Specification - Block II

c. This Specification

d. PS 2015000, Apollo Guidance and Navigation Equipment Master End Item Specification - Block II

e. Other documents referenced herein

2.3 Effectivity. - The effectivity of this specification shall be the date of approval by Supplemental Agreement to Contract NAS9-150 by the NASA.

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3.0 REQUIREMENTS

The GN&C subsystem functional requirements are defined in 3.1.1. Unless otherwise stated, all performance requirements are defined in 3.1.1.2 and are specified with respect to the NASA Design Reference Mission I as delineated in NASA Document, (TBD).

3.1 Guidance, Navigation, Control, Functional and Performance Requirements. - The GN&C shall provide the functions necessary for performance of the guidance, navigation, and control tasks for a manned lunar landing mission and for aborts from such a mission.

3.1.1 General Functional Requirements. - This section establishes and defines the guidance and navigation phases that shall be required of the Block II GN&C equipment. The general functional requirements of the GN&C are to provide:

a. The primary reference for spacecraft (SC) guidance and control, including the means to manually or automatically update this inertial reference with star sightings.

b. The primary guidance, navigation, and control capability for all SC thrusting and attitude maneuvers under control of CSM propulsion units.

c. A self-contained optics-inertial navigation capability which will be the primary navigation data source during lunar orbit and available as a backup during other coasting phases.

d. A means of utilizing primary navigation data supplied via up-data link in order to compute the required guidance commands to the control subsystem.

e. A backup optical attitude reference with regard to inertial space, required to manually orient the SC in accordance with instructions received from the ground via up-data link and/or voice.

f. Displays and controls required to operate the on board GN&C equipment and to indicate status thereof.

g. SC state vector data to the telemetry subsystem for transmission to Clear Lake Mission Control Center (CLMCC).

h. Launch vehicle GN&C monitoring signals for the Emergency Detection Subsystem (EDS).

[redacted]

i. Discrete signals as required to support the mission programmers on unmanned flights.

j. Provide synchronizing 1024 KC pulse to the Central Timing Equipment (CTE).

k. Rendezvous guidance and navigation capability for CSM active rescue of an incapacitated Lunar Excursion Module (LEM) and/or provision of guidance data required for LEM backup rendezvous with the CSM.

l. Computation of navigation and alignment data as required to provide activation and initial conditions for the LEM GN&C subsystem.

m. Stabilization and control computations in the guidance computer as required during the primary CSM guidance and control modes.

n. Means of accepting attitude and discrete attitude commands from the Stabilization and Control Subsystem (SCS) attitude sensors and hand controllers, respectively.

o. Means of generating CSM Reaction Control Subsystem (RCS) and Service Propulsion Subsystem (SPS) engine steering and ON-OFF commands during the primary CSM guidance and control mode.

p. A backup guidance and navigation capability to be used for Saturn IV-B (SIV-B) control subsystem in the event of launch vehicle GN&C subsystem malfunction. (A backup guidance and navigation capability to be used for Saturn II (SII) thrust control commands.) The GN&C subsystem shall have the capability of completing the Lunar Landing Mission provided take-over is initiated before excessive deviations from the nominal trajectory have occurred.

q. Display on the Display and Keyboard Unit (DSKY) selected parameters required by astronauts in various GN&C operations.

r. Provide means of astronaut selection of a mode wherein the Inertial Measurement Unit (IMU) is caged to the SC body axes.

3.1.1.1 Functional Requirements for Each Mission Phase. - The functional requirements as they apply to specific mission phases, are as described below:

3.1.1.1.1 Prelaunch -

a. Align and hold attitude reference automatically.

b. Provide attitude error signals to Flight Director Attitude Indicator (FDAI) for gross check on alignment.

3.1.1.1.2 Saturn I (S-I) Boost. -

a. Compute position and velocity using accelerometer data.

b. Display Boost Monitor parameters on DSKY.

c. Drive Coupling Data Units (CDU's) with S-I nominal pitch program so that FDAI attitude error meters indicate boost vehicle attitude error.

d. Provide total attitude signals for display on the FDAI.

3.1.1.1.2.1 Abort From Saturn I/Saturn II Boost with Launch Escape Subsystem (LES). - The GN&C subsystem shall provide the capability of a rapid stable platform alignment to the SC body axis for a LES abort. This shall be used to orient the Command Module (CM) for entry.

3.1.1.1.3 Saturn II Boost. -

a. Compute position and velocity using accelerometer data.

b. Display Boost Monitor parameters on DSKY.

c. Provide capability to drive CDU's with attitude plus steering errors to that FDAI attitude error meters indicate boost vehicle attitude error.

d. Provide total attitude signals for display on the FDAI.

e. Guide S-II toward earth orbit on SPACECRAFT CONTROL command from astronaut.

f. Initiate program to guide abort on ABORT command from astronaut.

3.1.1.1.3.1 Abort From Saturn II Boost (After LES Jettison). - The following abort modes shall be implemented by the GN&C subsystem for nonguidance failures in the booster:

a. Guide CSM to earth orbit using S-IVB and SPS thrust (control required with SPS thrust).

b. Guide and control CSM and LEM to earth orbit using S-IVB thrust.

c. Guide and control CSM to earth orbit using SPS thrust.

d. Guide and control CM to selected recovery area using SPS and SM RCS thrust and CM lift vector control.

The Apollo Guidance Computer (AGC) shall be programmed to execute a particular abort mode depending on the time it receives the ABORT command.

3.1.1.1.4 Saturn-IVB Boost Into Earth Orbit. -

a. Compute position and velocity using accelerometer data.

b. Display Boost Monitor parameters on DSKY.

c. Provide capability to drive CDU's with attitude plus steering errors so that FDAI attitude error meters indicate boost vehicle attitude error.

d. Provide total attitude signals for display on the FDAI.

e. Guide S-IVB on SPACECRAFT CONTROL command.

3.1.1.1.4.1 Abort From Saturn-IVB Boost. - Two abort modes shall be implemented by the GN&C subsystem:

a. Guide CSM to earth orbit using SPS thrust.

b. Guide CM to selected recovery area using SPS and SM RCS thrust and CM lift vector control.

The AGC shall have the capability of being programmed to execute a particular abort mode depending on the time it receives the ABORT command.

3.1.1.1.5 Earth Orbit. -

a. Determine that a suitable orbit has been attained.

b. Maintain best estimate of position and velocity (Orbit Ephemeris).

c. Update best estimate of position and velocity on basis of navigation data from:

(1) Star-horizon measurements

(2) Low orbit landmark tracking

(3) Manned Space Flight Network (MSFN) tracking via UPLINK.

d. Provide an inertial reference for attitude control of the SC S-IVB. This reference will be updated from star-sighting data.

e. Display appropriate GN&C parameters on DSKY.

f. Drive CDU's with attitude errors so that FDAI attitude error meters indicate vehicle attitude error.

g. Provide total attitude signals for display on the FDAI.

h. Compute abort trajectories.

i. Initiate program to guide abort on command from astronaut.

j. The GN&C subsystem shall provide local vertical information.

k. Determine initial conditions for translunar injection.

l. Initiate program to control translunar injection.

3.1.1.1.5.1 Earth Orbit Aborts. - Guide and control CM through safe entry and to selected landing sites using SPS and SM RCS thrust and CM lift vector control. An abort from earth orbit shall be selectable for minimum time or desired landing site.

3.1.1.1.6 Translunar Injection.-

a. Compute position and velocity from accelerometer data.

b. Display Boost Monitor parameters on DSKY, including ΔV to go.

c. Initiate program to guide abort on command from astronaut.

d. Provide capability to drive CDU's with attitude plus steering errors so that FDAI attitude error meters indicate boost vehicle attitude error.

e. Provide total attitude signals for display on the FDAI.

CO[redacted]

f. Guide SC S-IVB to proper translunar trajectory on SPACECRAFT CONTROL command from astronaut.

3.1.1.1.6.1 Translunar Injection Aborts. - Guide and control CSM to trans-earth abort trajectory using SPS thrust on astronaut command. Aborts from translunar injection shall be selectable for minimum time or desired landing site.

3.1.1.1.7 Translunar Coast. -

a. Determine that a suitable translunar trajectory has been attained.

b. Maintain best estimate of position and velocity.

c. Update best estimate of position and velocity on basis of navigation data from:

(1) Star-landmark measurements

(2) MSFN tracking via UPLINK

(3) Star-horizon measurements

d. Determine initial conditions for mid-course corrections and lunar orbit insertion.

e. During times of IMU operation, provide SC attitude control. The IMU reference will be established and updated from star-sighting data.

f. Control mid-course corrections to achieve proper initial conditions for lunar orbit insertion, (1) Primary automatic SPS, (2) manual SPS, and (3) automatic RCS.

g. Display appropriate GN&C data on DSKY.

h. Provide attitude and attitude error signals for display on the FDAI.

i. Compute abort trajectories.

j. Initiate abort program to guide abort on command from astronaut.

k. Initiate program to control lunar orbit insertion.

l. Accept manual control inputs.

3.1.1.1.7.1 Translunar Coast Aborts. - Guide and control CSM to trans-earth trajectory using SPS thrust on astronaut command. Abort from trans-lunar coast shall be selectable for minimum time or for a desired landing site.

3.1.1.1.8 Lunar Orbit Insertion. -

a. Compute position and velocity using accelerometer data.

b. Guide and control SC into lunar orbit using SPS thrust.

c. Display appropriate GN&C parameters on DSKY.

d. Provide attitude and attitude error signals for display on the FDAI.

e. Initiate program to guide abort on ABORT command from astronaut.

3.1.1.1.8.1 Lunar Orbit Insertion Aborts. -

a. Guide and control SC to lunar parking orbit of acceptable period for subsequent trans-earth injection.

b. Guide and control SC to direct abort to transearth trajectory.

c. Mode a. above shall be executed by an immediate or delayed thrust cutoff of the SPS. Mode b. above shall be accomplished by immediate thrust cutoff and reorientation of the SC and SPS thrust to inject to a transearth trajectory.

3.1.1.1.9 Lunar Orbit. -

a. Determine that a suitable orbit has been attained.

b. Maintain best estimate of position and velocity (Orbit-Ephemeris).

c. Update best estimate of position and velocity on basis of navigation data from:

(1) Low orbit landmark tracking

(2) MSFN tracking via UPLINK

(3) Star-horizon measurements

(4) Period measurements

(5) IMU accelerometer data during thrusting phases

(6) Star occultation measurements

d. Determine initial conditions for transearth injection and LEM guidance.

e. During time of IMU operation provide attitude control of the SC or CSM. The IMU reference will be updated from star-sighting data.

f. Supply information for LEM IMU coarse alignment and LEM Guidance Computer (LGC) initialization.

g. Compute transearth trajectories.

h. Initiate program to control transearth injection.

i. Display appropriate GN&C parameters on DSKY.

j. Provide attitude and attitude error signals for display on the FDAI.

k. Accept manual control inputs during nonthrusting periods.

l. Track intended landing point in order to:

(1) Locate landing site in navigation coordinates

(2) For visual monitor

m. Maintain best estimate of LEM descent coast orbit, lunar surface position, and ascent coast orbit.

n. Provide LEM with CSM orbit ephemeris for use by LEM abort guidance subsystem.

o. Compute LEM rendezvous mid-course corrections for transmission to LEM as required.

p. Compute CSM rendezvous mid-course correction. Guide and control CSM to accomplish rendezvous mid-course corrections as required.

q. Compute LEM terminal rendezvous maneuver for transmission to LEM as required.

[redacted]

r. Guide and control CSM to accomplish terminal rendezvous maneuver if such a maneuver is required of the CSM.

3.1.1.1.10 Transearth Injection. -

a. Compute position and velocity using accelerometer data.

b. Guide and control CSM to transearth trajectory using SPS thrust.

c. Display appropriate G&NC parameters on DSKY.

d. Provide attitude and attitude error signals for display on the FDAI.

e. Steering for transearth injection will be compatible with manual takeover.

3.1.1.1.11 Transearth Coast. -

a. Determine that a suitable transearth trajectory has been attained.

b. Maintain best estimate of position and velocity.

c. Update best estimate of position and velocity on basis of navigation data from:

(1) Star-landmark measurements

(2) MSFN tracking via UPLINK

(3) Star-horizon measurements

d. Determine initial conditions for mid-course corrections and entry.

e. During times of IMU operation provide CSM attitude control. The IMU reference will be established and updated from star-sighting data.

f. Control mid-course corrections to achieve proper initial conditions for entry.

g. Display appropriate GN&C data on DSKY.

h. Initiate program for entry guidance.

i. Provide attitude and attitude error signals for display on the FDAI.

j. Accept manual control inputs.

[redacted]

k. Compute and display inertial velocity and range to go at a specified earth radius prior to entry for insertion into Entry Monitoring Subsystem (EMS).

3.1.1.1.12 Entry. -

a. Compute positions and velocity using accelerometer data and MSFN tracking data via UPLINK.

b. Display appropriate GN&C parameters on DSKY.

c. Guide and control CM to landing site using lift vector control.

d. Accept manual control inputs.

e. Provide attitude and attitude error signals for display on the FDAI.

f. Display attitude error for manual lift vector control.

g. Provide rate damping in pitch and yaw.

h. Command the lift orientation for initial atmosphere penetration compatible with the EMS corridor verification.

i. Control the entry trajectory to be within critical flight limits defined by the thermal protection subsystem design, structural and crew load tolerance, subsystem lifetimes, entry range limits, and trajectory monitoring requirements defined by the EMS.

3.1.1.2 Performance Requirements.- The GN&C shall accomplish the guidance functions within the ΔV budget limitations given in Table I with the following performance requirements and with the propulsion subsystem operating within their 3-sigma performance bounds.

3.1.1.2.1 Alignmenment Requirements.- The alignment requirements for the GN&C Navigation Base and CSM engines are as described below. The Apollo Vehicle Coordinate Reference Systems Diagram is shown in Figure 1.

3.1.1.2.1.1 Navigation Base Alignment.- For any time in coasting flight while the IMU is operating, the uncertainty in the inertial attitude of the navigation base shall be no more than 3.85 mr (0.22 degrees) one sigma base on one IMU alignment per orbit.

3.1.1.2.1.2 Service Propulsion Subsystem Thrust Vector Alignment.- The engine thrust vector shall pass within 0.125 inch of the intersection of the gimbal axes. The thrust vector shall be perpendicular within ±0.5 degree to the plane established by the engine mount plane when the gimbal actuators are in the null position. The thrust vector is defined as a line connecting the geometric centroids of the throat and the chamber section at the nozzle attach flange as determined by dimensional measurement. Installed alignment relative to engine indexes must be zero degrees plus or minus 15 minutes on the Z-axis, and 4 degrees plus or minus 15 minutes plus Y-inclination on the Y-axis.

3.1.1.2.1.3 Reaction Control Subsystem Thruster Alignment.- The RCS thruster alignment requirements for the SM and the CM are as described below.

a. Service Module - The RCS engine clusters are mounted externally to the SM mold line and canted 10 degrees outboard from the SM surface. Two engines in each quad provide roll control, and the remaining two engines provide pitch control (Quads A & C) or yaw control (Quads B & D). The dimensional alignment requirements are shown in Figure 2.

b. Command Module - The RCS thrusters are mounted internally, with the engine nozzle extensions scarfed to match the CM mold line. The dimensional alignment requirements are as shown in Figures 3 and 4.

3.1.1.3 Guidance and Navigation Requirements.- During times of IMU operation, the GN&C equipment shall provide an inertial reference for attitude control of the SC. Prior to boost, the IMU will be aligned to one sigma accuracy of 0.25 mr vertical and 2.5 mr in azimuth. The GN&C subsystem shall be capable of Scanning Telescope (SCT) manual or servo controlled alignment of the IMU with respect to inertial coordinates with an uncertainty which shall not exceed 0.66 mr (one sigma) in each axis. The SCT shall be capable of determining the attitude of the navigation base with respect to inertial coordinates utilizing the telescope panel angle counters and the SCT in the manual mode with an accuracy of 0.66 mr (one sigma).
Each IMU alignment requires vehicle orientation to acquire two stars. An additional orientation will be required to align the SC or SC S-IVB thrust axis. During earth orbit, the maneuver required is a roll of 120 degrees maximum at a maximum rate of 0.5 deg/sec starting from an attitude with the +Z axis at local vertical. During other flight phases (for purposes of thermal and RCS propellant calculations) each maneuver is considered to be a new random attitude at a maximum rate of 0.2 deg/sec for translunar and transearth and 0.5 deg/sec for lunar orbit.

Each IMU alignment shall be completed in no more than 10 minutes. At least 8 minutes will be available for SCS initialization following the SC alignment maneuver which aligns the thrust axis to the desired ΔV and prior to ullage.

3.1.1.3.1 Performance Requirements for Each Mission Phase.- The performance requirement for each mission phase are as described below.

3.1.1.3.1.1 Boost.- The boost phase is defined as existing from pad liftoff to the end of the powered phase for earth orbit insertion. The GN&C shall function as specified if any of the following contingencies occur.

a. Atmospheric Abort - After LES separation the GN&C shall provide commands to the SPS and RCS such that the CM can be returned safely to earth.

   (1) Extra-Atmospheric Abort.- The GN&C shall provide commands to the SPS and RCS such that the CM can assume a safe trajectory and orientation for entry. The GN&C shall provide an early SPS cutoff in the event the time of free fall to the entry threshhold falls below (TBD) seconds.

   (2) Abort Into Orbit.- The GN&C shall provide commands to the SPS and RCS such that an earth orbit with a perigee above 90 nautical miles (NM) and an apogee below 450 NM can be achieved.

b. Guidance and Navigation Takeover of Saturn Guidance.- The GN&C shall have the capability to provide guidance commands to the S-II and/or S-IVB stages of the Saturn vehicle in order to achieve an earth orbit suitable for completing the translunar injection after a maximum stay time of 3 orbits.

   (1) Launch Vehicle Orbital Insertion Accuracy.- The acceptable Launch Vehicle earth orbital insertion accuracy under GN&C takeover is:

Velocity	(TBD)
Flight Path Angle	(TBD)
Altitude	(TBD)
Azimuth Angle	(TBD)

3.1.1.3.1.2 Earth Orbit.- During earth orbit all attitude maneuvers will be performed using the S-IVB Auxiliary Propulsion Subsystem.

a. The GN&C equipment shall provide attitude control of the SC S-IVB.

b. The GN&C equipment shall be capable of orienting the SC S-IVB in a preferred earth referenced attitude with the +Z SC axis down the local vertical. This maneuver will require a roll of 180 degrees at a maximum rate of 0.5 deg/sec from nominal attitude at earth orbit insertion.

c. The IMU stable member will be aligned once per orbit and a maximum of 3 times.

d. A maximum of 5 navigation acquisitions per orbit for a maximum of 3 orbits will be made. Each acquisition requires a roll maneuver about the earth oriented attitude (SC Z-axis in local vertical) of a maximum of ±45 degrees at a maximum rate of 0.5 deg/sec. The navigation acquisitions may be either landmark acquisitions or star-horizon measurements. Each navigation acquisition and sighting shall consume no more than 5 minutes.

e. Prior to translunar injection, the CSM state vector shall be:

Velocity	(TBD)
Position	(TBD)
Time	(TBD)

f. The RCS propellant allotted for GN&C maneuvers during the earth orbit phase shall be in accordance with Table II.

3.1.1.3.1.3 Translunar Coast.- Following translunar injection the vehicle will be maintained in attitude hold for 10 minutes to allow tracking to update the navigation data.

The GN&C attitude and translation control modes shall be available during the transpose and dock maneuver.

During translunar coast, the IMU will be aligned not more than 4 times and no more than 3 mid-course corrections will be made with the SPS. The time required for each mid-course correction, including IMU alignment, shall be less than 40 minutes. Following mid-course correction, the vehicle will be maintained in Attitude Hold for 10 minutes to allow ground tracking to update navigation measurements. The initial condition errors and the translunar injection errors will be such that the total 3 mid-course corrections shall not exceed the value shown in Table I for the SPS. The RCS shall provide no more than 2 corrections whose sum shall not exceed the value shown in Table I.

Prior to each mid-course correction, the CSM state vector shall be:

1st Mid-course		2nd Mid-course		3rd Mid-course	
Velocity	(TBD)	Velocity	(TBD)	Velocity	(TBD)
Position	(TBD)	Position	(TBD)	Position	(TBD)
Time	(TBD)	Time	(TBD)	Time	(TBD)

GN&C maneuvers during the translunar coast phase shall be in accordance with Table III.

3.1.1.3.1.4 Lunar Orbit Insertion.- During lunar orbit insertion, the GN&C shall use no more than the value shown in Table I over the ideal velocity increment.

3.1.1.3.1.5 Lunar Orbit.- During lunar orbit, the IMU will be aligned no more than 10 times and a maximum of 20 optical sightings will be made. These include landmark sightings, horizon sightings, and period measurements. The time required for a landmark sighting shall not exceed 5 minutes. The time required for a star-horizon sighting shall not exceed 5 minutes. The residual rate during navigational sightings shall not exceed 5 arc min/sec about any axis.

Prior to LEM separation and descent, the CSM state vector shall be:

Velocity	(TBD)
Position	(TBD)
Time	(TBD)

If the CSM must perform an active rendezvous, the maximum velocity change required shall not exceed the value shown in Table I in no more than 10 maneuvers. The GN&C subsystem performance shall be such that at the end of the terminal rendezvous, the relative range and range rate at the docking interface shall be 500 ± 300 ft and 5 ± 3 fps. No more than 8 SPS ignitions shall be required.

Prior to transearth injection, the CSM state vector shall be:

Velocity	(TBD)
Position	(TBD)
Time	(TBD)

The RCS propellant allotted for GN&C maneuvers during the lunar orbit phase shall be in accordance with Table III.

3.1.1.3.1.6 Transearth Injection.- During transearth injection, the GN&C shall not use more than the value shown in Table I over the ideal velocity increment.

The steering law implemented during transearth injection should normally provide a constant SC inertial attitude orientation during this maneuver.

The initial position and velocity uncertainty just prior to transearth injection shall be equal to or better than the following:

$$\epsilon_{\Delta R} = 3000 \text{ ft.,} \quad \epsilon_{\Delta \dot{R}} = 1.5 \text{ fps}$$

$$\epsilon_{\Delta T} = 3000 \text{ ft.,} \quad \epsilon_{\Delta T} = 1.5 \text{ fps}$$

$$\epsilon_{\Delta N} = 3000 \text{ ft.,} \quad \epsilon_{\Delta \dot{N}} = 1.5 \text{ fps}$$

3.1.1.3.1.7 Transearth Coast.- During the transearth coast phase, the IMU will be aligned 4 times and 3 mid-course corrections will be made with the SPS. Mid-course corrections, including IMU alignment, shall not consume more than 40 minutes. The last IMU alignment shall not be less than (TBD) minutes from the entry interface. The initial condition errors and the transearth injection errors will be such that the total of 3 mid-course corrections shall not exceed the value shown in Table I. The RCS shall provide 3 vernier corrections not to exceed the value shown in Table I. These allotments assume use of the primary GN&C for transearth injection and mid-course navigation and ΔV corrections.

Prior to each mid-course correction, the CSM state vector shall be:

1st Mid-course		2nd Mid-course		3rd Mid-course	
Velocity	(TBD)	Velocity	(TBD)	Velocity	(TBD)
Position	(TBD)	Position	(TBD)	Position	(TBD)
Time	(TBD)	Time	(TBD)	Time	(TBD)

A maximum of 50 star-landmark navigational measurements will be required to satisfy the entry corridor requirements if the backup optical navigation is used. No more than 33 SC attitude changes will be required. Each maneuver is considered to be a new random attitude. The time required to sight a star and a landmark shall not exceed 5 minutes.

Prior to entry, the CSM state vector shall be:

Velocity	(TBD)
Position	(TBD)
Time	(TBD)

The RCS propellant allotted for GN&C maneuvers during the transearth phase shall be in accordance with Table III.

3.1.1.3.1.8 Entry.- Entry as defined in this specification begins at CM separation and terminates at parachute deployment. The 3 sigma entry corridor (depth vacuum perigee variation) due to navigation accuracy and mid-course execution errors will be no greater than 20 nautical miles. The 1 σ initial condition uncertainties (given with respect to local vertical coordinates at start of entry) shall be less than:

Velocity Uncertainty	ΔV_x	(TBD) fps
Velocity Uncertainty	ΔV_y	(TBD) fps
Velocity Uncertainty	ΔV_z	(TBD) fps
Altitude Uncertainty	Δh	(TBD) ft
Range Uncertainty	ΔR	(TBD) ft
Cross Range Uncertainty	ΔR	(TBD) ft

The GN&C subsystem shall control the SC such that an SC deceleration greater than 320 ft/sec^2 will not be encountered during normal operation except during boost abort where the SC maximum deceleration is limited to 15 g's.

The entry transit time will be a maximum of 30 minutes. The required touchdown accuracy for entry ranging requirement of 1500 NM minimum to 2500 NM maximum will be achieved for a lift-to-drag ratio not less than 0.3 at velocities greater than 25,000 fps.

During the entry phase, the GN&C subsystem shall display range-to-go on the DSKY. The touchdown accuracy shall be (TBD).

3.1.1.3.2 Spacecraft Mass Properties.- The SC mass properties for the Design Reference Mission (DRM) I mission are as listed in Appendix A.

3.1.1.4 Propulsion Performance. - The propulsion performance parameters for the SPS, the SM RCS and the CM RCS are as follows:

3.1.1.4.1 Service Propulsion Subsystem.- The SPS propulsion performance parameters are described below. The SPS actuator interface definitions are shown in Figure 5.

3.1.1.4.1.1 Thrust.- The SPS shall nominally develop a vacuum thrust of 20,000 pounds during continuous operation. The SPS shall operate at a thrust of 20,000 pounds ±20 percent during the entire mission. The SPS thrust shall not vary by more than ± (TBD) percent during any single burn.

3.1.1.4.1.2 Thrust Transient Rates.- The startup and shutdown transient rates are as follows.

a. Startup Transient.- The SPS shall develop 90 percent steady-state thrust within 0.3 to 0.5 second after onset of the electrical command signal to the pilot valve. The start transient total impulse from onset of electrical command to 90 percent rated thrust shall be from 400 pound-seconds (minimum) to 1200 pound-seconds (maximum). The run-to-run tolerance on start transient impulse shall be ±200 pound-seconds (1 sigma).

b. Shutdown Transient.- The SPS shall accomplish thrust decay to 10 percent rated thrust within 0.4 to 0.6 second after receipt of the command signal. The SPS shutdown impulse from onset of electrical command signal to 10 percent rated thrust shall be from 5000 pound-seconds (minimum) to 8500 pound-seconds (maximum). The shutdown impulse from 10 percent to 1 percent rated thrust shall not exceed 500 pound-seconds. The run-to-run tolerance on the shutdown impulse shall ±200 pounds-seconds (1 sigma).

3.1.1.4.1.3 Impulse.- The rocket engine attains the following impulse values during vacuum operating conditions:

a. Continuous Operation.- The SPS shall develop an average nominal specific impulse of 314.9 seconds and a minimum specific impulse (minus 3 sigma) of 313.0 seconds after 750 seconds firing duration.

b. Total Impulse.- The total impulse provided by the SPS to satisfy normal design mission and emergency requirements shall be 11,966,200 pound-seconds nominal, minus 4,500 pound-seconds for each engine restart.

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3.1.1.4.1.4 Reliable Operating Life.- The SPS is capable of a minimum of 36 starts during the operational life of 750 seconds. Starts are accomplished under either sustained or intermittent operation within the tolerances specified in 3.1.2.3. The SPS is capable of accepting a start signal anytime after receipt of a shutdown signal. Conversely, the SPS is capable of accepting a shutdown signal at any time after receipt of a start signal with a minimum impulse bit equal to or less than 5000 pound-seconds and a run-to-run tolerance of 200 pound seconds (1 sigma).

3.1.1.4.2 Service Module Reaction Control Subsystem.- The SM RCS propulsion performance parameters are described below.

3.1.1.4.2.1 Thrust.- The rocket engine develops a continuous operation vacuum thrust of 100 pounds ± 5 percent.

3.1.1.4.2.2 Thrust Transient Rate.- Thrust transient characteristics are depicted below for injector temperatures between 20 - 125 degrees F and temperatures above 125 degrees F.

a. Thrust Transients for Injector Temperatures Between 20 - 125 Degrees F.- The "ON" characteristics (from electrical signal "ON") to 70 percent of rated thrust shall occur in 30 milliseconds or less. The "OFF" characteristics (from electrical signal "OFF") to 25 percent of rated thrust shall occur in 15 milliseconds or less.

b. Thrust Transients for Injector Temperature Above 125 Degrees F.- The "ON" characteristics (from electrical signal "ON") to 70 percent of rated thrust shall occur in 110 milliseconds or less. The "OFF" characteristics (from electrical signal "OFF") to 25 percent of rated thrust shall occur in 15 milliseconds or less.

3.1.1.4.2.3 Impulse.- The rocket engine attains the following impulse values during vacuum operating conditions.

a. Continuous Operation.- The specific impulse plotted against average propellant temperature for operating time greater than 5 seconds is depicted in Figure 6.

b. Minimum Impulse.- Minimum impulse data is depicted in Figure 7.

c. Specific Impulse.- The specific impulse as a function of electrical pulse widths less than 1 second is depicted in Figure 8.

3.1.1.4.2.4 Reliable Operating Life.- Following acceptance tests, the engine has a minimum reliable operating life of 1000 seconds. The engine is capable of withstanding a minimum of 10,000 operational cycles during a 1000 second operating life without deterioration.

3.1.1.4.2.5 Operation Time and Frequency Response Characteristics.- The continuous operating time and frequency response characteristics are depicted below.

a. Continuous Operation.- The engine is capable of continuous operation for a period not to exceed 500 seconds.

b. Pulse Mode Operation.- The engine responds to signals up to 35 cycles per second. The minimum impulse intervals shall be 500 milliseconds and a start after shutdown signal shall be instantaneous.

3.1.1.4.3 Command Module Reaction Control Subsystem.- The CM RCS propulsion performance parameters are described below.

3.1.1.4.3.1 Thrust.- The rocket engine develops not less than 88.3 pounds thrust during continuous operation.

3.1.1.4.3.2 Thrust Transient Rate.- The thrust "ON" characteristics (from electrical signal "ON") exhibit zero thrust from 0 to 6 milliseconds and shall rise to 90 percent of rated thrust from 6 to 30 milliseconds or less. The thrust "OFF" characteristics (from electrical signal "OFF") exhibit no change from rated thrust from 0 to 6 milliseconds and decrease to 10 percent of rated thrust in 6 to 50 milliseconds.

3.1.1.4.3.3 Impulse.- The rocket engine attains the following impulse values during vacuum operating conditions.

a. Continuous Operation.- The engine develops a minimum instantaneous specific impulse of 266 seconds when operated for a period in excess of 800 milliseconds.

b. Minimum Impulse.- The engine develops a minimum impulse of 1 to 2 pounds-seconds at an electrical signal (pulse width) of 20 milliseconds.

c. Specific Impulse.- The vacuum specific impulse as a function of electrical signal "on time" for periods less than 1 second is depicted in Figure 9.

3.1.1.4.3.4 Reliable Operating Life.- The engine has a reliable operating life of at least 130 seconds without removal for servicing. The engine is capable of undergoing a minimum of 3,000 operating cycles during the 130 second reliable operating life.

3.1.1.4.3.5 Total Operating Life.- The engine total operating life is 200 seconds. Deviation from specification performance may occur between 130 and 200 seconds; however, crew safety shall not be compromised.

3.1.1.4.3.6 Operation Time and Frequency Response.- A continuous operation time of 30 seconds during the first 130 seconds of engine life will not degrade engine reliability or performance. Additional continuous operation to 70 seconds does not degrade reliability however, the engine performance will be derated. The engine is capable of responding to signal frequencies up to 30 cycles per second and shall restart after engine shutdown signal in 10 milliseconds.

3.1.1.5 Attitude Control Requirements. - The GN&C equipment shall provide the primary attitude control function through the AGC. During SPS thrusting periods, engine gimbal angle commands shall be supplied to the SCS servo amplifiers. During CSM and CM reaction control modes, on-off RCS command shall be supplied to the RCS driver amplifiers.

3.1.1.5.1 Service Propulsion Subsystem Control Requirements. - The SPS control mode is utilized during the translunar and transearth mid-course corrections, during lunar orbit insertion and transearth injection periods and during those abort and rescue thrusting periods which require the SPS engine. The GN&C equipment shall have the capability of performing timed ΔV corrections in order to make optimum use of the inherent SPS minimum impulse. The IMU shall supply the attitude references for the SPS control mode. Attitude rate sensors shall not be employed.

3.1.1.5.1.1 Trim. - The GN&C equipment shall have the capability of applying the pre- $\overline{\Delta V}$ SC attitude and SPS gimbal trim corrections automatically for all CSM-LEM and CSM burning periods. The GN&C equipment shall accept SPS engine gimbal trim commands through the DSKY prior to ignition.

3.1.1.5.1.2 Sequencing. - Prior to the start of the SPS control mode, the GN&C shall be placed in the minimum deadband RCS attitude hold mode. At initiation of the SPS mode and prior to SPS engine ignition, the AGC shall provide both the SPS and RCS control modes simultaneously. The RCS attitude hold mode shall be terminated in the pitch and yaw axes 1 second after engine ignition and shall be reinitiated by the SPS engine cut-off signal. The SPS control mode shall be terminated (TBD) second(s) after the engine cut-off signal.

3.1.1.5.1.3 Limit Cycles and Transient Behavior. - The SPS control mode shall not induce structural loads in excess of those specified in the SC loads criteria document.

These criteria shall include but not be limited to engine ignition and shutdown transients and any limit cycle behavior during SPS engine thrust periods. During shutdown of the SPS engine, the angular impulse imparted by the engine which must be removed by the RCS shall not exceed (TBD).

3.1.1.5.2 Service Module Reaction Control Subsystem Control Requirements. - The GN&C subsystem will provide automatic and manual control through the SM RCS. This mode is available for CSM and CSM-LEM attitude and translation control during periods when SPS thrusting is not required, and for roll control during SPS thrusting periods. Allowable propellant consumption per SM RCS automatic maneuver is shown in Table III.

3.1.1.5.2.1 Manual Control. - The GN&C equipment shall accept discrete inputs from the 2 CM rotational controllers, the CM translational controller, and the GN&C minimum impulse controller.

a. Rotational Controller. - Two control modes shall be provided for rotational controller inputs:

   (1) Minimum Impulse. - The GN&C equipment shall output rotational control SM RCS engine on-off pulses in any single axis, in any two axes or in all three axes as commanded by the controller.

   (2) Rate Command. - The GN&C equipment shall provide SM RCS engine on-off commands such that the SC rotates at a constant attitude rate about any single axis, any two axes or all three axes as commanded by either of the rotational controllers. The attitude rate shall nominally be 0.20 deg/sec, but a high rate of (TBD) deg/sec shall be available for one-axis-at-a-time special maneuvers; such as, transposition, docking or abort. For purposes of SM RCS fuel economy, a low rate of (TBD) deg/sec shall also be available for multi-axis rotation.

   The desired attitude rate shall be entered through the DSKY. With the GN&C in the rate command mode, but in the absence of any rate commands, the subsystem will enter the attitude hold mode; see 3.1.1.5.2.2.

b. Translational Controller. - The GN&C equipment shall provide SM RCS engine on-off commands such that the CSM or CSM-LEM accelerates along any tranlational axis, any two axes or along all three axes as commanded by the translational controller. The translational axes are defined as the CSM roll axis and two other orthogonal axes which pass through the center of the RCS SM Quads A and C and Quads B and D, respectively.

The translational mode shall operate simultaneously with the manual rate command mode or attitude hold mode with attitude control commands to the SM RCS jets given priority over translational commands. The GN&C equipment shall provide the required logic for preventing the simultaneous firing of any two opposed SM RCS engines.

c. Minimum Impulse Controller. - The GN&C equipment shall provide rotational control SM RCS on-off pulses as commanded by the minimum impulse controller. Each command will be mutually exclusive. The minimum residual rate for mid-course shall not exceed 2.4 arc min/sec and for lunar orbit 5 arc min/sec.

3.1.1.5.2.2 Attitude Hold. - Upon command, the GN&C equipment shall provide an attitude hold mode for the CSM and CSM-LEM. In the attitude hold mode, two values of attitude control deadband shall be provided. The first ± (5 ± 0.5) degrees in each axis shall constitute the normal mode. The second, ± (0.5 ± 0.05) degree, shall be available upon command and shall be commanded automatically to SPS engine thrusting periods. During SPS engine thrusting, the roll axis deadband shall be ± (0.5 ± 0.05) degree. During docking maneuvers the primary control subsystem shall achieve limit cycle rates equal to or less than the following:

Lunar Orbit	Transposition & Docking
Pitch & Yaw ± 0.017 deg/sec	Pitch ± 0.013 deg/sec
Roll ± 0.05 deg/sec	Roll ± 0.027 deg/sec
	Yaw ± 0.012 deg/sec

3.1.1.5.2.3 Automatic Maneuvers. - The GN&C equipment shall have the capability of automatically reorienting the vehicle to a new attitude. The automatic vehicle maneuver rates shall be identical to the manual vehicle maneuver rates.

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3.1.1.5.2.4 Ullage Control. - Prior to ignition of the SPS engine, the SPS propellants must be settled by accelerating the vehicle along the positive X axis. The GN&C equipment shall command and control this ullage thrusting (using the SM RCS engines) as part of the SPS engine ignition sequence. The ullage thrusting shall normally be terminated 1 second after SPS engine ignition. SPS engine ignition shall be commanded after the SM RCS engines have added the required impulse. The GN&C equipment shall provide the required logic for preventing the simultaneous firing of any two opposed RCS engines.

3.1.1.5.3 Command Module Reaction Control Subsystem Control Requirements. - The GN&C subsystem shall provide automatic control through the CM RCS. This mode is available for CM maneuvering and attitude hold prior to entry following CM-SM separation and for pitch and yaw attitude rate damping and roll control during entry.

3.1.1.5.3.1 Manual Control. - The GN&C equipment shall accept inputs from the two CM rotational controllers. It shall output CM RCS engine on-off commands such that the SC (in the absence of disturbance torques) rotates at a constant attitude rate about any single axis, only two axes or all three axes as commanded by either of the rotational controllers. The vehicle maneuver rates shall be the same as those specified for the CSM manual rate mode.

If the vehicle is experiencing more than 0.05 g's, this mode will be automatically disabled.

In the absence of any rate inputs, the subsystem shall enter one of two modes:

a. If the vehicle is experiencing less than 0.05 g's, the GN&C equipment will enter an attitude hold mode.

b. If the vehicle is experiencing more than 0.05 g's, the GN&C equipment shall enter a roll attitude control mode (with guidance commands) and a pitch and yaw attitude rate damping mode. Manual roll control shall be available to the astronaut.

3.1.1.5.3.2 Attitude Hold. - Upon command, the GN&C equipment shall provide an attitude hold mode provided the vehicle is experiencing less than 0.05 g's. If the vehicle is experiencing more than 0.05 g's, the mode shall be disabled.

The vehicle orientation during attitude hold will be determined by:

a. Attitude commands input through the DSKY.

b. Attitude commands input through the ground UP-LINK.

c. The attitude at which manual rate commands go to zero.

The attitude deadband in this mode will be ± (5 ± 0.5) degrees in each axis.

3.1.1.5.3.3 Automatic Reorientation. - Following separation of the SM, the CM shall be automatically reoriented to the entry attitude.

3.1.1.5.3.4 Entry Mode. - The entry mode will be initiated when the vehicle first experiences 0.05 g's. In the case of a skip trajectory, the entry mode will be terminated when the vehicle acceleration falls below 0.05 g's and the attitude hold mode will be entered. The entry mode will be reinitiated when the vehicle again experiences 0.05 g's. In the entry mode, the GN&C equipment will provide attitude rate damping in the pitch and yaw axes by appropriate sequencing of CM RCS engine on-off commands. The rate deadband in these axes will be ± (2 ± 0.2) deg/sec. A minimum reentry roll rate of 20 deg/sec about the stability axis is required.

The GN&C subsystem shall be capable of guiding the SC safely back to earth on a single CM RCS using no more than 104.5 pounds of propellant. Pitch and yaw limits are 7 deg/sec ±15 percent.

3.1.1.6 Attitude Display Requirements. - The GN&C equipment will supply output signals for the purpose of driving attitude and attitude error displays. It will also provide a decimal attitude display on the DSKY as commanded.

3.1.1.6.1 Inertial Measurement Unit Euler Attitude. - The IMU gimbal angles will be available as analog signals for purposes of display. During free fall, the accuracy of these signals will be ± 0.25 degree (1σ) plus the inertial reference error as specified in 3.1.1.3. During thrusting periods, the maximum error shall be less than the following allocation:

	Pitch	Roll	Yaw
Attitude Uncertainty, mr (During Saturn thrusting periods)	(TBD)	(TBD)	(TBD)
Attitude Uncertainty, mr (During SPS thrusting periods)	(TBD)	(TBD)	(TBD)
Attitude Uncertainty, mr (During entry)	(TBD)	(TBD)	TBD)

3.1.1.6.2 Apollo Guidance Computer Attitude Error. - The attitude error existing at any time in the AGC shall be available as an analog signal for display purposes. The analog display signals shall reproduce the AGC error signal within (TBD) degrees (one sigma). Upon command, the AGC shall provide an attitude error transformed to body coordinates, formed by the difference between IMU gimbal angles and desired gimbal angles as selected through the DSKY. The accuracy of these signals shall be the same as the inertial reference accuracy specified in paragraph 3.1.3 plus a scale factor error of (TBD) percent (one sigma).

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3.1.1.6.3 <u>Display and Keyboard Unit Attitude</u>. - The attitude and attitude error signals shall be available for display on the DSKY as decimal numbers upon command. The accuracy of this readout shall be the same as the inertial reference accuracy specified in 3.1.1.3.

3.1.1.6.4 <u>Gyro Display Coupler (GDC) Attitude Error</u>. - The AGC shall accept pulses from SCS GDC's. Each pulse shall represent (TBD) degrees of attitude change as measured in body coordinates. Using this information, the AGC shall compute the vehicle euler angles, difference these with desired euler angles selected through the DSKY, and output attitude errors in body coordinates. The accumulated error attributable to the AGC and its conversion equipment shall not exceed 0.2 degrees (one sigma) in any axis at the completion of the following maneuvers:

Roll 45 degrees at 0.5 deg/sec with a 5 degrees attitude error in pitch and yaw.

Pitch 60 degrees at 0.5 deg/sec with a 5 degrees attitude error in roll and yaw.

Roll 45 degrees at 0.5 deg/sec with a 5 degrees attitude error in pitch and yaw.

Limit cycle for 10 minutes about all three axes with a limit cycle rate of 0.1 deg/sec and a deadband of ±5 degrees in each axis.

3.1.2 <u>Operability</u>

3.1.2.1 <u>Reliability</u>. - The mission success reliability apportionment for the GN&C subsystem from earth launch to (TBD) shall not be less than (TBD) for the NASA Design Reference Mission I.

3.1.2.1.1 <u>Failure Rates</u>. - The inherent failure rates of the GN&C equipment which may be used in a backup mode shall be less than:

Backup Configuration	Failure Rate Per 10^6 Hours
(TBD)	(TBD)

The analytical methods of showing compliance with the estabilished failure rates shall be approved by NASA-MSC prior to the acceptance of flight hardware.

[redacted]

[redacted]

3.1.2.2 Maintainability.

3.1.2.2.1 Maintenance. - Equipment arrangements, accessibility, and interchangeability features that allow efficient preflight servicing and maintenance shall be given full consideration. Design considerations shall also include efficient mission scrub and recycle procedures. In-flight maintenance shall not be performed on the GN&C subsystem.

3.1.2.2.2 Maintenance Concept. - Field maintenance of the GN&C subsystem shall be performed as follows:

a. For airframe electrical/electronic equipment (either installed or on the bench), checkout and replacement shall be at the integral package (Black box) level. A "black box" is defined as a combination of factory replaceable units which are contained within a physical package, and which is removable from the CSM as an integral unit.

b. For non-electrical/electronic equipment (either installed) or on the bench), checkout and replacement shall be at the lowest replaceable serialized unit level, which includes only those parts which are removable as integral units from the GN&C subsystem.

3.1.2.3 Useful Life

3.1.2.3.1 Service Life. - The service life of the GN&C subsystem, when exposed to the environment and mission specified elsewhere in this specification shall not be less than 336 flight hours, plus 1,664 hours under ground-checkout and pre-launch conditions.

3.1.2.3.2 Storage Life. - The storage life of the GN&C subsystem, when exposed to the environments specified elsewhere in this specification, shall not be less than 3 years.

3.1.2.4 Natural Environment. - The natural ground and flight environment in which the GN&C subsystem must perform in accordance with requirements specified elsewhere in this specification are defined in ICD MH01-01348-416.

3.1.2.5 Transportability

3.1.2.5.1 Ground Handling and Transportability. - Full design recognition shall be given to the durability requirements of the GN&C equipment during preflight preparation. Wherever possible, the equipment shall be designed to be transported by common carrier with a minimum of protection. Special packaging and transportation methods shall be as required to prevent subsystem penalties.

3.1.2.6 Human Performance. -

3.1.2.6.1 Flight Crew. - The CSM flight crew shall consist of three men.

3.1.2.6.2 Crew Participation. - The flight crew shall have the capability to control the CSM through all flight modes. The flight crew shall participate in navigation, control, monitoring, computing, and observation of the GN&C subsystem as required. Status of the subsystem shall be displayed for crew monitoring, failure detection, and operational mode selection. The GN&C subsystem shall be designed so that a single crewman will be able to perform all tasks essential to return of the CSM to earth in case of emergency.

3.1.2.6.3 Abort Initiation. - Provisions shall be made for crew initiation of all abort modes.

3.1.2.7 Safety.

3.1.2.7.1 Hazard Proofing. - The design of the GN&C subsystem and support equipment shall minimize the hazard of fire, explosion, toxicity to the crew, launch area personnel, and facilities. The hazards to be avoided include accumulation of leakage of combustible gases, the hazard of spark on ignition sources including static electricity discharge.

3.1.2.7.2 Equipment. - Design of equipment shall be in accordance with MSFC 10M01071 during any part of the mission operation. Where practicable, the various components shall be hermetically sealed or of explosion-proof construction.

3.1.2.7.3 Failsafe. - Subsystem failure shall not propagate sequentially; that is, design shall "failsafe."

3.1.2.8 Induced Environment. - The induced ground and flight environments in which the GN&C subsystem must perform in accordance with requirements specified elsewhere in this specification are defined in ICD MH01-01348-416.

3.2 Interface Requirements. - The GN&C subsystem interface information is contained in the Interface Control Documents (ICD) listed in paragraph 6.2 subject to the terms stated.

3.3 Design and Construction

3.3.1 Guidance, Navigation, and Control Equipment Definition. - The Airborne Guidance, Navigation, and Control Equipment shall consist of the following major assemblies:

Navigation Base (NVB)
Inertial Measurement Unit (IMU)
Optical Unit Assembly (OUA)
Power and Servo Assembly (PSA)
Apollo Guidance Computer (AGC)
Display and Controls (D&C)
Coupling Data Units (CDU) (5)
Signal Conditioner Assembly (SCA)
Interconnecting Harness
Display and Keyboard (DSKY) (2)
PIPA Electronics Assembly (PEA)

3.3.1.1 General Design Features. - The design features and physical characteristics of the major assemblies of the equipment shall conform with the requirements of the following subparagraphs.

3.3.1.1.1 Navigation Base. - The NVB shall be a rigid structure capable of supporting and maintaining the alignment of the IMU, the OUA, and associated hardware. The NVB shall be hard mounted to the SC structure.

3.3.1.1.2 Inertial Measurement Unit. - The IMU shall sense vehicle attitude and acceleration. The IMU shall consist of three single-degree-of-freedom accelerometers (PIPA) on a stable member isolated from vehicle orientation by a servo-driven three degree-of-freedom gimbal system. The IMU shall be mounted in the SC with roll axis coincident with the longitudinal axis of the SC.

3.3.1.1.3 Optical Unit Assembly. - The OUA shall consist of a Sextant, a Scanning Telescope (SCT), eyepieces, and a bellows assembly.

3.3.1.1.3.1 Sextant. - The SXT shall be a two line-of-sight superimposed image, 1.8 degrees field of view, 28 power measuring instrument to provide measurements of the angle between identified stars and navigation reference features of the earth or the moon. The SXT shall be capable of being used visually by the astronaut by using a detachable eyepiece, automatically or semi-automatically, with the built-in Horizon Photometer and Star Tracker.

3.3.1.1.3.1.1 Horizon Photometer and Star Tracker. - The Horizon Photometer and Star Tracker, a navigation instrument, shall be built into the SXT providing an automatic star tracker on the articulated line-of-sight, and an automatic sun illuminated horizon brightness photometer manually pointed by SC orientation to the reference brightness on the horizon beneath the star. The star tracker shall provide for automatic centering on a star within a one-half degree square field when star brightness is above a prescribed level.

3.3.1.1.3.2 Scanning Telescope. - The SCT shall be a single line-of-sight, 60 degree field of view, unity power, articulated telescope used for general viewing of earth or moon, orbital landmark navigation sighting, as an acquisition aid for the sextant, and for backup alignment of the SC.

3.3.1.1.3.3 Bellows Assembly. - The bellows assembly allows movement of the portion of the optics external to the SC while maintaining capsule seal.

3.3.1.1.4 Power and Servo Assembly. - The PSA shall consist of the electronic equipment that provides most of the support electronics, power supplies, IMU, and OUA servo and gyro pulse torquing modules. The PSA shall be made up of modules which plug into the PSA header assembly.

3.3.1.1.5 Apollo Guidance Computer. - The AGC shall be a general purpose computer with special capability for organizing simultaneous real time operations and control data processing for guidance, navigation, and control. Flexibility shall be obtained by the use of fast basic instructions and slower but memory conserving, interpretive routines. The basic fixed memory shall be 36864, 15 bit words (plus parity). The erasable memory shall be 2048 words.

3.3.1.1.6 Display and Controls. - The D&C shall consist of operating controls and status lights in the lower equipment bay associated with the GN&C equipment.

3.3.1.1.7 Coupling Data Units. - The CDU is a conversion device for digitizing resolver outputs and contains a functionally separate section used to convert pulse train AGC outputs to analog voltages. There are five CDU's. They are used to digitize the following shaft angle resolver outputs:

IMU gimbal angles (3)
Optics shaft angles (2)

The output sections of the CDU's are used to convert the following AGC outputs to analog form:

IMU align (3)
Attitude errors (3)
Optics drive (2)
SPS engine gimbal drive (2)

3.3.1.1.8 Display and Keyboard Unit. - The DSKY shall provide the operating controls and display for the AGC. The DSKY shall consist of a keyboard for entering instructions and data into the computer and a multidigital numerical display of program mode and data. It shall also display alarm indications based upon detected malfunctions in the computer itself or in the rest of the guidance, navigation, and control equipment. One DSKY will be located in the lower equipment bay of the CM at the navigation station, operating in parallel with a similar unit located on the main panel between the left and center couches.

3.3.1.1.9 Signal Conditioner Assembly (SCA). - The SCA shall receive GN&C signals designated as available for telemetry and normalize them for pulse code modulation.

3.3.1.1.10 Pulsed Integrating Pendulous Accelerometer (PIPA) Electronic Assembly (PEA). - The PEA shall contain the pulse torquing electronics associated with the three PIPA loops.

3.3.1.2 Design Critera

3.3.1.2.1 General Design Analysis Criteria. - The GN&C subsystem shall be designed capable of functioning at limit load conditions contained in ICD MH01-01348-416.

3.3.1.2.2 Performance Margins.

3.3.1.2.2.1 Multiple Failure. - The decision to design for single or multiple failures shall be based on the expected frequency of occurrence as it affects subsystem reliability and safety.

3.3.1.2.2.2 Design Margins. - The GN&C subsystem shall be designed to zero or positive margins of safety.

3.3.1.2.2.3 Attitude Constraints. - Attitude control is permissible to eliminate constraints which would impose excessive subsystem requirements, subject to attitude manuever fuel and other SC attitude requirements.

3.3.1.2.2.4 Thermal Control. - Thermal design of the GN&C subsystem shall normally use passive means of thermal control, such as insulation, coatings, and control of thermal resistances. Full cognizance shall be taken of thermodynamic considerations in establishing conceptual design and selection of working fluids and materials for the subsystem such that the maximum allowable temperature range consistent with other design considerations shall be provided. Thermal design may incorporate the application of cold plates subject to further negotiation between contractor(s).

3.3.1.3 **Weights.** - **The weight of the major assemblies of the GN&C equipment shall not exceed those specified in ICD MH01-01356-416. The total weight of all assemblies, components and parts, shall not exceed 400 pounds.**

3.3.2 Selection of Specifications and Processes. - Not applicable.

3.3.3 Materials, Parts, and Processes. -

3.3.3.1 Flammable Materials. - Materials that may support combustion or are capable of producing flammable gases (which in addition to other additives to the environment, may reach a flammable concentration) shall not be used in areas where the environment or conditions are such that combustion would take place.

3.3.3.2 Toxic Materials. - Unless specific written approval is obtained from the NASA, materials that produce toxic effects or noxious substances when exposed to CM interior conditions shall not be used.

3.3.3.3 Unstable Materials. - Materials that emit or deposit corrosive substances, induce corrosion, or produce electrical leakage paths within an assembly, shall be avoided or protective measures incorporated.

3.3.4 Standard Materials, Parts, and Processes. -

3.3.4.1 Soldering Requirements. - The soldering of electrical connectors shall be in accordance with specification MSFC-PROC-158, as amended by MSC-ASPO-S-5.

3.3.5 Moisture and Fungus Resistance. - Fungus-inert materials shall be used to the greatest extent practicable. Fungus-nutrient materials may be used if properly treated to prevent fungus growth for a period of time, dependent upon their use within the CSM. When used, fungus-nutrient materials shall be hermetically sealed or treated for fungus and shall not adversely affect equipment performance or service life.

3.3.6 Corrosion of Metal Parts. - All metals shall be of corrosive-resistant type or shall be suitably protected to resist corrosion during normal service life. Gold, silver, platinum, nickel, chromium, rhodium, palladium, titanium cobalt, corrosion-resistant steel, tin, lead-tin alloys, tin alloys, Alcad aluminum, or sufficiently thick platings of these metals may be used without additional protection or treatment.

3.3.6.1 Dissimilar Metals. - Unless suitably protected or coated to prevent electrolytic corrosion, dissimilar metals, as defined in MS-33586, shall not be used in intimate contact.

3.3.6.2 Electrical Conductivity. - Materials used in electronics or electrical connections shall have such characteristics that, during specified environmental conditions, there shall be no adverse effect upon the conductivity of the connections.

3.3.7 Interchangeability and Replaceability. - Not applicable.

3.3.8 Workmanship. - Not applicable.

3.3.9 Electromagnetic Interference. - The GN&C equipment shall not generate electromagnetic interference in excess of, or be susceptible to electromagnetic interference within, the allowable limits of Specification MIL-I-26600/MSC-EMI-10.

Bonding requirements, wire treatment, and signal classification shall be provided in accordance with Specification MIL-I-26600/MSC-EMI-10 and supplemented, as required, by applicable ICD's.

4.0 QUALITY ASSURANCE

4.1 Quality Control. - NASA shall be responsible for the quality control provisions required to insure that the GFE requirements specified are in accordance with the overall Apollo Quality Assurance Program.

4.2 Reliability. - NASA shall be responsible for the reliability provisions required to assure that the GFE specified are in accordance with the overall Apollo Reliability Program.

5.0 PREPARATION FOR DELIVERY

5.1 Responsibility.- The NASA shall be responsible for the preparation and shipment of the GFE specified.

6.0 NOTES

6.1 MSC Internal Note No. 65-FM-56 dated 6 May 1965. - Subject Note describes the methods used in computing and justification for the CSM ΔV values shown in Table I.

6.2 Interface Control Documents (ICD).- The following ICD's are subject to the following terms and conditions:

a. The ICD's shall be approved and dated prior to completion of the Critical Design Review (CDR).

b. At completion of the CDR, the approved ICD's will be deleted from this section (6.0 Notes) and incorporated in paragraphs 2.0 and 3.0 as applicable.

c. Subsequent to CDR, a Specification Change Notice (SCN) will be required to change an approved ICD.

Guidance, Navigation, and Control Subsystem
Interface Control Documents

Title	Number
Nav. Base to CM Structure	MH01-01301-116
Computer to LEB Structure	MH01-01302-116
PSA to LEB Structure	MH01-01303-116
G&N Controls & Displays to LEB Structure	MH01-01304-116

[redacted]

DSKY to CM MDC Structure	MH01-01305-116
G&N Wire Routing to LEB Structure	MH01-01306-116
CDU to TVC Servo Amplifiers	MH01-01307-216
Coolant Lines, and Connections to G&N	MH01-01308-116
G&N External/Internal Leakage	MH01-01311-416
G&N Installation Handling Equipment Attach Points	MH01-01313-100
S/C to Optical Range in 290	MH01-01314-100
Optical Field of View Installed	MH01-01315-116
Eyepiece and Misc. Equipment Stowage	MH01-01316-116
Attitude Error Signals	MH01-01324-216
Total Attitude Signals	MH01-01325-216
Electrical Input Power	MH01-01327-216
G&N Data Transmission to Operational Telemetry	MH01-01328-416
ICTC and PSA Adapter Module to SID Cable Set	MH01-01335-200
Condition and Display Lights	MH01-01342-416
Mode Control Signals	MH01-01344-216
G&N Thermal Requirements	MH01-01349-416
G&N Installation Procedure	MH01-01350-416
Materials Compatibility	MH01-01251-416
MIT Optical GSE to SID Optical Alignment Support	MH01-01364-100

CO[redacted]

Special R&D Meas. for 2TV-1	MH01-01375-416
Electrical Power to MIT Optical GSE	MH01-01376-100
AGC Electrical Interface	MH01-01380-216
LTC to GSE Hatch	MH01-01381-100
Electrical Power to LTC	MH01-01382-200
PSA Adapter Module Hardline Downlink	MH01-01383-200
Attitude Error Signals to Saturn G&N	MH01-01386-216
Lighting, Design Req., Functional Performance Criteria	MH01-01388-416
G&N/ACE Signal Conditioners	MH01-01390-200
Nomenclature, Markings, and Color (CM/LEM Control and Display Standardization)	MH01-05174-414

[redacted]

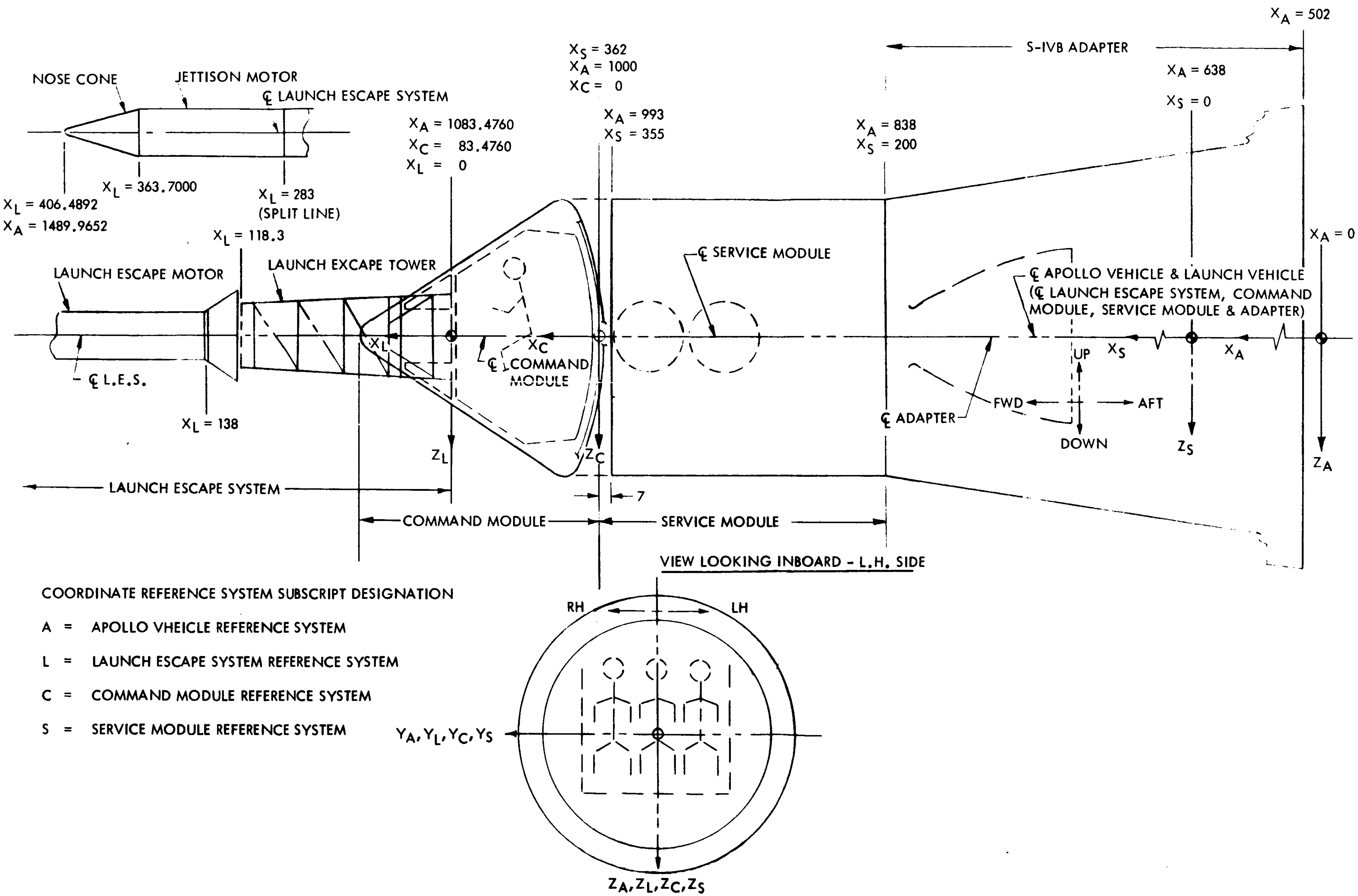
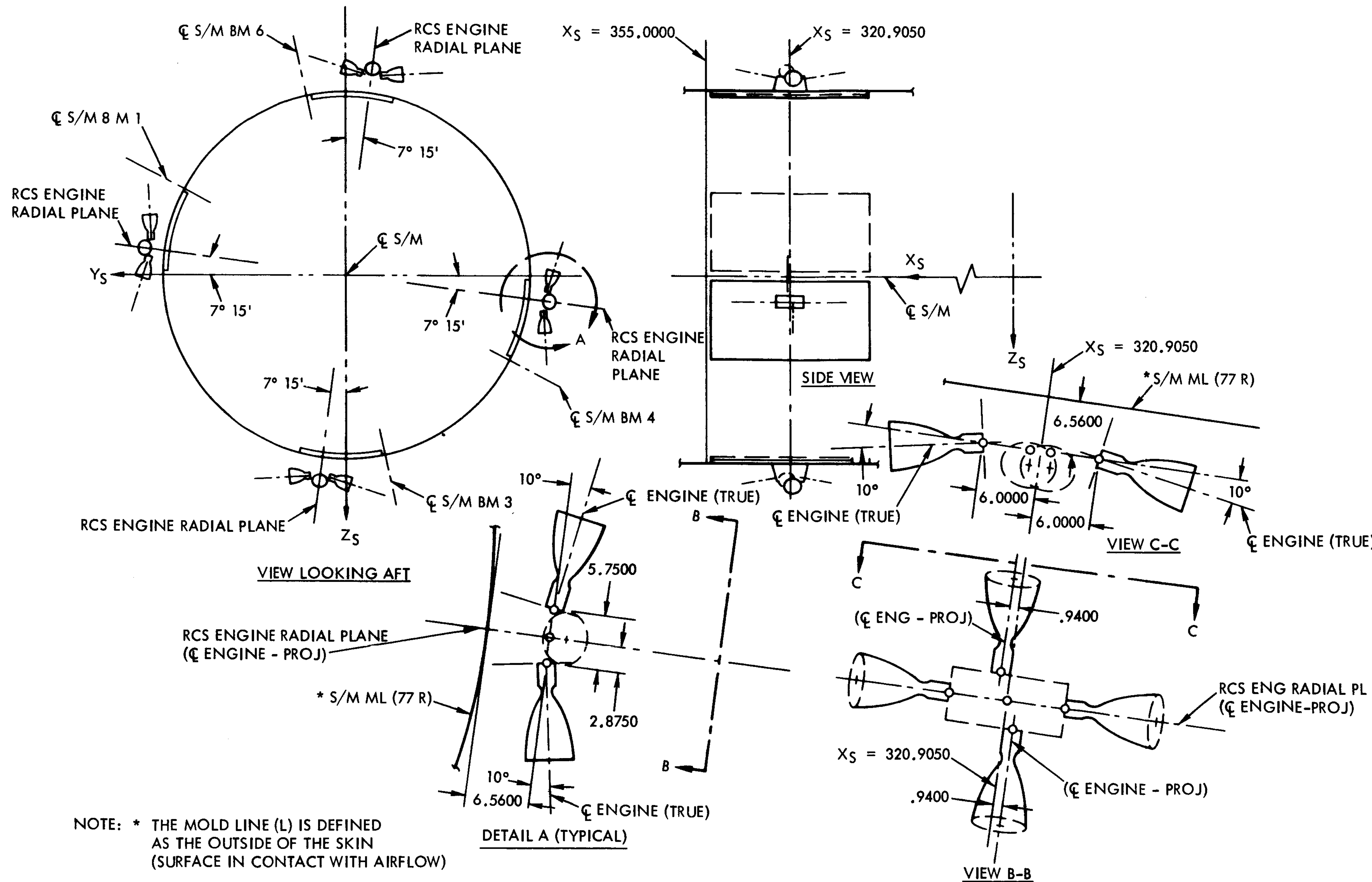


Figure 1. Apollo Vehicle Coordinate Reference Systems Diagram

[redacted]

[redacted]

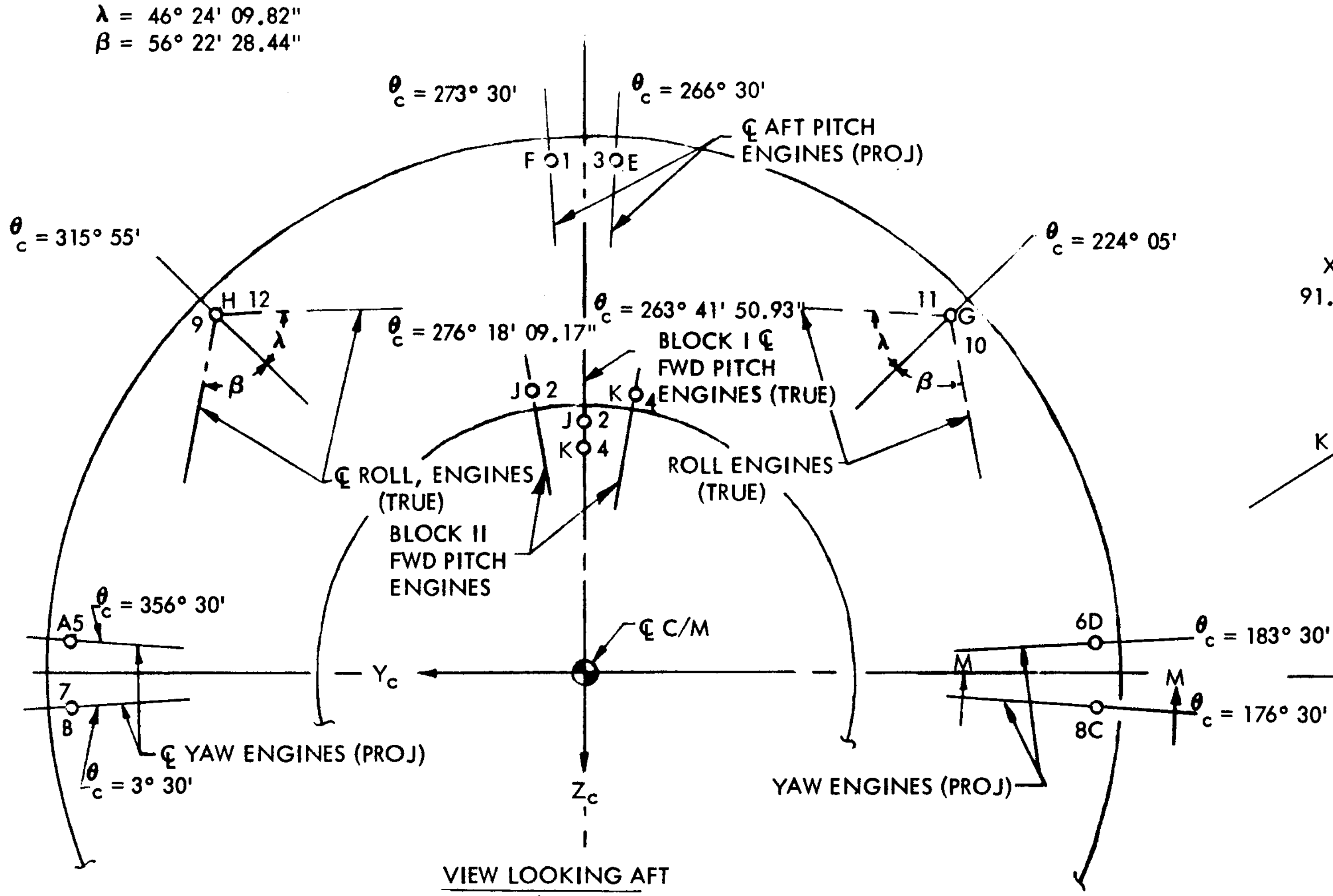


NOTE: * THE MOLD LINE (L) IS DEFINED AS THE OUTSIDE OF THE SKIN (SURFACE IN CONTACT WITH AIRFLOW)

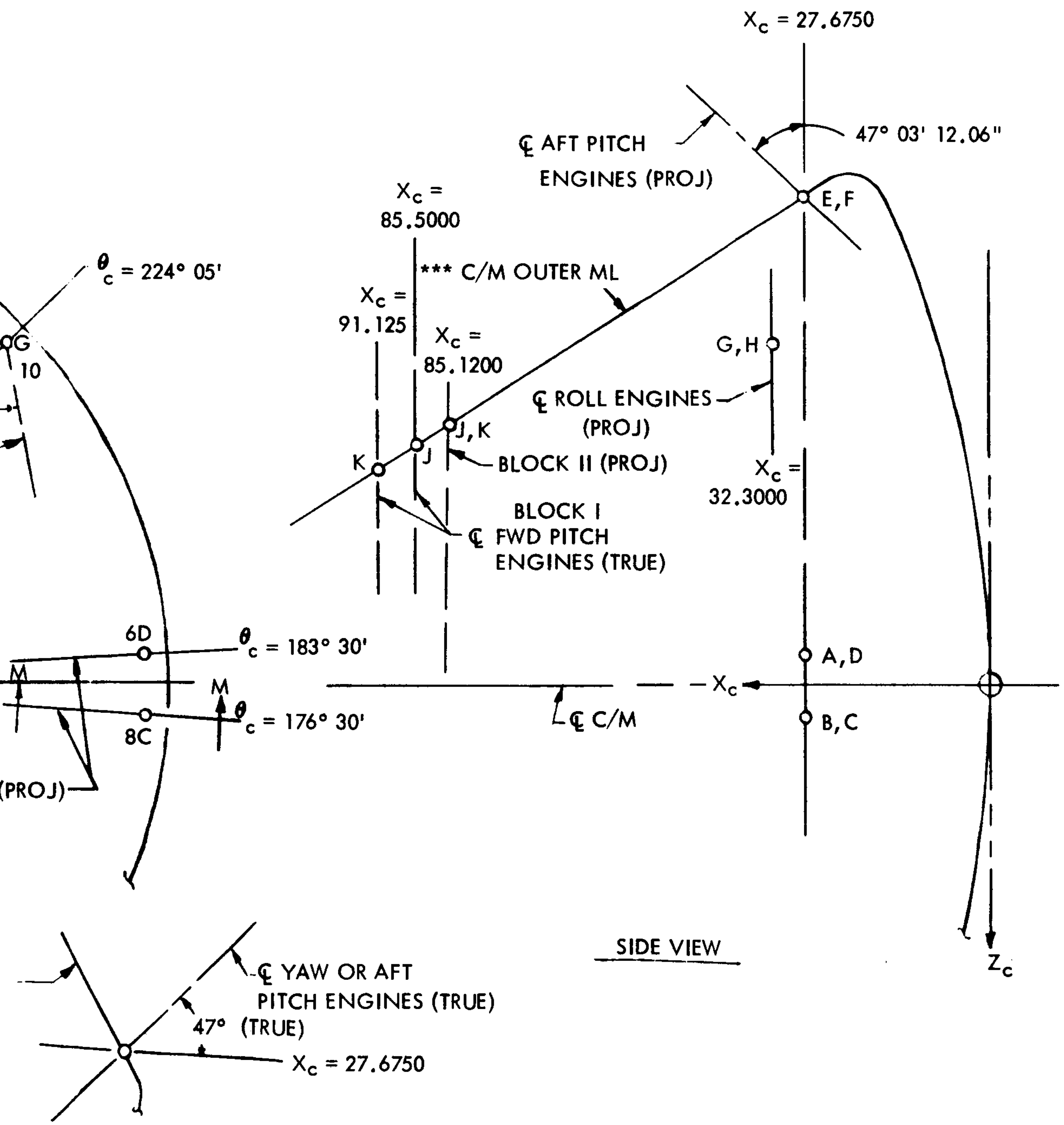
Figure 2. Service Module Reaction Control Subsystem ℄ Diagram (Service Module Reference System)

[redacted]

[redacted]



	X_c	Y_c	Z_c	R_c	
A	27.6750	72.2846	-4.4211	72.4197	
B	27.6750	72.2846	4.4211	72.4197	
C	27.6750	-72.2846	4.4211	72.4197	
D	27.6750	-72.2846	-4.4211	72.4197	
E	27.6750	- 4.4211	-72.2846	72.4197	
F	27.6750	4.4211	-72.2846	72.4197	
*G	32.3000	-51.9826	-50.3454	72.3661	
*H	32.3000	51.9826	-50.3454	72.3661	
J	85.5000	0	-35.5483	35.5483	BLOCK I
K	91.1250	0	-31.9616	31.9616	BLOCK I
J**	85.1200	3.929	-35.5743	35.7906	BLOCK II **
K**	85.1200	- 3.929	-35.5743	35.7906	BLOCK II **



*** OUTER ML

SECTION M -M
TYPICAL RADIAL SECTION THRU
YAW OR AFT PITCH ENGINES

NOTE: * NOT ON OUTER ML - INTERS PT OF ℄ ROLL ENGINES

*** THE CM OUTER MOLD LINE (ML)
IS DEFINED AS THE INTERFACE
SURFACE BETWEEN THE ABLATOR
AND THE HEAT SHIELD SUBSTRUCTURE

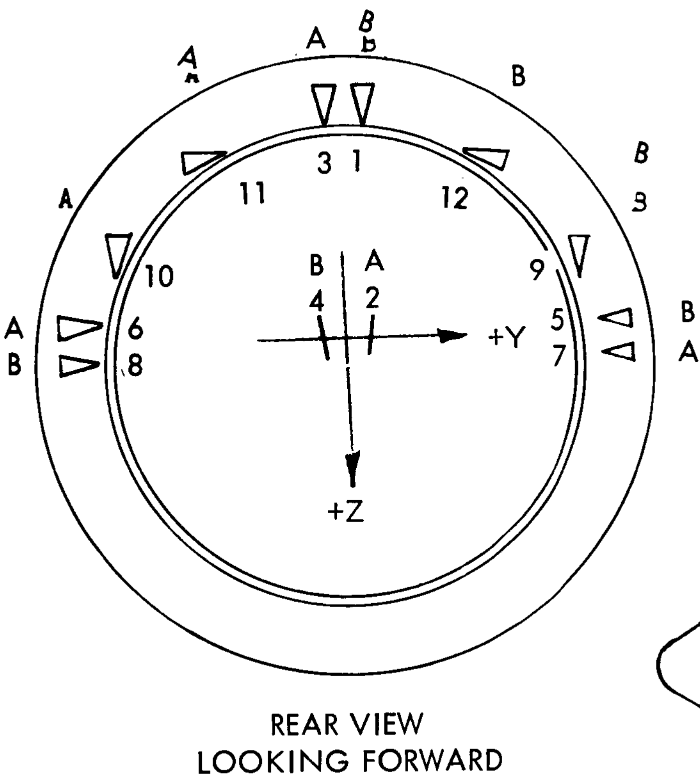
Figure 3. Command Module Reaction Control Engines Diagram (Command Module Reference System)

[redacted]

REDUCE TO 11 INCHES

CO[redacted]

	A		B
+ PITCH JETS NO.	3	AND	1
- PITCH JETS NO.	2	AND	4
+ YAW JETS NO.	7	AND	5
- YAW JETS NO.	6	AND	8
+ ROLL JETS NO.	11	AND	9
- ROLL JETS NO.	10	AND	12



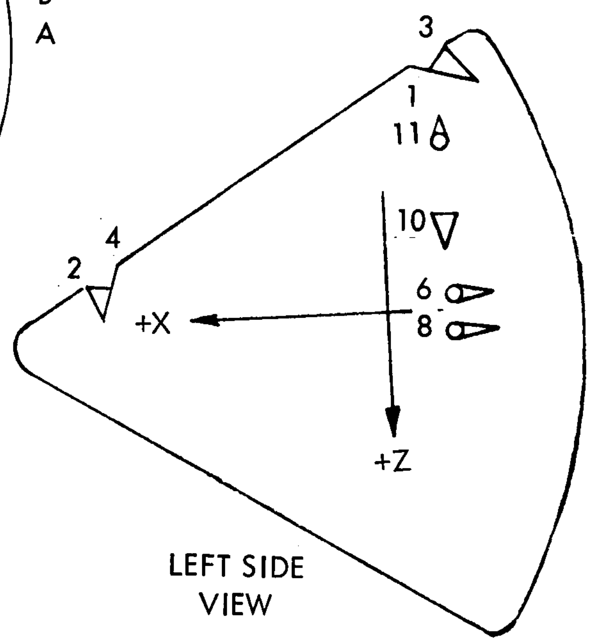


Figure 4. Command Module Reaction Jet Configuration Systems A and B

[redacted]

[redacted]

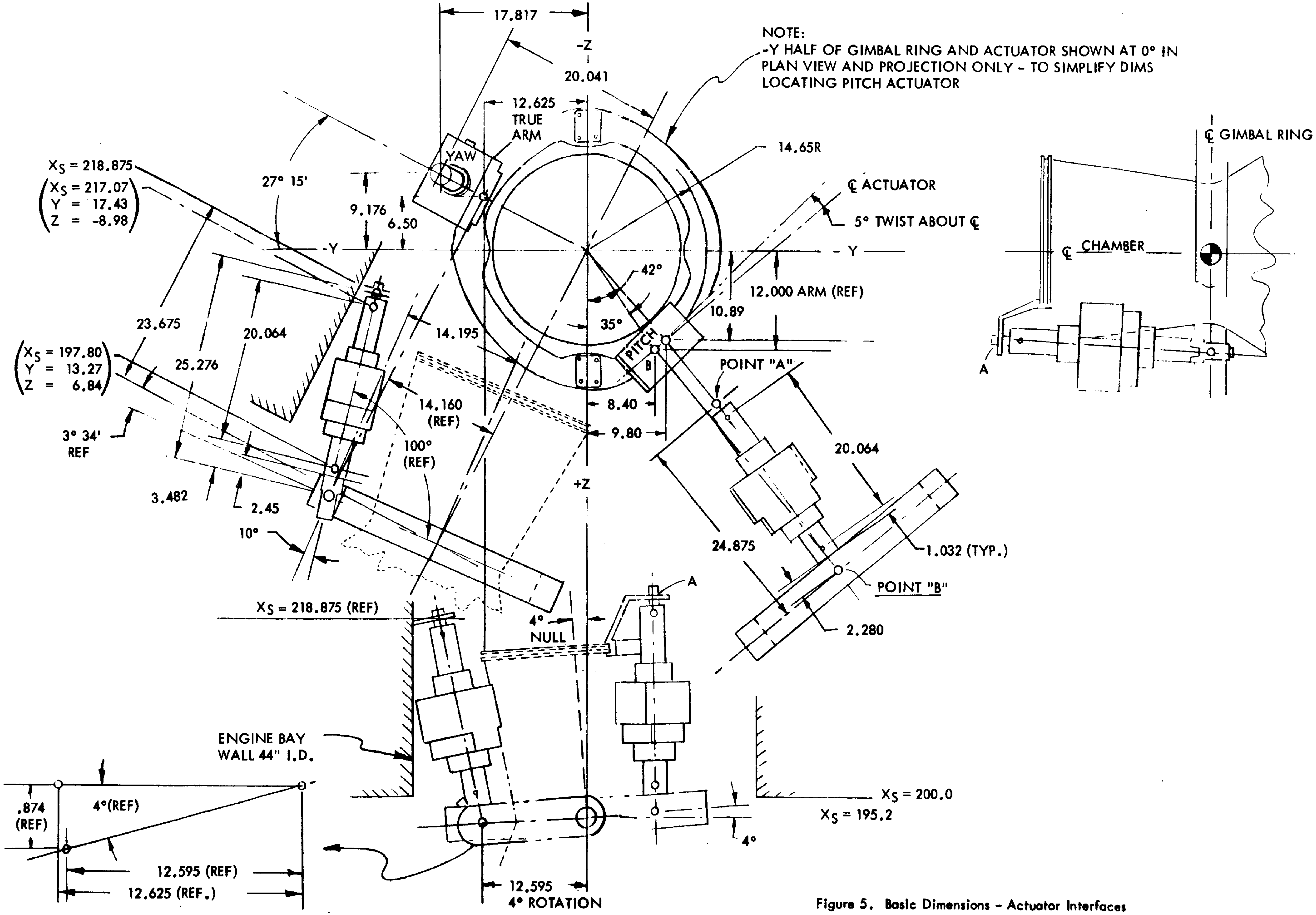


Figure 5. Basic Dimensions - Actuator Interfaces

[redacted]

REDUCE TO 11 INCHES

CO[redacted]

CURVE A IS AVERAGE OF FOUR (4) - 5 SECOND RUNS
CURVE B IS FOR RUNS GREATER THAN 5 SECONDS

NOTE: INDIVIDUAL DATA POINTS SHALL BE WITHIN ±3 SECONDS OF THE MEAN OF THE 4 POINTS

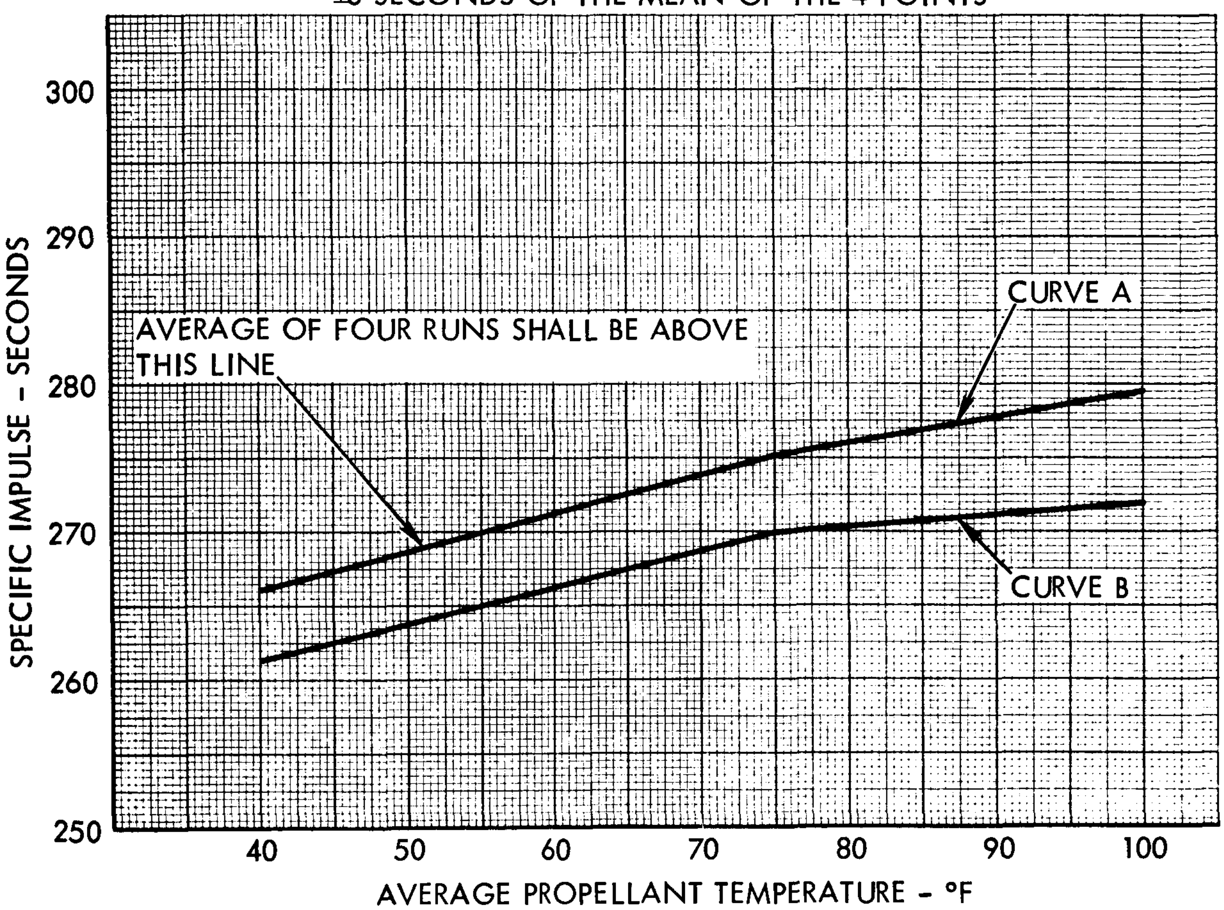


Figure 6. Specific Impulse vs Propellant Temperature

CON[redacted]

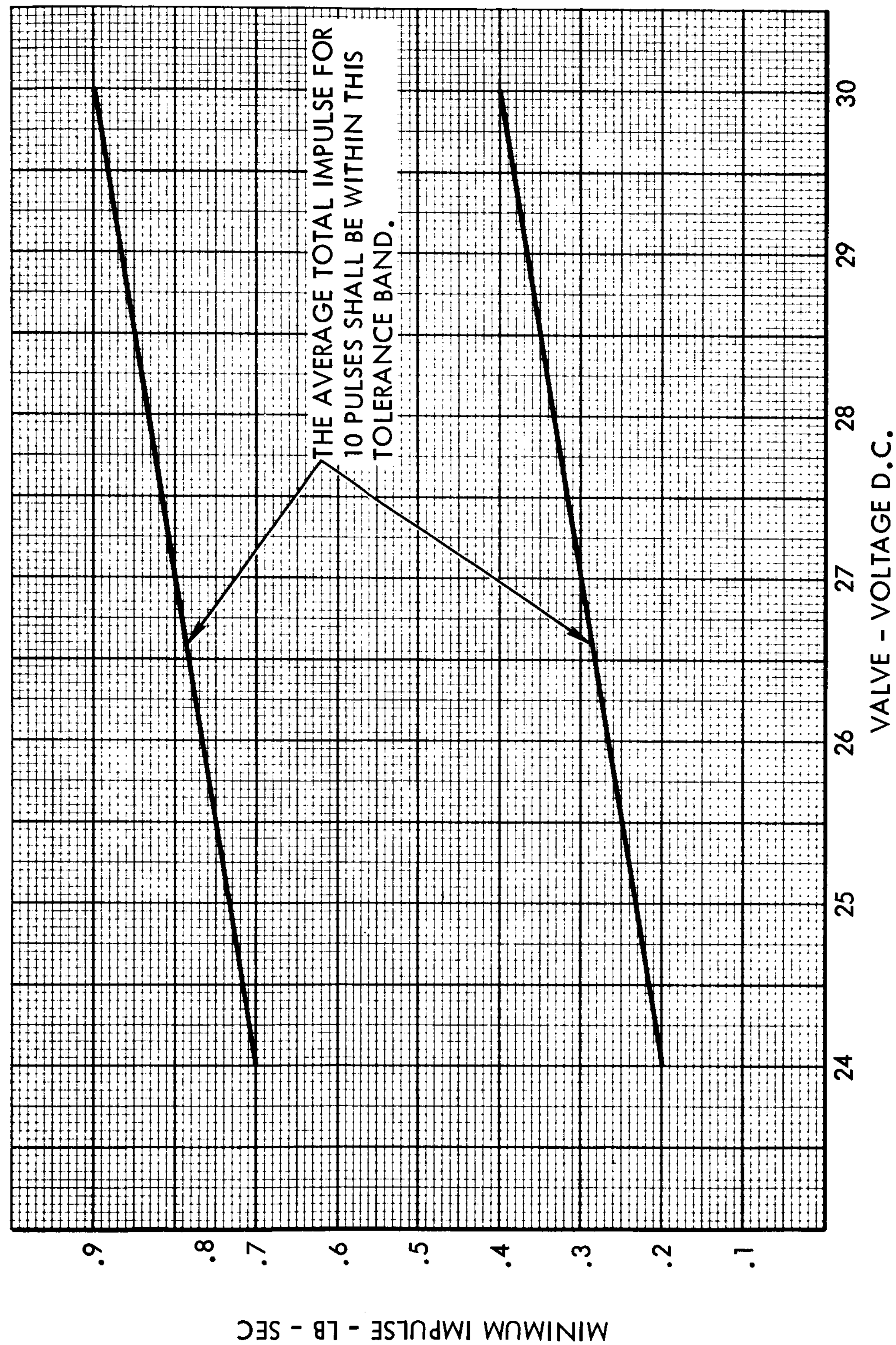


Figure 7. Minimum Impulse vs Valve Voltage 10ms Electrical Pulse Width

[redacted]

CO[redacted]

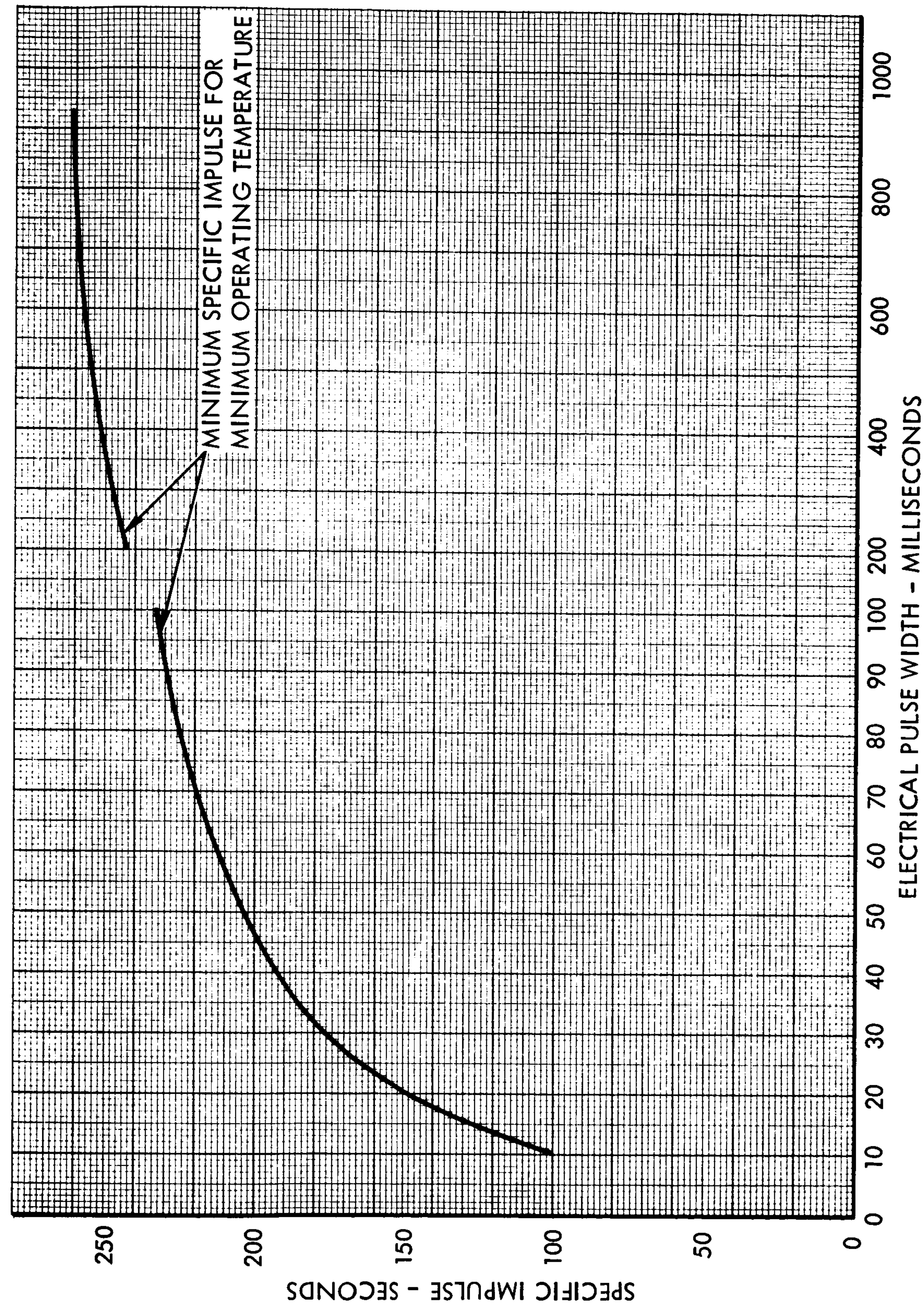


Figure 8. Specific Impulse vs Electrical Pulse Width

[redacted]

CO[redacted]

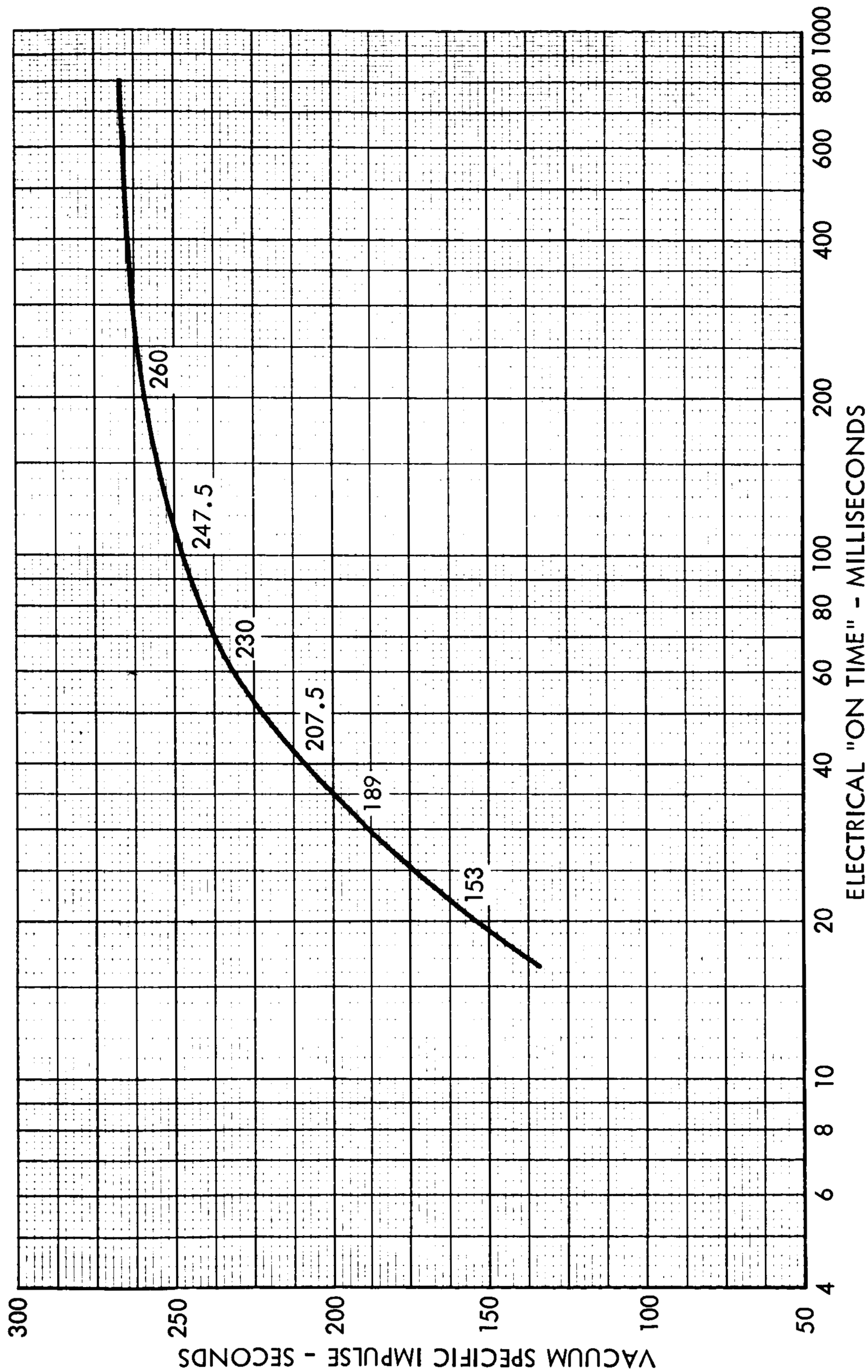


Figure 9. Transient Engine Performance Vacuum Specific Impulse vs Electrical "On Time"

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Table I. Service Module Service Propulsion Subsystem ΔV Budget

TRANSLUNAR

Mission Phase	Minimum Possible	Flexibility	Patch Conic Calibration Bias		Guidance		Contingencies	Weight Reporting
			Mean	3σ	Mean	3σ		
Midcourse*	—	—	—	—	68	(91)	—	68
Lunar Orbit Inertion	2600	800	35	(15)	10	(20)		3445
							RSS of 3σ Values	(94)
							Total	3607

TRANSEARTH

Mission Phase	Minimum Possible	Flexibility	Patch Conic Calibration Bias		Guidance		Contingencies	Weight Reporting
			Mean	3σ	Mean	3σ		
LEM Rescue	—	—	—	—	—	—	680	680
Transearth Injection	2600	400	85	(15)	3	—	—	3088
Midcourse**	—	—	—	—	40	(60)	—	40
							RSS of 3σ Values	(62)
							Total	3870

*Midcourse allowance based on 2 ft/sec ΔV available in RCS budget for vernier correction.

**Midcourse allowance based on 6 fps ΔV available in the RCS for vernier corrections.

[redacted]

C[redacted]

Table II. Saturn S-IVB Auxiliary Propulsion Subsystem
Propellant Allotment

(To be determined)

~~CONFIDENTIAL~~

[redacted]

Table III. Service Module Propellant Required Per Automatic Maneuver

MAXIMUM MANEUVER RATES / AXES / MISSION PHASE		PROPELLANT PER MANEUVER * (LBS) (NO SM RCS QUAD FAILURE)						
		0.5°/SEC			0.2°/SEC			Additional Navigation Sighting Maneuver Propellant Due to Minimum Impulse Maneuver
		3-AXES	PITCH OR YAW	ROLL	3-AXES	PITCH OR YAW	ROLL	
TRANSLUNAR					3.1	2.6	0.24	0.35
LUNAR ORBIT	WITH LEM	5.2	4.3	0.43				
	WITHOUT LEM	1.08	0.71	0.19				
TRANSEARTH					0.45	0.31	0.07	

[redacted]

[redacted]

APPENDIX A

BLOCK II LOR MISSION SPACECRAFT MASS PROPERTIES

TIME (HOURS)	WEIGHT (LBS)	X-CG (IN.)	Y-CG (IN.)	Z-CG (IN.)	I XX	I YY	I ZZ (SLUG - FEET SQUARED)	I XY	I YZ	I XZ
-4.000	100953.4	849.38	0.24	1.15	61687.43	1035180.59	1041119.30	623.96	3351.23	3937.01
-2.500	100953.4	849.38	0.24	1.15	61688.32	1035193.26	1041133.92	619.41	3352.25	3934.45
-2.500	101517.5	850.44	0.22	1.08	61788.35	1039620.18	1045580.21	553.46	3359.58	3634.22
0.	101517.5	850.44	0.22	1.08	61789.07	1039646.52	1045605.33	555.15	3359.67	3638.28
-0.	101517.5	850.44	0.22	1.08	61789.07	1039646.52	1045605.33	555.15	3359.67	3638.28
0.048	101516.5	850.44	0.22	1.08	61788.17	1039640.84	1045598.86	557.46	3359.46	3638.96
0.197	93313.5	810.88	0.25	1.18	61254.43	628466.18	634423.18	742.14	3288.82	4577.48
0.197	93313.5	810.88	0.25	1.18	61254.43	628466.18	634423.18	742.14	3288.82	4577.48
3.011	93306.2	810.88	0.25	1.17	61249.32	628441.02	634401.43	751.05	3291.55	4562.72
3.011	93306.2	810.88	0.25	1.17	61249.32	628441.02	634401.43	751.05	3291.55	4562.72
3.099	93306.2	810.88	0.25	1.17	61249.35	628442.40	634402.79	751.10	3291.59	4562.79
3.099	60081.2	930.45	0.34	1.97	32474.57	71510.22	78060.68	373.63	3255.63	1236.39
3.349	60061.9	930.44	0.34	1.97	32455.19	71495.41	78047.89	373.68	3255.64	1237.01
3.349	93274.7	1008.73	0.27	1.14	68951.07	714000.83	719828.27	-561.44	3267.69	562.11
3.500	93263.1	1008.74	0.27	1.14	68939.37	713986.93	719815.60	-561.65	3267.71	562.19
3.500	93260.6	1008.74	0.27	1.14	68938.04	713966.48	719813.88	-562.41	3267.90	562.30
3.678	93246.9	1008.74	0.27	1.14	68924.26	713969.95	719798.77	-562.65	3267.91	562.39
3.678	89531.5	1029.96	0.23	1.32	51852.99	482545.51	488817.30	-78.15	3265.46	-1313.77

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BLOCK II LOR MISSION SPACECRAFT MASS PROPERTIES (Cont)

TIME (HOURS)	WEIGHT (LBS)	X-CG (IN.)	Y-CG (IN.)	Z-CG (IN.)	I XX	I YY	I ZZ	I XY	I YZ	I XZ
						(SLUG - FEET SQUARED)				
3.800	89531.2	1029.96	0.23	1.32	51852.74	482544.39	488816.21	-78.32	3265.50	-1313.59
3.800	89523.9	1029.97	0.23	1.32	51848.83	482523.54	488795.03	-84.30	3267.29	-1307.87
5.099	89520.9	1029.97	0.23	1.32	51846.18	482512.07	488783.86	-86.16	3267.71	-1306.03
5.104	88217.2	1031.13	0.64	1.13	51166.08	480515.86	486533.52	-707.21	3132.44	-1003.04
9.500	88206.8	1031.15	0.64	1.13	51157.07	480476.47	486495.11	-713.71	3133.88	-996.71
9.500	88204.4	1031.15	0.64	1.13	51155.76	480476.45	486493.83	-713.88	3134.07	-996.68
15.500	88190.2	1031.17	0.64	1.13	51143.45	480422.56	486441.27	-722.76	3136.04	-988.04
15.500	88187.7	1031.17	0.64	1.13	51142.14	480422.54	486439.99	-722.93	3136.23	-988.01
21.500	88173.6	1031.20	0.64	1.13	51129.83	480368.85	486387.64	-731.80	3128.20	-979.37
21.500	88171.1	1031.20	0.64	1.13	51128.52	480368.83	486386.36	-731.97	3138.39	-979.34
27.500	88157.0	1031.22	0.65	1.13	51116.22	480314.89	486333.75	-740.86	3140.36	-970.69
27.500	88154.5	1031.22	0.64	1.13	51114.91	480314.87	486332.48	-741.03	3140.55	-970.67
33.500	88140.4	1031.24	0.65	1.13	51102.60	480260.91	486279.86	-749.91	3142.52	-962.02
33.500	88137.9	1031.24	0.65	1.13	51101.29	486260.89	486278.58	-750.08	3142.71	-961.99
39.500	88123.7	1031.27	0.65	1.12	51088.98	480206.92	486225.93	-758.96	3144.68	-953.34
39.500	88121.3	1031.27	0.65	1.12	51087.67	480206.90	486224.66	-759.13	3144.87	-953.32
45.500	88107.1	1031.29	0.65	1.12	51075.37	480153.12	486172.21	-768.02	3146.84	-944.66
45.500	88104.7	1031.29	0.65	1.12	51074.06	480153.10	486170.94	-768.19	3147.03	-944.64

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BLOCK II LOR MISSION SPACECRAFT MASS PROPERTIES (Cont)

TIME (HOURS)	WEIGHT (LBS)	X-CG (IN.)	Y-CG (IN.)	Z-CG (IN.)	I XX	I YY	I ZZ (SLUG - FEET SQUARED)	I XY	I YZ	I XZ
51.500	88090.5	1031.31	0.65	1.12	51061.75	480099.08	486118.25	-777.08	3149.00	-935.98
51.500	88088.0	1031.31	0.65	1.12	51080.44	480099.06	486116.97	-777.25	3149.19	-935.96
57.500	88073.9	1031.34	0.66	1.12	51048.13	480045.02	486064.26	-786.14	3151.16	-927.30
57.500	88071.4	1031.34	0.66	1.12	51046.82	480045.00	486062.98	-786.31	3151.35	-927.28
59.261	88067.3	1031.34	0.66	1.12	51043.21	480029.17	486047.55	-788.92	3151.92	-924.74
59.265	87210.2	1032.21	0.93	1.02	50593.11	478420.17	484270.67	-1248.86	3065.39	-755.80
63.251	87200.8	1032.22	0.93	1.01	50584.90	478383.65	484235.01	-1254.90	3066.71	-750.00
63.253	86774.7	1032.66	1.09	0.99	50356.79	477568.90	483338.93	-1538.18	3024.06	-717.25
63.500	86774.1	1032.66	1.09	0.99	50356.28	477566.72	483336.80	-1538.56	3024.14	-716.89
63.500	86771.6	1032.66	1.09	0.99	50354.99	477566.71	483335.55	-1538.69	3024.33	-716.87
64.251	86769.9	1032.67	1.09	0.99	50353.44	477559.71	483328.72	-1539.84	3024.58	-715.77
64.251	86769.9	1032.67	1.09	0.99	50353.44	477559.71	483328.72	-1539.84	3024.58	-715.77
64.256	85552.0	1034.09	1.50	0.81	49705.77	474632.31	480155.04	-2318.29	2902.58	-395.23
64.256	85515.3	1034.13	1.51	0.81	49685.98	474541.17	480056.25	-2338.77	2899.01	-385.55
64.261	84260.5	1035.72	1.95	0.64	49012.01	471177.26	476435.67	-3214.42	2775.64	-57.08
64.266	83005.7	1037.47	2.40	0.49	48327.34	467279.64	472276.65	-4178.25	2656.47	267.77
64.272	81751.2	1039.42	2.84	0.33	47629.76	462560.87	467285.63	-5178.66	2541.81	631.40
64.277	80496.4	1041.54	3.31	0.15	46930.42	457198.38	461647.13	-6318.22	2426.73	1064.05

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BLOCK II LOR MISSION SPACECRAFT MASS PROPERTIES (Cont)

TIME (HOURS)	WEIGHT (LBS)	X-CG (IN.)	Y-CG (IN.)	Z-CG (IN.)	I XX	I YY	I ZZ (SLUG - FEET SQUARED)	I XY	I YZ	I XZ
64.282	79241.6	1043.89	3.78	-0.02	46213.47	450915.21	455077.91	-7500.18	2318.64	1490.35
64.287	77966.8	1046.41	4.29	-0.22	45496.83	443883.78	447756.85	-8881.89	2208.91	2014.37
64.292	76732.2	1049.15	4.81	-0.39	44765.46	435920.78	439500.90	-10343.75	2106.61	2514.46
64.297	75477.4	1052.09	5.33	-0.59	44019.37	427020.40	430290.46	-11858.95	2008.47	3079.89
64.303	74222.6	1055.29	5.88	-0.81	43269.45	416898.85	419850.14	-13576.76	1907.41	3764.23
64.308	72967.8	1058.74	6.48	-1.02	42516.17	405552.06	408192.51	-15450.02	1811.73	4432.95
64.313	71713.2	1062.42	7.05	-1.23	41733.41	393085.88	395391.67	-17378.45	1725.76	5144.05
64.318	70458.5	1065.03	7.11	-1.22	41129.61	385755.07	387845.42	-17974.11	1494.03	5322.12
64.323	69230.7	1066.87	6.74	-1.03	40564.66	382700.74	384646.14	-17402.85	1359.68	5042.87
64.328	67948.9	1068.92	6.36	-0.84	39994.49	379062.52	380860.00	-16766.37	1227.45	4729.28
64.333	66694.3	1071.19	5.97	-0.64	39418.90	374777.48	376423.71	-16061.16	1097.48	4379.64
64.339	65439.5	1073.71	5.56	-0.43	38837.37	369780.63	371272.26	-15282.75	969.84	3991.95
64.344	64184.7	1076.47	5.13	-0.21	38249.65	363994.83	365328.16	-14427.48	844.70	3563.62
64.349	62929.9	1079.51	4.69	0.01	37655.39	357328.51	358499.67	-13490.09	722.22	3092.55
64.351	62413.3	1080.84	4.50	0.11	37408.73	354311.82	355415.06	-13079.14	672.60	2885.60
64.351	62413.1	1080.84	4.50	0.11	37408.62	354310.63	355413.84	-13078.95	672.57	2885.51
64.354	61675.3	1082.83	4.23	0.25	37054.28	349699.09	350704.11	-12465.58	602.56	2576.46
64.600	61672.5	1082.86	4.24	0.25	37044.72	349689.36	350690.80	-12472.19	601.92	2577.09

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BLOCK II LOR MISSION SPACECRAFT MASS PROPERTIES (Cont)

(HOURS)	WEIGHT (LBS)	X-CG (IN.)	Y-CG (IN.)	Z-CG (IN.)	I XX	I YY	I ZZ (SLUG - FEET SQUARED)	I XY	I YZ	I XZ
64.600	61665.9	1082.87	4.24	0.24	37040.64	349649.60	350650.44	-12481.17	603.79	2585.05
65.783	61652.3	1082.98	4.27	0.24	36994.64	349602.45	350586.05	-12513.05	600.70	2588.08
65.783	61652.3	1082.98	4.27	0.24	36994.64	349602.45	350586.05	-12513.05	600.70	2588.08
65.783	61652.3	1084.33	4.27	0.34	37006.51	350310.76	351286.73	-12630.60	589.52	2605.92
68.070	61626.1	1084.39	4.27	0.34	36981.66	350188.50	351166.68	-12637.93	592.14	2613.86
68.070	61626.1	1084.39	4.27	0.34	36981.66	350188.50	351166.68	-12637.93	592.14	2613.86
68.070	31440.8	943.61	8.42	0.58	17194.36	53388.16	54406.15	-4555.57	576.20	3121.44
69.500	31435.7	943.61	8.43	0.57	17190.05	53384.62	54404.63	-4557.01	577.91	3120.47
69.500	31434.7	943.61	8.43	0.57	17189.70	53382.84	54402.51	-4557.79	577.97	3120.60
75.500	31413.4	943.62	8.44	0.55	17171.65	53367.86	54396.00	-4563.84	585.13	3116.56
75.500	31412.5	943.62	8.44	0.55	17171.30	53366.09	54393.90	-4564.62	585.19	3116.68
81.500	31391.1	943.63	8.45	0.52	17153.23	53351.09	54387.38	-4570.67	592.36	3112.64
81.500	31390.2	943.62	8.45	0.52	17152.88	53349.32	54385.27	-4571.45	592.41	3112.77
87.500	31368.8	943.63	8.46	0.49	17134.81	53334.32	54378.76	-4577.50	599.59	3108.73
87.500	31367.9	943.63	8.46	0.49	17134.46	53332.54	54376.64	-4578.28	599.64	3108.85
90.000	31359.0	943.63	8.47	0.48	17126.92	53326.27	54373.91	-4580.80	602.63	3107.17
90.000	31359.0	943.63	8.47	0.48	17126.92	53326.27	54373.91	-4580.80	602.63	3107.17
93.500	31346.5	943.64	8.47	0.47	17116.37	53317.53	54370.13	-4584.33	606.82	3104.82

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BLOCK II LOR MISSION SPACECRAFT MASS PROPERTIES (Cont)

TIME (HOURS)	WEIGHT (LBS)	X-CG (IN.)	Y-CG (IN.)	Z-CG (IN.)	I XX	I YY	I ZZ (SLUG - FEET SQUARED)	I XY	I YZ	I XZ
93.500	31345.6	943.64	8.47	0.47	17116.02	53315.76	54368.02	-4585.11	606.88	3104.94
99.500	31324.2	943.65	8.48	0.44	17097.93	53300.73	54361.49	-4591.17	614.06	3100.91
99.500	31323.3	943.64	8.48	0.44	17097.57	53298.96	54359.38	-4591.94	614.11	3101.04
105.500	31301.9	943.65	8.50	0.42	17079.47	53283.93	54352.86	-4598.00	621.30	3097.01
105.500	31301.0	943.65	8.50	0.42	17079.12	53282.15	54350.75	-4598.78	621.36	3097.13
105.571	31300.8	943.65	8.50	0.42	17078.90	53282.03	54350.73	-4598.85	621.44	3097.08
105.571	37014.9	978.01	7.14	0.43	19997.49	107553.29	107690.48	-6640.09	623.21	3108.14
105.600	37014.8	978.01	7.14	0.43	19997.40	107553.11	107690.35	-6640.14	623.24	3108.15
105.600	37013.5	978.01	7.14	0.43	19996.54	107551.85	107688.90	-6640.82	623.63	3108.71
105.800	37012.8	978.01	7.14	0.42	19995.94	107551.94	107688.37	-6641.11	623.87	3108.77
105.800	37012.8	975.89	7.15	0.36	19983.57	103179.46	103328.75	-6458.10	641.56	3042.13
105.900	37012.4	975.89	7.15	0.36	19983.21	103179.17	103328.48	-6458.17	641.64	3042.21
105.900	37012.4	976.12	7.15	0.36	19983.21	103766.60	103915.91	-6471.13	641.64	3021.55
106.237	37011.1	976.12	7.15	0.36	19981.99	103765.26	103914.64	-6471.39	641.89	3041.82
109.137	31740.4	944.72	8.33	0.35	17196.82	53669.71	54771.47	-4700.30	638.15	3054.70
109.137	31740.4	944.72	8.33	0.35	17196.82	53669.71	54771.47	-4700.30	638.15	3054.70
109.140	30992.5	945.56	7.87	0.64	16865.10	53324.00	54352.77	-4589.42	552.19	2987.56
109.143	30244.3	946.56	7.39	0.94	16529.19	52889.20	53843.19	-4457.90	468.05	2907.52

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BLOCK II LOR MISSION SPACECRAFT MASS PROPERTIES (Cont)

TIME (HOURS)	WEIGHT (LBS)	X-CG (IN.)	Y-CG (IN.)	Z-CG (IN.)	I XX	I YY	I ZZ (SLUG - FEET SQUARED)	I XY	I YZ	I XZ
109.146	29496.4	947.73	6.88	1.25	16188.97	52377.63	53254.98	-4304.37	385.91	2813.67
109.149	28748.2	949.09	6.35	1.58	15843.91	51771.11	52569.58	-4126.84	305.87	2704.83
109.152	28000.3	950.64	5.79	1.93	15493.80	51049.60	51767.04	-3923.89	228.17	2579.34
109.155	27252.1	952.41	5.20	2.30	15138.03	50200.08	50834.07	-3693.75	152.93	2436.20
109.158	26504.0	954.41	4.58	2.69	14776.23	49207.03	49754.87	-3434.25	80.40	2274.30
109.162	25756.0	956.66	3.92	3.10	14408.00	48046.21	48505.06	-3141.53	10.83	2091.67
109.165	25007.9	959.19	3.22	3.54	14032.53	46692.45	47059.21	-2812.93	-55.55	1885.91
109.165	24920.8	959.50	3.14	3.59	13988.32	46520.81	46876.63	-2772.18	-63.06	1860.38
109.165	24920.5	959.50	3.14	3.59	13988.20	46520.31	46876.10	-2772.07	-63.08	1860.31
109.168	24259.9	962.02	2.48	4.00	13649.39	45112.42	45383.71	-2444.91	-118.42	1655.34
111.500	24255.1	962.04	2.48	4.00	13645.22	45110.57	45381.42	-2446.10	-117.91	1657.73
111.500	24252.6	962.03	2.48	4.00	13643.98	45107.49	45377.20	-2448.00	-117.66	1658.14
117.500	24240.1	962.07	2.50	4.00	13633.27	45102.63	45371.17	-2451.05	-116.36	1664.29
117.500	24237.6	962.07	2.49	4.00	13632.03	45099.55	45366.96	-2452.95	-116.10	1664.69
123.500	24225.1	962.11	2.51	4.00	13621.31	45094.72	45360.97	-2456.01	-114.80	1670.84
123.500	24222.6	962.10	2.51	4.00	13620.07	45091.64	45356.76	-2457.91	-114.55	1671.25
129.165	24210.8	962.14	2.53	3.99	13609.94	45087.01	45351.03	-2460.80	-113.31	1677.06
129.165	24210.8	962.14	2.53	3.99	13609.94	45087.01	45351.03	-2460.80	-113.31	1677.06

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BLOCK II LOR MISSION SPACECRAFT MASS PROPERTIES (Cont)

TIME (HOURS)	WEIGHT (LBS)	X-CG (IN.)	Y-CG (IN.)	Z-CG (IN.)	I XX	I YY	I ZZ	I XY	I YZ	I XZ
					(SLUG - FEET SQUARED)					
129.166	23858.2	963.60	2.16	4.22	13426.63	44251.86	44469.73	-2272.12	-141.76	1558.40
129.500	23857.5	963.60	2.16	4.22	13426.04	44251.59	44469.39	-2272.29	-141.69	1558.74
129.500	23855.1	963.60	2.16	4.22	13424.78	44248.63	44465.28	-2274.16	-141.43	1559.15
135.500	23842.5	963.64	2.18	4.22	13414.14	44243.13	44458.68	-2277.31	-140.15	1565.28
135.500	23840.1	963.63	2.17	4.22	13412.88	44240.17	44454.58	-2279.17	-139.89	1565.69
141.500	23827.6	963.67	2.19	4.22	13402.23	44234.67	44447.96	-2282.32	-138.61	1571.82
141.500	23825.1	963.67	2.18	4.22	13400.97	44231.71	44443.85	-2284.19	-138.35	1572.22
147.500	23812.6	963.71	2.20	4.21	13390.32	44226.18	44437.22	-2287.34	-137.08	1578.36
147.500	23810.1	963.70	2.20	4.22	13389.07	44223.23	44433.12	-2289.21	-136.82	1578.76
153.500	23797.6	963.74	2.22	4.21	13378.42	44217.69	44426.47	-2292.37	-135.54	1584.90
153.500	23795.1	963.74	2.21	4.21	13377.16	44214.73	44422.37	-2294.23	-135.28	1585.31
159.500	23782.6	963.78	2.23	4.21	13366.50	44209.18	44415.70	-2297.40	-134.00	1591.44
159.500	23780.1	963.77	2.23	4.21	13365.25	44206.23	44411.60	-2299.26	-133.74	1591.85
165.500	23767.6	963.82	2.25	4.21	13354.59	44200.66	44404.91	-2302.44	-132.47	1597.99
165.500	23765.2	963.81	2.24	4.21	13353.34	44197.71	44400.82	-2304.30	-132.21	1598.39
171.500	23752.6	963.85	2.26	4.20	13342.67	44192.12	44394.11	-2307.48	-130.93	1604.53
171.500	23750.2	963.84	2.26	4.20	13341.42	44189.18	44390.02	-2309.34	-130.67	1604.93
174.165	23744.6	963.86	2.26	4.20	13336.68	44186.69	44387.03	-2310.75	-130.10	1607.66

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BLOCK II LOR MISSION SPACECRAFT MASS PROPERTIES (Cont)

TIME (HOURS)	WEIGHT (LBS)	X-CG (IN.)	Y-CG (IN.)	Z-CG (IN.)	I XX	I YY	I ZZ	IXY	I YZ	IXZ
					(SLUP - FEET SQUARED)					
174.166	23513.5	964.87	2.02	4.36	13215.88	43601.92	43771.72	-2181.59	-148.36	1526.21
177.500	23505.8	964.89	2.03	4.35	13209.37	43597.49	43767.14	-2183.18	-147.44	1529.14
177.500	23503.3	964.89	2.02	4.35	13208.10	43594.63	43763.12	-2185.02	-147.18	1529.54
183.500	23489.5	964.93	2.05	4.35	13196.38	43586.67	43754.88	-2187.87	-145.54	1534.72
183.500	23487.0	964.92	2.04	4.35	13195.11	43583.81	43750.87	-2189.71	-145.27	1535.12
189.500	23473.2	964.96	2.06	4.34	13183.39	43575.79	43742.55	-2192.57	-143.63	1540.30
189.500	23470.7	964.95	2.06	4.34	13182.12	43572.93	43738.54	-2194.41	-143.36	1540.70
195.500	23456.8	965.00	2.08	4.33	13170.39	43564.94	43730.26	-2197.28	-141.71	1545.88
195.500	23454.4	964.99	2.07	4.34	13169.13	43562.09	43726.26	-2199.12	-141.45	1546.28
197.259	23450.3	965.00	2.08	4.33	13165.69	43559.73	43723.82	-2199.96	-140.97	1547.80
197.259	23335.7	965.51	1.95	4.41	13105.51	43267.97	43416.88	-2135.29	-149.81	1506.98
198.009	23334.0	965.51	1.96	4.41	13104.05	43266.93	43415.81	-2135.65	-149.61	1507.63
198.009	10919.8	1042.22	-0.43	6.85	4889.72	4169.21	3880.91	28.58	21.76	-299.97
198.259	10919.6	1042.22	-0.43	6.85	4889.42	4169.16	3880.64	28.48	21.63	-300.02
198.438	10419.5	1043.40	-0.36	5.89	4528.24	3819.15	3595.68	25.23	29.22	-249.82
198.439	10419.5	1043.40	-0.36	5.89	4528.24	3819.16	3595.68	25.23	29.22	-249.82
198.439	10113.7	1041.99	-0.37	6.04	4582.40	3703.79	3481.93	24.09	29.34	-234.33
198.446	10113.6	1041.99	-0.37	6.04	4582.39	3703.79	3481.92	24.09	29.33	-234.33

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BLOCK II LOR MISSION SPACECRAFT MASS PROPERTIES (Cont)

TIME (HOURS)	WEIGHT (LBS)	X-CG (IN.)	Y-CG (IN.)	Z-CG (IN.)	I XX	I YY	I ZZ	I XY	I YZ	I XZ
						(SLUG - FEET SQUARED)				
198.446	10057.4	1041.72	-0.37	6.19	4572.18	3667.50	3453.56	23.88	29.46	-218.79
198.625	9922.3	1041.98	-0.30	5.50	4465.60	3577.94	3414.98	20.85	37.21	-190.12
198.656	9922.3	1041.98	-0.30	5.50	4465.56	3577.93	3414.94	20.84	37.20	-190.13
198.656	9487.3	1039.76	-0.26	5.41	4413.41	3327.02	3144.44	25.12	37.38	-199.65
198.658	9487.3	1039.76	-0.26	5.41	4413.41	3327.03	3144.46	25.12	37.38	-199.65
198.658	9487.3	1039.76	-0.26	5.41	4413.41	3327.06	3144.48	25.12	37.38	-199.65
200.510	0.	0.	-0.	0.	-0.	-0.	-0.	-0.	-0.	0.

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