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C66-6327

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

Bethpage, L. I., N. Y.

Code 26512

SPECIFICATION

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Specification No. LSP-370-3

Release Date 3-18-66

LUNAR EXCURSION MODULE

PRIMARY GUIDANCE, NAVIGATION AND CONTROL

SUBSYSTEM EQUIPMENT (GFE)

PERFORMANCE AND INTERFACE SPECIFICATION [redacted]

Approved by: ______

T. J. Kelly Project Engineer

Contractual Authority: SA #41

GROUP 4

Downgrade at 3 year intervals; declassified after 12 years.

[redacted] information affecting [redacted] of the United St[redacted] 794, the transmission or [redacted] in any manner [redacted] person is prohibited by [redacted]

Contract No. NAS 9-1100

Exhibit E; para. 4.1 Document Type Contract Line Item 3 Primary No. 281

ENG. 200.22 1-66

[redacted]

GRUMMAN AIRCRAFT ENGINEERING CORPORATION
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[redacted]

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LUNAR EXCURSION MODULE

PRIMARY GUIDANCE, NAVIGATION AND CONTROL

SUBSYSTEM EQUIPMENT (GFE)

PERFORMANCE AND INTERFACE SPECIFICATION (U)

1 SCOPE

1.1 Scope. - This specification defines the government-furnished equipment (GFE) for the Primary Guidance, Navigation, and Control Subsystem (PGNCS) equipment performance characterisitics and interfaces which place design constraints on the spacecraft and spacecraft subsystems; and the spacecraft and spacecraft subsystem performance characteristics and interfaces which place design constraints upon the GFE PGNCS. This specification covers hardware to meet the requirements of the lunar landing mission.

2 APPLICABLE DOCUMENTS

2.1 Project Documents. - The following documents of the dates shown form a part of this specification to the extent specified herein.

NASA

MSC Internal Note No. 65-FM-56	Apollo Spacecraft Δ V Budget, dated TBD
MSFC 10M01071 dated March 6, 1961	Environmental Protection when using Electrical Equipment within the Areas of Saturn Complexes where Hazardous Areas Exist, Procedure for

[redacted]

[redacted]

2.1 (Continued)

Military

MIL-I-26600/MSC-EMI-10A	Interference Control Requirements, Aeronautical Equipment dated 2 June 1958 with Amendment No. 2 dated 17 June 1959 and Notice 1 dated 1 June 1962
MIL-E-9500	Glycol Composition
MS-33586A 16 December 1958	Metals, Definition of Dissimilar

GRUMMAN DOCUMENTS

LED 540-12 (MSC TBD)	Design Reference Mission, Apollo Mission Planning Task Force, 30 October 1964 Henceforth Referred to as DRM

2.1.1 Referenced Documents. - The appendix incorporates a composite listing of Apollo Interface Documents. This listing is intended for information purposes only and will be periodically updated, but does not constitute a part of this specification.

Selections from this list of documents have been referenced in Section 3 of this specification for convenience. Documents so referenced are also not a part of this specification, but their applicability to the respective contracts including latest applicable revision as IRN's thereto, are specified in the applicable contractor's, Master End Item Specification.

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SPECIFICATION NO. LSP-370-3

2.2 Precedence. - The order of precedence, in case of conflict, shall be as follows:

(a) MIT/IL Documents -

Contract

Top Specification

P & I Specification

MEI Part I Specification

Other Documents Referenced Herein

(b) Grumman Documents -

Contract

Top Specification (LSP-470-1A)

P & I Specification

MEI Specification (LSP-470-2A)

Other Documents Referenced Herein

2.3 Effectivity. - The effectivity of this specification shall be the date of issue and subsequent approved Specification Change Notices (SCN).

[redacted]

[redacted]

3 GFE-PGNCS REQUIREMENTS

3.1 Functional and Performance Requirements. - The GFE-PGNCS shall provide the functions necessary for performance of the navigation, guidance, and control tasks for a manned lunar landing mission as described in LED-540-12, hereinafter referred to as, DRM and for aborts from such a mission. The detailed functional requirements for the GFE-PGNCS are outlined below.

3.1.1 Navigation Functional Requirements. - The GFE-PGNCS shall provide the navigational capabilities required for guidance of the LM for the DRM and aborts therefrom. The GFE-PGNCS shall be capable of inertial alignment using line of sight data from either the AOT or LOTS (contingent upon configuration). In the performance of the lunar landing mission, the GFE-PGNCS shall have the capability of operating independently of MSFN data. The GFE-PGNCS shall produce signals for initializing and aligning the AGS, provide data to the flight crew for determining the location of the computed landing site in conjunction with the LPD, and provide navigational information for display and telemetry. The navigation data shall be as follows:

(a) LGC Initialization Data

(b) Inertial Sensor Data

(c) RR Tracking Data or LOTS Tracking Data

(d) LR Tracking Data

(e) LPD Data

(f) MSFN Data

3.1.2 Guidance Functional Requirements. - The guidance functional mission and abort related requirements are listed in the following subparagraphs.

3.1.2.1 Nominal Requirements. - The GFE-PGNCS shall provide guidance functions to accomplish the following mission related requirements:

[redacted]

3.1.2.1 (Continued)

(a) Orientation for transfer insertion

(b) Insertion into the required coasting descent transfer orbit that will cause the LEM to arrive at a predetermined position relative to the preselected lunar landing site

(c) Powered descent guidance to:

(1) A preselected landing site

(2) A crew selected landing site via the LPD during the powered descent

(d) Determine the engine ignition time and ignition window limit for all powered maneuvers

(e) Powered ascent guidance to achieve:

(1) Burnout conditions resulting in a LEM trajectory that intercepts the CSM at the predetermined aim point and time of arrival, and with a pericynthion altitude greater than a specified clear pericynthion altitude constraint or

(2) Burnout conditions resulting in a parking orbit with a specified clear pericynthion altitude

(f) Midcourse guidance to reduce dispersions about the nominal aim point

(g) Terminal rendezvous guidance

3.1.2.2 Abort Related Requirements. - The GFE-PGNCS shall provide the guidance function to abort from any point in the lunar landing mission to achieve rendezvous with the CSM by:

(a) Establishing burnout conditions resulting in a LEM trajectory that intercepts the CSM and with a pericynthion altitude greater than a specified pericynthion altitude constraint

3.1.2.2 (Continued)

(b) Establishing burnout conditions resulting in a parking orbit with a specified clear pericynthion

(c) Performing minimum time emergency launch from the lunar surface to CSM intercept or parking orbit injection

(a) and (b) above are restricted time aborts if performed during descent phases. The GFE-PGNCS shall also provide the capability to perform midcourse and terminal rendezvous guidance after performing (a) and (b) above

3.1.2.2.1 Abort Capability. - The powered ascent portion of the aborts shall be accomplished with either ascent or descent engine alone, or in combination, as determined by the propellant remaining in the descent stage.

(a) The GFE-PGNCS shall provide the abort capability described in paragraph 3.1.2.2 for cases of RCS failures described in paragraph 3.1.4.1.1.2.

(b) The GFE-PGNCS shall have the capability of completing powered ascent guidance with reduced ascent engine thrust or by using the RCS within the constraints of available propellant and of trajectory dynamics.

(c) The GFE-PGNCS shall have the capability of accomplishing the midcourse and terminal rendezvous portions of the above aborts with:

(1) The RCS thrusters

(2) The ascent engine

(3) The descent engine

(4) Appropriate combinations of (1), (2), and (3)

3.1.2.2.1 (Continued)

(d) The GFE-PGNCS shall have the capability (prior to LEM descent orbit insertion) to perform the required guidance and control functions utilizing the LEM descent engine, that will allow the Command Module to achieve a safe re-entry corridor.

3.1.3 Stabilization and Control Functional Requirements. - The GFE-PGNCS shall provide for vehicle stabilization and control when operating in conjunction with the SCS in both automatic and attitude hold modes. The characteristics of the control signals provided to the SCS shall be such as to permit spacecraft attitude control during either coasting or powered flight under either automatic or manual control modes. In the attitude hold mode, the GFE-PGNCS shall accept and execute manual rotation and translation command signals and rate of descent controller inputs from the flight crew. Attitude control shall be provided by individual RCS thruster commands and descent engine trim commands. In addition, the GFE-PGNCS shall provide descent engine commands as follows:

(a) Thrust control limited between 10 percent and 57.5 percent

(b) Maximum throttle setting commands

(c) Engine On/Off Commands

3.1.4 Other Functional Requirements. - In addition to the guidance, navigation, and control functional requirements of the GFE-PGNCS listed above, the following functional capabilities shall also be provided.

3.1.4.1 Automatic Mode. - In the normal GFE-PGNCS operation of this control mode, vehicle translation and attitude, and flight path profiles shall be under control of the GFE-PGNCS. This control shall be accomplished by means of commands which are transmitted to the CES in the form of:

(a) RCS jet commands

(b) Descent engine throttling increase and decrease signals

(c) Ascent and/or descent engine ON/Off signals

(d) Descent engine pitch and roll gimbal actuator On/Off commands

[redacted]

3.1.4.1.1 Characteristics. - The basic characteristics of the automatic mode are the following:

(a) When in the automatic mode, all attitude and translational control commands necessary to perform all LEM mission phases automatically, with the exception of separation and docking, originate in the LGC.

(b) During the latter phases of the power descent a Landing Point Designator (LPD) may be used in conjunction with the GFE PGNCS to redesignate the landing site.

(c) Attitude maneuvering about the X-axis (yaw) may be commanded by the crew in a manner identical to the Attitude Hold Mode, described below, except when the LPD is controlling as specified by the LGC program. Such attitude maneuvers shall be accomplished without disturbing the flight profile. In the absence of attitude maneuver commands, the LGC will maintain yaw attitude at the value existing at the conclusion of the last attitude maneuver command. A DSKY entry will restore automatic control to the X-axis.

3.1.4.1.2 RCS Jet Thruster Commands. - The RCS jet commands from the LGC are individual On/Off signals which are fed to the preamplifiers of the jet drivers in the CES. The driver amplifier outputs are then fed to the RCS to provide the required attitude and translational control. The RCS jet thruster commands shall have the following functional characteristics:

(a) Reaction control forces are commanded relative to the LEM body axes based on the RC thruster locations stated per 3.1.5.1.4.3.

(b) In the automatic mode, translation along the X-axis shall use all four available RC thrusters. After coasting phases, the GFE-PGNCS will provide automatic ullage settling X-axis translation commands as specified in (1) and (2) below. The ullage settling commands shall be sustained for 0.5 seconds after initiation of engine turn on.

(1) Descent Engine Ullage Settling	4 RCS engines for 5.5 seconds prior to descent engine on command
(2) Ascent Engine Ullage Settling	4 RCS engines for 2 seconds prior to ascent engine on commands

[redacted]

[redacted]

3.1.4.1.2 (Continued)

(c) Commands from the LGC shall be such that opposing RCS thrusters are never commanded On simultaneously.

(d) Two-thruster couples are normally commanded for attitude control about each axis. Four thruster couples may be switched on automatically by the LGC on an as-needed basis as a function of position and rate steering error magnitude.

(e) During powered ascent or when using ascent engine, the LGC shall automatically restrict RC thruster selection for pitch and roll control so that unbalanced couples are used. The thrusters to be used are those that provide forces in the +X direction (Thruster Nos. I-d, II-d, III-d, and IV-d). If moment unbalanced couples do not provide sufficient control capability for stable operation (e.g., at lunar launch), the LGC shall automatically revert back to balanced couples on an as-needed basis.

(f) During undisturbed coasting flight, a minimum impulse limit cycle shall be established with an attitude dead zone of nominally 5.0 degrees about all three axes. During thrusting phases, the dead zone shall be established based on guidance steering requirements.

(g) In the case where an RCS thruster pair failure is detected, a thruster pair failure discrete is sent to the LGC by means of a manual switch operation. The LGC will cease issuing commands to the failed thruster pair and will initiate an alternate program to issue commands to a combination of other thruster pairs to achieve the desired control response. The thruster pairs that can be shutoff are indicated in Figure 1.

(h) Attitude control shall be maintained by the GFE-PGNCS during all mission phases when:

(1) RCS jet thruster failure indication has been sent to the LGC.

[redacted]

[redacted]

3.1.4.1.2. (Continued)

(h) (Continued)

(2) RCS thruster failure information is not available to the LGC and one of the following failures has occurred.

a. The ON failure of any single RCS jet

b. The OFF failure of any quad or sub-combination of jets within a quad.

c. The OFF failure of any number of jets in either System A or System B.

3.1.4.2 Engine Commands. -

3.1.4.2.1 On/Off. - In the normal operation, when the GFE-PGNCS is in use, the main engine (ascent or descent) is manually selected and armed by the crew. This is accomplished when the crew places the Engine Arm Switch in either the descent or ascent position. At this time, an engine OFF signal is issued from the LGC. After proper ullage-settling is automatically accomplished by the GFE-PGNCS, the armed engine can be commanded on automatically by an engine ON signal from the LGC. The engine can be commanded off automatically by an engine OFF signal from the LGC or manually by the crew. Engine On/Off signals are normally received from the LGC at the beginning and end of all powered phases except lunar touchdown. Descent engine shut-off at touchdown shall be initiated by the crew based on signals received from electromechanical probes extending from the landing pads. A capability exists of manually overriding automatic On/Off signals at the crew stations. The engine On/Off signals are directed to the sequencing circuitry of the S&C control panel where they are gated with the status signals regarding engine arm, engine firing and abort conditions. Output signals are then directed to latching relay devices for operating either the ascent or descent engine (depending upon the phase of the mission) to lock the engine either on or off. The engine On/Off signals from GFE-PGNCS shall be discrete in nature consisting of D.C. voltage as defined in ICD LIS-370-10004. The Display and Keyboard Panel (DSKY) of the GFE-PGNCS may be interrogated by the crew to determine time-to-go prior to engine ignition and shut-down in order to monitor each of these operations.

3.1.4.2.2 Descent Engine Throttling. - (TBD)

[redacted]

3.1.4.3 Descent Engine Gimbal Trim On/Off Commands. -

(a) Gimbal trim commands are generated in the LGC and directed to the DECA in the form of D.C. discretes. Four discretes are used to command positive and negative pitch and roll gimbal motions. The discretes activate power switches in the DECA which in turn activate the GDA's.

(b) The GDA's operate in an On/Off fashion at a constant speed of 0.2 deg/sec. The rise time to reach steady state speed is 0.1 sec. The maximum angular range of each actuator is ± 6.0 degrees.

(c) If a GDA failure occurs, automatic failure detection circuitry in the DECA notifies the LGC of the failure by one discrete. If the crewman shuts off power to the GDA the LGC will receive a discrete. The LGC will then cease issuing commands to the failed gimbal.

3.1.4.4 Attitude Hold Mode. -

3.1.4.4.1 Semi-Automatic. - This is a semi-automatic mode implemented to operate with either the GFE-PGNCS or AGS.

3.1.4.4.1.1 GFE-PGNCS Operation. - GFE-PGNCS operation is as follows:

(a) The Attitude Hold Mode will be used during certain non-thrusting phases and for a manual landing by the crew employing instruments and out-of-window cues. Manual attitude and translation commands from the attitude and translation controllers are fed to the LGC which provides the autopilot function and commands RC thruster operation in a manner similar to that used in the automatic mode. Similarly, throttle increase and decrease signals are generated as a function of manual rate of descent commands. Engine on commands and engine gimbal trim On/Off commands shall be sustained.

(b) Upon receipt of an "out of detent" signal, the LGC shall command attitude rates that are proportional to controller displacement about each axis. Rate commands shall range nominally from +20 deg/sec to -20 deg/sec. about each axis.

3.1.4.4.1.1 (Continued)

(c) Upon removal of the "out of detent" signal, the LGC shall command reduction of attitude rates to zero. When the vector sum about all axes of attitude rates goes below a specified (TBD) deg/sec. the vehicle attitude angle at that time shall be held by means of RC thruster commands.

(d) The selection of 2 jet or 4 jet control torque couples shall be performed automatically in a manner identical to the Automatic mode.

(e) The vehicle response to crew commanded rates, from the attitude controller when the LEM is in the Attitude Hold control mode shall be within the times given in Table I, the elapsed time from the initiation of controller displacement until the vehicle reaches within 0.15 deg/sec. of its steady-state vehicle rate shall not exceed the values given in the table. The final vehicle rate attained shall be within 1.0 deg/sec. of the commanded rate during ascent and 0.4 deg/sec. during descent.

When the attitude controller is dropped into detent and the PGNCS is in the Attitude Hold control mode, the maximum time for the vehicle to reach a specified (TBD) deg/sec from the actual vehicle rate (at the time of absence of the "out of detent" signal) shall not exceed in all axes the time; $(\Delta \dot{\Theta}/a) + 0.2$ sec.

where $\Delta\dot{\Theta}$ = the difference in the two rates above

a = ratio of the RCS engine torque to the rigid body inertia (for the time calculation it is assumed that 2 RCS jets will be used for the maneuver).

The attitude control system shall be capable of maintaining, in this mode, at the completion of the initial attitude transient, a minimum impulse limit cycle. A minimum impulse limit cycle shall also be maintained during all periods of undisturbed operation (i.e., ascent or descent engine non-operative, no large c.g. shifts, absence of external disturbances). A minimum impulse limit cycle is one in which a single

[redacted]

[redacted]

TABLE I

FLIGHT CONTROL SYSTEM

DYNAMIC PERFORMANCE

ATTITUDE HOLD MODE

RATE COMMAND RESPONSE

Commanded Vehicle Rate (Rad/Sec)	Rigid Body Moment of Inertia (Slug - Ft^2)	Response * Time (Sec)
.050	1500	0.3
.100	1500	0.35
.200	1500	0.45
.050	6000	2.0
.100	6000	2.5
.200	6000	2.7
.050	10000	0.65
.100	10000	1.2
.200	10000	2.2
.050	20000	1.1
.100	20000	2.2
.200	20000	4.0

* Time for error to converge to within 0.15 deg/sec of rate dead zone (Two Jet Response - All Axes - 1100 lb - ft. torque)

[redacted]

3.1.4.4.1.1 (Continued)

(e) (Continued)

torque impulse (about each axis) is imparted to the vehicle at each end of the deadband in order to maintain vehicle attitude within the deadband limits. A minimum torque impulse shall be less than 10.0 ft-lb-sec.

(f) The attitude deadband limit during descent engine thrusting phases in the Attitude Hold mode shall not exceed 0.3°.

(g) During undisturbed coast flight, a minimum impulse limit cycle shall be established in all three axes with a wide or narrow attitude deadband selected by the crew. The DSKY shall be used for this purpose. The wide deadband shall be nominally equal to 5.0° and the narrow deadband shall not exceed 0.3°.

3.1.4.4.1.2 RCS Thruster Commands. - RCS thruster commands shall be related to translation commands from the T/TCA in the following manner:

(a) Upon receipt of a discrete signal from the T/TCA, the LGC shall command an open loop acceleration along the appropriate vehicle axis. Six such discretes are used to command positive and negative acceleration along each axis.

(b) Two thruster operation is used to obtain accelerations along the vehicle axes. The selection of which two out of four possible thrusters available along the X axis shall be performed automatically by the LGC. The selection shall be such that performance is optimized in the presence of simultaneous attitude commands and/or thruster failures.

(c) During the final approach phase (Phase No. 3), when the descent engine is operative, GDA trim commands shall continue to be generated by the LGC as in the Automatic mode.

3.1.4.4.1.3 During the manually commanded attitude change, attitude error remains at zero. The vehicle is automatically held at the attitude it had when the attitude controller was returned to neutral consistent with the requirements of 3.1.4.4.

[redacted]

3.1.4.5 Direct Mode. - An emergency direct control is also available on an individual axis basis when the attitude controller is moved to the hardover position, whereby 4 jet operation is commanded. The emergency direct mode is independent of all other attitude control modes for GFE-PGNCS or AGS operation.

3.1.4.5.1 An override of +X translation is obtainable in all modes by commanding 4 jet operation direct to the RCS secondary coils by means of a control button on the panel.

3.1.4.6 Abort. -

3.1.4.6.1 The crew has the choice of aborting utilizing the descent engine only, the descent-ascent engines in combination or with the ascent engine only. The decision involves such factors as: the reason for abort, the descent engine fuel remaining, the phase of the mission when abort situations arise, etc.

3.1.4.6.2 If abort utilizing the descent engine only or the descent-ascent engine combination is selected, the crew pushes the Abort Button. This arms the descent engine, and commands the LGC and the AGS to initiate an Abort Guidance Program. The vehicle will be controlled along an appropriate abort trajectory in much the same way as during the LEM normal mode. When descent engine fuel is nearly expended, the crew presses the Abort Stage button. This button, by means of CES and control panel electronics, initiates the shut-down of the descent engine, pressurizes and arms the ascent engine, and signals the LGC and the AGS to initiate the Abort Guidance Program appropriate for aborting with the ascent engine. When the ascent engine is commanded on by the LGC, staging is initiated by means of CES and control panel electronics. The ascent engine is inhibited from firing by the CES for 200 ms after Abort-Stage initiation.

3.1.4.6.3 If the crew elects to abort utilizing the ascent engine only, the Abort Stage Button is pressed. The system response is the same as just described above for the Abort Stage Button actuation. Ullage settling commands from the GFE-PGNCS shall be provided in accordance with paragraph 3.1.4.1.1.2 for aborts from coasting phases.

[redacted]

[redacted]

3.1.4.7 Rate of Descent (ROD) Mode. - The ROD mode shall be operational when the Attitude Hold mode is selected in either the landing approach phase (Phase 2) or the final approach phase (Phase 3)*. Upon switching to the ROD mode, the LGC shall command descent engine throttling such that the vehicle rate of descent along the calculated local vertical at the time of switchover is maintained. Incremental changes in the rate of descent shall be commanded by means of discretes coming from the crew station, which are directed to the LGC, to be executed in the form of throttle commands. The discretes shall represent incremental changes of one ft/sec. Engine throttling control shall be within the requirements of 3.1.5.3.6.

3.1.4.8 GFE-PGNCS Operation when AGS is in Control. - (TBD)

3.1.4.9 Displays. - The GFE-PGNCS shall provide the signals to displays specified in ICD LIS-540-10001. The GFE-PGNCS shall provide via the DSKY a display of status, navigation, and guidance data. The GFE-PGNCS shall be capable of being programmed to display these data automatically or at the command of the flight crew via the DSKY. The DSKY shall, as a minimum, also be capable of permitting the flight crew to initiate the LGC programs for all mission phases, perform in-flight checkout, insert updated navigation data, and display manual LGC entries prior to actual entry into LGC. The GFE-PGNCS shall provide the capability of displaying caution and status signals.

3.1.4.9.1 Controls. - The GFE-PGNCS control functions are specified in ICD LIS-540-10001.

In addition, the following crew interface functional requirements exist:

*If the AH mode is selected in the braking phase (Phase 1), automatic throttling shall continue to be based on guidance steering.

[redacted]

[redacted]

3.1.4.9.1 (Continued)

(a) AOT Controls - The AOT will have a reticle dimming control provided on the AOT Control Box. The AOT will provide control and readout for measurements of star position angles. The AOT Control Box will provide MARK X, MARK Y, and MARK REJECT controls for entering star crossings of AOT reference coordinates into the computer. The AOT will provide the capability to be placed in 6 detent positions with a detent position readout.

(b) DSKY Dimming Controls - The spacecraft annunciator/numeric and integral dimming controls will provide for dimming of the DSKY E L Lamps. The spacecraft will also provide dimming control for the DSKY incandescent lamps.

(c) Circuit Breakers - The spacecraft will provide circuit breakers for control of power to the GFE-PGNCS. This interface is controlled in ICD LIS-390-10002. The circuit breaker requirements are:

(1) IMU Standby

(2) IMU Operate

(3) LGC Power

(4) AOT Heater

(5) AOT Lighting

(6) LOTS Power

NOTE: If item (6) is included, items (4) and (5) shall not be required.

3.1.4.10 Radar Functional Requirements. -

3.1.4.10.1 Rendezvous Radar (RR) Functional Requirements and Operation. - The RR is required to measure and furnish the GFE PGNCS with range, range rate, and line-of-sight (LOS) angle information with respect to the transponder on the CSM. The RR shall be capable of providing data at all times during unpowered mission phases except when attached to the CSM.

[redacted]

3.1.4.10.1 (Continued)

The RR may be operated either with GFE-PGNCS computer (LGC) or in a manual mode under crewman control. This specification delineates only those requirements necessary for the LGC mode of operation.

The GFE-PGNCS shall be capable of angle designating the RR antenna to the predicted CSM line-of-sight, and shall issue the auto-angle-tracking enable signal when the indicated LOS is within 1 degree of the computed target position. In addition, the GFE PGNCS shall protect against RR sidelobe acquisition within electrical tracking limits, and slew antenna gimbals from one angular coverage mode to another. The angle reference interface between the RR and the GFE-PGNCS is at the navigation base (NAVBASE) and all RR angle data is referenced to this interface.

3.1.4.10.1.1 GFE-PGNCS RR Interface. - The electrical interface between the RR and the GFE-PGNCS is defined in LIS-370-10004 and LIS-370-10006.

3.1.4.10.2 Landing Radar (LR) Functional Requirements. - The LR is required to measure and furnish the GFE-PGNCS with vehicle range and velocity data relative to the lunar surface below 25,000 ft. altitude. The LR data output to the GFE-PGNCS is referred to the NAVBASE by angle transformations in the GFE-PGNCS.

The LR antenna is a two position device, occupying either of two fixed positions. The GFE-PGNCS shall command the LR antenna from position 1 to position 2 at the appropriate time in the mission. (See Figure 6) The LEM modes of operation during which LR data will be required are:

(a) Automatic control of LEM by the GFE-PGNCS.

(b) Semi-Automatic control of LEM involving astronaut landing site redesignation during Phase 2 or astronaut translation control in the final approach and landing phases.

(c) Complete manual control of LEM when within the LR operating limits.

3.1.4.10.2 (Continued)

NOTE: The GFE-PGNCS is the controlling system in the first two modes listed above. During automatic, semi automatic and complete manual control modes, the GFE-PGNCS must maintain current estimates of vehicle position and velocity for abort and display requirements. Thus, in all three modes, the GFE-PGNCS will require LR data. This note does not imply that the GFE-PGNCS is not required to maintain a current state vector estimate for abort or display in the absence of LR data.

3.1.4.10.2.1 GFE-PGNCS LR Interface. - The electrical interface between the LR and the GFE-PGNCS is defined in LIS-370-10004.

3.1.4.11 Landing Point Designator Requirements. - The LPD consists of a double reticle, on the commander's window, which is used with the GFE-PGNCS DSKY and a controller to display the computed landing site and to enable the crew to redesignate the landing site.

3.1.4.11.1 LGC LPD Requirements. - The LGC shall compute and display, in the form described below, the position of the landing site to which the GFE-PGNCS is guiding the LEM, with an accuracy in heading of 0.5° (one sigma) and a computation accuracy in look angle of 0.15° (one sigma).

(a) Heading Reference - Heading reference to the planned landing site is displayed by orienting the LEM about the X body axis so that the LEM XZ body plane intersects the planned landing site.

(b) Look Angle - Look angle to the planned landing site is displayed through the DSKY as the angle in degrees rounded to 0.5°, measured from the LEM Z body axis to the line of sight to the planned landing site.

(c) The LGC shall accept and process incremental change commands from the commander's crew station to modify the planned landing site. Each closure in yaw shall represent a 0.5° change about the LEM X body axis and each closure in pitch shall represent a 0.2° change about the LEM Y body axis.

[redacted]

3.1.4.11.1.1 Reticle Requirements. - The window, at the commander's position, shall be equipped with a double reticle system which, when viewed from the position in which the reticles coincide, identifies the landing area in the form described below, with an accuracy in both heading and look angle of ± 1° max.

HEADING REFERENCE of the LEM is indicated by a vertical line which represents the intersection of the LEM XZ body plane with the landing area. Calibration marks to the left and right of the vertical line indicate the magnitude of angular changes about the LEM X body axis in 5° increments.

LOOK ANGLE of points within the landing area is indicated by calibration marks along the line representing vertical heading which indicate the angle below the LEM Z body axis in 2° increments.

TABLE II

LFD Accuracy Budgets

HEADING	Error about LEM X Body Axis (1 σ)
GFE-PGNCS Heading Control	.50°
LFD Reticle Alignment	.50°
Controller Resolution (.5°)	.14°
Crewman	.20°
	.75°

LOOK Angle	Error about LEM Y Body Axis (1 σ)
GFE-PGNCS Accuracy	.15°
DSKY resolution (0.5°)	.14°
LFD Reticle Alignment	.50°
LFD Reticle Linearity	.10°
LFD Reticle Resolution (2°) (0.2°) (with Crewman Interpolation)	.12°
Crewman	.20°
Controller Resolution (0.2°)	.06°
	.60°

[redacted]

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3.1.4.12 IMU Alignment LEM/CSM Docked. - These requirements are covered in ICD MH01-05076-414.

3.1.4.13 Electrical Power. - The spacecraft shall provide the electrical power requirements of the GFE-PGNCS in accordance with ICD's LIS-390-10002 and LIS-370-10004.

3.1.4.14 Telemetry. - The GFE-PGNCS shall provide serial digital data and analog measurements in accordance with ICD's LIS-370-10003, LIS-370-10004, and LIS-540-10001.

3.1.4.15 LOTS Functional Requirements. -

3.1.4.15.1 Alignment. - The LOTS shall provide the capability to track stars for GFE-PGNCS alignment purposes under LGC control during the following mission phases:

(a) While attached to the CSM

(b) During coasting flight

(c) On lunar surface

3.1.4.15.2 Tracking. - The LOTS shall have the capability of tracking a flashing light mounted on the CSM or a sun illuminated CSM for purposes of navigation.

3.1.5 Performance Requirements. -

3.1.5.1 Alignment Requirements. - The alignment requirements are as specified in ICD's LIS-540-10001 and MH01-05076-414. The alignment functions shall be capable of being performed with the LEM docked to the CSM, the LEM in coasting orbit, and the LEM on the lunar surface. The GFE-PGNCS shall be capable of accepting inputs for initialization, information as to the relative LEM-CSM attitude when docked. Such information shall be entered through flight crew operation of the display keyboard.

3.1.5.1.1 AOT Alignment. - The mechanical misalignment between the AOT line of sight and the axes of the coordinate system defined by the GFE-PGNCS navigation base mounting points shall not exceed 0.2 mr (1σ) per axis.

[redacted]

[redacted]

3.1.5.1.2 AGS Alignment. - The GFE-PGNCS shall provide data to align the AGS to the accuracy specified below:

3.1.5.1.2.1 AGS/GFE-PGNCS Transfer Alignment. - The AGS shall normally be aligned to the IMU gimbal angles as follows:

When the AGS is operating, the accumulators of the AEA will accept incremental IMU gimbal angle signals and the CDU ZERO signals from the GFE-PGNCS. The incremental signals will be in the form of pulses and will represent IMU inner, middle and outter gimbal angles. The CDU ZERO signal will be a pulse train of 300 millisecond minimum duration and will be used to zero the counters in the AEA. During the presence of the CDU ZERO signal, the corresponding counters in CDU, LGC and AGS will be brought to zero. At the termination of the CDU ZERO signal, the incremental pulses will step all reference counters up to a value of the IMU gimbal angles. The counters can be considered to contain IMU gimbal angles after 3 seconds. In the absence of a CDU ZERO signal, the AEA counters will continuously accumulate the incremental IMU gimbal angle signals. When the crewman desires to align the AGS from the IMU, the data stored in the AEA accumulators will be employed to effect the alignment.

3.1.5.1.2.1.1 The AEA accumulators will continue to accumulate IMU gimbal angle information even while the AGS alignment is taking place.

3.1.5.1.2.1.2 A transfer alignment of the AGS from the GFE-PGNCS will normally be accomplished in the following phases of the mission:

(a) Once in lunar orbit before separation from the CSM

(b) Once in lunar orbit prior to injection into a Hohmann descent transfer orbit

(c) Once during coast in descent transfer orbit prior to start of powered descent

(d) Once on the lunar surface prior to launch

(e) As required during parking orbits

3.1.5.1.2.1.3 Xp, Yp and Zp constitute the IMU inner member reference orthogonal triad of coordinates parallel to the corresponding IMU accelerometer directions.

[redacted]

3.1.5.1.2.1.4 In lunar orbit the IMU will be aligned with the Xp axis parallel to the calculated nominal landing site vertical at the predicted nominal time of landing with the Zp-axis parallel to the cross product of the H vector and the Xp vector where the Xp vector is a vector co-linear with the Xp-axis and the H vector is the CSM angular momentum vector. The Yp-axis completes the right-handed orthogonal triad. The point (o,o,o) in this coordinate frame is the lunar center. Figure 2 shows the coordinate system discussed.

3.1.5.1.2.1.5 On the lunar surface the Xp-axis will be aligned parallel to the local vertical, with the Zp-axis parallel to the cross product of the H vector and the Xp vector, and the Yp-axis completes the right-handed orthogonal triad. The local vertical and the CSM orbit momentum vector are defined for actual local conditions at the planned time of initiating the ascent.

3.1.5.1.2.1.6 The accuracy of the AGS alignment to the above orientation is determined by: errors associated with the measurements and computations involved in defining the desired orientation, the process of IMU fine alignment, the orientation drift in the IMU since the last fine alignment, the angle readout associated with the CDU's, and the errors associated with the mounting misalignment of the ASA with respect to the attachment points of the GFE-PGNCS navigation base. Most of these factors are specified in other control documents. A limit on AGS alignment input data from the CDU referred to the GFE-PGNCS navigation base attachment points for purposes of interface design is 2 milliradians plus 3 milliradians times the time in hours (3 σ) since the last IMU fine alignment.

3.1.5.1.3 <u>AGS Self Alignment</u>. - After landing and before shut-down of the GFE-PGNCS, the IMU outer gimbal angle shall be recorded by the crew for use by the AGS in the event of subsequent GFE-PGNCS failure.

3.1.5.1.4 <u>Propulsion Subsystem Thrust Vector Alignment Requirements</u>. - The location and angular alignment of the main engine and RCS thrust vectors with respect to the vehicle body axes (the body axes are an ideal set of axes assumed to be angularly aligned to the navigation base with zero error) shall meet the requirements set forth below.

3.1.5.1.4.1 <u>Descent Engine Thrust Vector Alignment</u>. - The descent engine thrust vector location (defined as the spatial position of the resultant reactive force of the rocket engine during operation) has the nominal coordinates in inches of (151.5, 0, 0) for the X, Y, and Z body axes respectively.

3.1.5.1.4.1 (Continued)

The error tolerance on these nominal coordinates shall not exceed 0.2 inches (3 σ). The angular alignment of the descent engine thrust vector shall meet the following requirements:

(a) Thrust vector alignment to the engine reference line shall be within 0.5 degrees (3 σ).

(b) At installation the gimbal deflection corrected engine reference line (This corrected reference line compensates for gimbal deflection at engine start thrust level) shall be aligned parallel to the body X-axis with an error not exceeding 0.3 degrees (3σ).

(c) At engine start thrust level gimbal deflection uncertainty shall not exceed 0.1 degrees (3 σ).

(d) Thrust vector angular deviation from the zero thrust positions (due to gimbal deflection) shall not exceed 0.75 degrees (3σ) when the engine is operating at a static thrust level of 10,500 pounds.

(e) Alignment error introduced by actuator inflight checkout shall not exceed 0.3 degrees (3 σ).

3.1.5.1.4.2 Ascent Engine Thrust Vector Alignment. - The ascent engine thrust vector location (defined as indicated in paragraph 3.1.5.1.4.1 for the decent engine) has the nominal coordinates in inches of (+234, 0, 0) for the X, Y and Z body axes respectively. The error tolerance on these nominal coordinates shall not exceed 0.2 inches (3 σ). The angular alignment of the ascent engine shall be such that the thrust vector will be aligned parallel to the vehicle x axis with an error not exceeding 1.0 degree (3 σ).

3.1.5.1.4.3 RCS Thrust Vector Alignment. - RCS thruster identification is contained in Figure 1. RCS thrust vector locations (defined as indicated in paragraph 3.1.5.1.4.1 for the descent engine) shall have the nominal coordinates in inches with respect to the X, Y and Z body axes given below.

3.1.5.1.4.3 (Continued)

The error tolerance on these nominal coordinates shall not exceed 0.3 inches (3 σ). The angular alignment of the respective RCS thrust vectors shall be such that they are aligned parallel to their corresponding vehicle axis with an error not exceeding 3.0 degrees (3 σ).

TABLE III

THRUST VECTOR COORDINATES (NOMINAL)

Quadrant	(u) Thrusters	(d) Thrusters	(f) Thrusters	(s) Thrusters
I	(+258.8, -66.1, +66.1)	(+248.7, -66.1, +66.1)	(+254.0, -61.5, +66.35)	(+254.0, -66.35, +61.5)
II	(+258.8, -66.1, -66.1)	(+248.7, -66.1, -66.1	(+254.0, -61.5, +66.35)	(+254.0, -66.35, -61.5)
III	(+258.8, +66.1, -66.1)	(+248.7, +66.1, -66.1)	(+254.0, +61.5, -66.35)	(+254.0, +66.35, -61.5)
IV	(+258.8, +66.1, +66.1)	(+248.7, +66.1, +66.1)	(+254.0, +61.5, +66.35)	(+254.0, +66.35, +61.5)

3.1.5.1.5 Landing Point Designator Alignment. - The mechanical alignment of the LPD reticle set shall define the orientation of a line of sight to the planned landing site in reference to the GFE-PGNCS Navigation Base with errors which do not exceed 1.0° in either axis.

3.1.5.2 Navigation Performance Requirement. - The GFE-PGNCS shall provide initialization of the AGS as specified below. AGS initialization data to be transferred is specified in ICD LIS-540-10001. The one sigma (1 σ) uncertainties given below are based on DRM. Upon command via the DSKY, the LGC shall perform transformations of the LEM and CSM state vectors to the LEM IMU alignment coordinate system defined in Figure 3 and provide these transformed state vectors to the LGC digital downlink to AGS. During AGS initialization, no interrupts shall occur to the state vectors or ID words and CDU zero shall be sent to AGS. The data for each AGS initialization shall be transmitted 10 times before returning to the normal downlink format.

3.1.5.2.1 Initialization for Descent Transfer Insertion. - DRM-I Time: 68 hours - 17 minutes - 04 seconds.

Landing Alignment:	δX_{SM} (ft)	δY_{SM} (ft)	δZ_{SM} (ft)	$\delta \dot{X}_{SM}$ (fps)	$\delta \dot{Y}_{SM}$ (fps)	$\delta \dot{Z}_{SM}$ (fps)	RMS Pos. (ft)	RMS Vel. (fps)
LEM/CSM	640	500	3850	2.6	0.9	0.5	3950	2.8

3.1.5.2.2 Initialization for Powered Descent. - DRM-I Time: 69 hours 17 minutes - 18 seconds.

Landing Alignment:	δX_{SM} (ft)	δY_{SM} (ft)	δZ_{SM} (ft)	$\delta \dot{X}_{SM}$ (fps)	$\delta \dot{Y}_{SM}$ (fps)	$\delta \dot{Z}_{SM}$ (fps)	RMS Pos. (ft)	RMS Vel. (fps)
LEM	870	470	3770	3.5	1.1	1.1	3900	3.8
CSM	740	450	2400	2.2	1.0	0.7	2550	2.5

3.1.5.2.3 Initialization for Powered Ascent. - DRM-I Time: 103 hours - 56 minutes - 48 seconds.

Launch Alignment:	δX_{SM} (ft)	δY_{SM} (ft)	δZ_{SM} (ft)	$\delta \dot{Y}_{SM}$ (fps)	$\delta \dot{Y}_{SM}$ (fps)	$\delta \dot{Z}_{SM}$ (fps)	RMS Pos. (ft)	RMS Vel. (fps)
LEM	1500	1600	3500	<0.1	<0.1	<0.1	4150	0.1
CSM	4000	1650	2650	2.0	2.2	3.1	5050	4.3

3.1.5.3 Guidance Performance Requirements and Constraints. -

3.1.5.3.1 Nominal Guidance Performance. - The GFE-PGNCS shall accomplish the nominal guidance functions within the ΔV budget limitations given in paragraph 3.1.5.3.4 with the following performance requirements and with the propulsion subsystems operating within their performance bounds (3σ) given herein, and with (3σ) radar input data stated in paragraph 3.1.5.5.

3.1.5.3.1.1 Lunar Landing Accuracy. - The GFE-PGNCS shall automatically guide the LEM to the design reference lunar surface within a one half nautical mile CEP of designated near equatorial locations, without landing

[redacted]

3.1.5.3.1.1 (Continued)

aids. When aided with the LPD to a range of 1500 feet in conjunction with a 12 foot diameter visible landing aid located at the landing site the CEP shall be 100 feet. The above guidance accuracy does not include lunar landmark mapping inaccuracy. The guidance shall be performed within the allocated descent ΔV budget.

3.1.5.3.1.2 Ascent and Rendezvous Accuracy. - The GFE-PGNCS shall provide ascent, midcourse, and rendezvous guidance to achieve conditions (a) and (b) below. This capability shall be provided from either direct ascent from the lunar surface or transfer from a parking orbit. The GFE-PGNCS shall have the capability to guide the vehicle to a lunar parking orbit.

(a) Maximum Miss Distance from CSM $\pm$ 500 ft (3σ)

(b) LEM Velocity relative to CSM at 500 ft range 0 - 10 ft/sec

3.1.5.3.2 Abort Guidance Requirements. - The GFE-PGNCS shall provide the guidance accuracy specified in section 3.1.5.3.1 when the LEM spacecraft and spacecraft propulsion subsystem operates within specification limits defined herein. Parking orbit for abort shall have a minimum clear pericynthion of 30,000 ft. The GFE-PGNCS shall be operationally ready for abort as follows:

(a) In-flight: Less than 0.5 seconds

(b) Lunar surface (GFE-PGNCS in standby)

(1) Coarse align to stored gimbal angles - 2 min.

(2) Fine align - 7 min. (5 minutes for crewman operation)

3.1.5.3.3 Landing Constraints. - For an Automatic Landing the terminal conditions at contact with the lunar surface shall be within the following limits:

Vertical velocity* - As in Figure below

Horizontal velocity** -

[redacted]

[redacted]

3.1.5.3.3 (Continued)

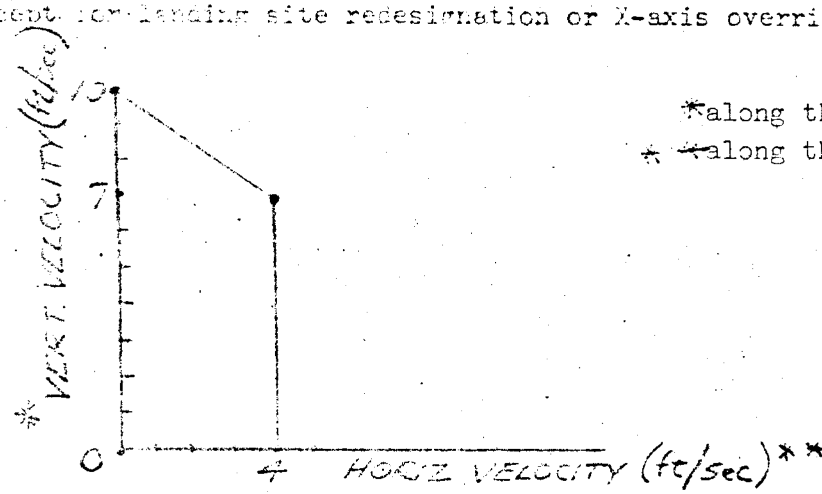
Pitch and Roll Attitude - 7° degrees deviation from vertical

Yaw Attitude - Random

Attitude rates about body axes - 3 deg/sec

NOTE: The above conditions will be achieved provided LR data is provided in accordance with 3.1.5.5.1.2

An automatic landing is defined as one in which the GFE-PGNCS controls the spacecraft to touchdown (no manual input commands except for landing site redesignation or X-axis override).



*along the local vertical
**along the local horizontal

3.1.5.3.4 **Δ V Budget.** - The GFE-PGNCS shall provide the guidance performance specified herein with the Δ V budget assigned for this purpose by the NASA-MSC in MSC Internal Note #65-FM-56.

3.1.5.3.5 Attitude Constraints. -

3.1.5.3.5.1 Visibility Constraints. - The GFE-PGNCS shall maintain a vehicle attitude during the final approach phase such that the crewman visual LOS to the landing site is within the commander's window at all times, prior to redesignation. Visibility may be restricted as a result of redesignation.

[redacted]

[redacted]

3.1.5.3.5.2 LEM Tracking Light Constraints. - The LEM tracking light shall be capable of radiating throughout a solid angle of 60° about a line parallel to the LEM +Z body axis. During coasting flight, for CSM tracking of the LEM, the LEM attitude shall be maintained such that the LEM-CSM LOS is within the above angle limits.

3.1.5.3.5.3 Communication Constraints. - Communication constraints shall be in accordance with ICD's LIS-380-10001 - Other (to be determined).

3.1.5.3.6 Propulsion Performance. -

3.1.5.3.6.1 Descent Propulsion Subsystem (DPS). - The Descent Propulsion Subsystem shall meet the following requirements.

3.1.5.3.6.1.1 Operational Life. - The DPS shall have a minimum operational life to meet the duty cycle shown in Figure 3.

3.1.5.3.6.1.2 Thrust Level Requirements. -

(a) Nominal Dynamic Range - The DPS thrust output shall be throttleable between 10 percent and 57.5 percent and shall have a fixed-throttle operating point corresponding to 95 percent thrust at the start of the duty cycle. The 100 percent reference thrust shall be defined as 10,500 pounds.

(b) Accuracy - Thrust accuracy when maximum thrust is commanded shall be as shown in Table IV, below. At the end of the mission duty cycle the Descent Propulsion Subsystem shall exhibit a maximum thrust output of the value determined after 5 seconds +10 percent, -1 percent.

[redacted]

[redacted]

3.1.5.3.6.1.2 (Continued)

(b) (Continued)

TABLE IV

THRUST ACCURACY

Parameter	Thrust Value	Thrust Tolerance
Engine thrust at start of duty cycle	92.5%	+3% -0%
DPS Thrust at start of duty cycle	Engine thrust at start of duty cycle	±1.5%
DPS Thrust after 410 seconds	DPS Thrust at start of duty cycle +5%	±1%

(c) Linearity - Linearity of thrust magnitude versus command signal shall be ± 5 percent over the entire throttling range. Linearity is defined as the thrust deviation from a linear thrust versus command signal curve that passes through the actual minimum and maximum thrust levels, divided by the thrust range, times 100. The actual input-output relationship must fall within this band. This requirement does not preclude the dynamic range requirements given above for the maximum thrust accuracy.

(d) Resolution - Thrust magnitude resolution shall be a maximum of 1 percent of total range of thrust or input signal. Resolution is defined as both:

(1) The smallest change in command signal which just produces a change in output thrust, divided by the total input voltage, multiplied by 100, and

(2) The maximum change in output thrust for an infinitesimal change in input command signal, divided by the total thrust range, multiplied by 100. The object here is to allow the automatic throttle closed-loop to command any desired thrust level within 1 percent.

[redacted]

[redacted]

3.1.5.3.6.1.2 (Continued)

(e) Step Response -

(1) The response time from maximum to minimum thrust and maximum to 50 percent thrust and vise versa shall not exceed 1.0 sec. and 0.5 respectively, in response to a step input signal as defined below. The response time is defined as the time required for the thrust transient to enter within ± 90 lbs. of the final thrust value.

(2) Engine thrust response to a step command of 1000 lbs. or less, as defined below shall be as follows:

overshoot < 50 lbs
time to reach and stay within ± 90 lbs. of the steady-state thrust level < 1.0 sec.

(3) A step input is defined as a linear ramp signal having a thrust change rate of 80,000 to 125,000 lb/sec.

3.1.5.3.6.1.3 On-Off Characteristics. - The descent engine is capable of a minimum of 20 starts under all conditions of LEM mission operation with engine life limited by the duty cycle given in paragraph 3.1.5.3.6.1.1. It will develop 90 percent of rated thrust within 0.30 seconds after receipt of an electrical ON signal command from LGC. The engine will accomplish thrust decay to 10 percent rated thrust within 0.40 seconds after receipt of the OFF signal command from LGC. The start and shut-down characteristics are repeatable to provide a predictable total impulse accuracy of ± 100 pound-seconds.

3.1.5.3.6.1.4 Specific Impulse. - The 3-sigma minimum specific impulse average value during the respective phases of the nominal mission duty cycle shall be:

Phase	ISP (sec)
(Fixed-Throttle Operating Point)	302.0
60%	303.2
50%	302.7
25%	300.3
10%	285.0

[redacted]

[redacted]

3.1.5.3.6.1.5 Gimbal Trim System Characteristics. -

Gimbal position	± 6° ± 5%
Gimbal Rate	0.2°/sec ± 10%
Steady-state rate reached	0.1 sec. after start
Overtravel	2.5%
Maximum frequency of operation	5.0 cps

3.1.5.3.6.2 Ascent Propulsion Subsystem (APS). - The APS shall meet the following requirements:

3.1.5.3.6.2.1 Operational Life. - The APS shall have a minimum life to meet the following duty cycle:

TABLE V

OPERATIONAL LIFE

Event	Operating Time (seconds)	Non-Operating Time
Acceptance	60	
Prelaunch		Up to 180 days
Spaceflight		Up to 180 hours
Powered Ascent	460	
Coast		5 min. to 9 hours
Transfer Orbit	5	
Insertion		
Post Firing		2 hours

[redacted]

3.1.5.3.6.2.2 Thrust Accuracy Requirements. - The nominal thrust level for the APS is 3500 pounds. The tolerance on this nominal level is ± 2.5 percent at the beginning of the mission duty cycle and + 7 to -2.5 percent at the end of the mission duty cycle.

3.1.5.3.6.2.3 Specific Impulse. - Ascent engine minimum specific impulse (3 σ) is 306.3 seconds.

3.1.5.3.6.2.4 On-Off Characteristics. - The ascent engine is capable of a minimum of 35 starts under all conditions of LEM mission operation with engine life limited by the duty cycle of paragraph 3.1.5.3.6.2.1. It will develop 90 percent of rated thrust within 0.45 seconds after receipt of the ON command signal from LGC. The engine will accomplish thrust decay to 10 percent rated thrust within 0.35 seconds after receipt of the OFF command signal from LGC. The engine start impulse shall be repeatable to within 35 pound-seconds. The engine shutdown impulse shall be repeatable to within 75 pound-seconds.

3.1.5.3.6.3 RCS Thrust Chamber Assemblies (TCA's). - The TCA's shall each meet the requirements set forth below:

3.1.5.3.6.3.1 Operating Life. - Each TCA shall have a minimum life of 1,000 seconds. The TCA is capable of 10,000 operational cycles during the 1,000 second operating life. The TCA is capable of continuous operation for a period of 500 seconds. The frequency of TCA operation shall not exceed 7.0 cycles per second.

3.1.5.3.6.3.2 Thrust Accuracy Requirements. - Each TCA shall be capable of developing a continuous operation vacuum thrust of 100 pounds ± 5 percent.

3.1.5.3.6.3.3 Specific Impulse. - When operating TCA's for periods in excess of one second, the specific impulse shall be 294 seconds nominal. Specific impulse for pulse mode operation shall be as shown in Figure 4.

3.1.5.3.6.3.4 On-Off Characteristics. - Each TCA shall demonstrate a thrust buildup and thrust decay as shown in Figure 5. Each TCA shall be capable of providing a minimum impulse of 0.4 ± 0.2 pound-seconds during vacuum operation with an electrical command signal (pulse width) of 12.5 milliseconds.

[redacted]

3.1.5.3.7 Spacecraft Display Requirements. - (TBD)

3.1.5.3.8 GFE-PGNCS Display Requirements. - Guidance and Navigation data both computed and measured shall be appropriately displayed during the various mission phases.

3.1.5.3.8.1 DSKY Display Requirements. - The DSKY shall display the following data:

(a) Status -

(1) Telemetry Activity

(2) No Attitude Reference

(3) Standby

(4) Key Release

(b) Caution -

(1) IMU Temperature Out-of-Limits

(2) Gimbal Lock

(3) Program Alarm

(4) Restart

(5) Tracker Alarm

(6) Operator Error

(c) Computer Activity

(d) Program

(e) Verb

(f) Noun

(g) Guidance and Navigation Data in 3 Five-Digit Registers

3.1.5.3.8.2 AOT Display Requirements. - The AOT will display the detent position and reticle rotation angle. The detent position display is located on the knob which controls the positioning of the AOT. The reticle angle readout is on a micrometer type knob which controls the rotation of the reticle. This information shall be displayed to an accuracy of 0.01 degrees.

3.1.5.4 Stabilization and Control Performance Requirements and Constraints. -

3.1.5.4.1 GFE-PGNCS Control Performance Requirements. - The GFE-PGNCS control performance requirements, including handling qualities, shall be as specified in ICD LIS-540-10001.

3.1.5.4.2 RCS Propellant Allocation for GFE-PGNCS Control Tasks. - The performance of the GFE-PGNCS in conjunction with its related LEM systems for the DRM shall be such that the RCS propellant consumption does not exceed the amount available for GFE-PGNCS functions. The GFE-PGNCS shall have the capability to perform the guidance and control tasks described below within the RCS propellant allotment listed. The performance of the RCS subsystem is specified in paragraphs 3.1.5.1.4.3 and 3.1.5.3.6.3. The spacecraft mass properties are specified in paragraph 3.1.5.6.

3.1.5.4.2.1 Orbit Insertion Control. - Insertion into the required coasting descent transfer orbit that will cause the LEM to arrive at a predetermined pericynthion altitude and lunar central angle from the preselected lunar landing site. The propellant allotment includes provision for RCS control during the descent engine start transient assuming an initial vehicle angular alignment error to the nominal insertion attitude of 10 degrees.

RCS Propellant Consumption: 8 lbs.

3.1.5.4.2.2 Powered Descent Control. - Powered descent maneuver from onset of braking phase to desired hover point, excluding pitch to vertical attitude at hover, within required mission constraints of the DRM. The propellant allotment includes provision for RCS control during the descent engine start transient.

RCS Propellant Consumption: 22 lbs.

3.1.5.4.2.3 Powered Ascent Control. - Powered ascent guidance with the ΔV budget constraints to achieve (1) burnout conditions resulting in a LEM trajectory that nominally intercepts the CSM at the predetermined aimpoint and (2) burnout conditions resulting in a parking orbit with a specified clear pericynthion altitutude.

RCS Propellant Consumption: 150 lbs.

Elasped Time in this Phase: 440 seconds

[redacted]

3.1.5.4.2.4 Rendezvous Control. - Translate the vehicle using the RCS thrusters to meet the required terminal conditions and maintain attitude control about all axes within the tight RCS deadband.

RCS Propellant Consumption Rate (Average) 0.7 lbs/ft/sec. for each axis.

3.1.5.5 Radar Performance Requirements and Constraints. -

3.1.5.5.1 Landing Radar. - The operating limits and associated performance listed in this specification for the LR represent the specifications to which this radar is designed. The radar performance to be used in PGNCS mission analysis and LGC program verification will be based on a radar mathematical model, supplied by Grumman subject to NASA MSC approval. Grumman will submit the mathematical model through the GN and C data exchange program and update it quarterly.

3.1.5.5.1.1 Operating Limits. - Unless otherwise specified all limits are with respect to DRM.

3.1.5.5.1.1.1 Altitude Limits. -

Maximum: 25,000 ft.

Minimum: 10 ft. for altitude data, 5 ft. for velocity data

NOTES: (1) Altitude refers to distance from the antenna along the local vertical. The LR measures altitude directly only when the range beam is vertical.

(2) The above altitude limits are based on the reflection coefficients tabulated below from the reflectivity model and excludes errors caused by plume effects.

Angle from normal:	Reflection in db:
0°	-14.0
10°	-16.9
20°	-20.6
30°	-22.9
40°	-24.7
50°	-26.6
60°	-28.5

[redacted]

[redacted]

3.1.5.5.1.1.2 Velocity Limits. - The three orthogonal velocity components provided to the LGC are denoted by V_{xa}, V_{ya}, and V_{za}.

V_{xa}: -2000, + 500 fps
V_{ya}: ± 500 fps
V_{za}: +3000, -500 fps
(plus sign indicates upward or forward velocities)

Refer to Section 3.1.5.5.1.2.2.1.

3.1.5.5.1.1.3 Linear Acceleration Limits. - The LR performance for the three LEM attitude control modes is listed in the following subparagraphs with respect to vehicle linear acceleration. These linear acceleration limits are considered singly in combination with the operating limits of 3.1.5.5.1.1.1 thru 3.1.5.5.1.1.2.

(a) LGC Automatic Control Mode - The linear acceleration levels of the LEM powered landing maneuver below an altitude of 25,000 feet shall not degrade the LR performance accuracy beyond that listed in 3.1.5.5.1.2.3. This assumes that effective smoothing time compensation is performed in the LGC, as defined in paragraph 3.1.5.5.1.2.3, note 5.

(b) Semi-Automatic and Manual Control Modes. - In these modes during the final approach or landing phase, a LR velocity measurement lag error not exceeding 0.04α fps, where α = linear acceleration per beam in fps2, will result from linear accelerations. The beam errors shall be resolved into errors along the LR coordinate axes and shall be combined with the accuracy numbers specified in 3.1.5.5.1.2.3. The range lag error linear acceleration shall be:

$$\epsilon_R = 0.04 \frac{dr}{dt}$$

Where R is range and t is time, the maximum linear acceleration in the manual mode during the final approach or landing phase shall not exceed 15 fps^2.

3.1.5.5.1.1.4 Altitude Limits. - The LR performance for the three LEM attitude control modes is listed in the following subparagraphs with respect to vehicle attitude limits which are considered singly in combination with the operating limits of 3.1.5.5.1.1.1 and 3.1.5.5.1.1.2.

[redacted]

3.1.5.5.1.1.4 (Continued)

(a) LGC Automatic Control Mode - Variations about the nominal DRM attitude result in LR velocity and range performance as summarized in Table X1X.

(b) Semi-Automatic and Manual Control Modes - Tables X thru XV111. (for pitch, yaw and roll) define the performance capability for off-nominal attitude conditions, for semiautomatic and manual control modes, phases I, II and III of the DRM.

3.1.5.5.1.1.5 Angular Rates. - The LR performance for the three LEM attitude control modes is specified in the following subparagraphs with respect to vehicle angular rates which are considered singly, one axis at a time, in combination with the operating limits of 3.1.5.5.1.1.1 and 3.1.5.5.1.1.2.

(a) LGC Automatic Control Mode - The angular rates of the DRM powered landing maneuver below an altitude of 25,000 feet shall not degrade the LR performance accuracy beyond that specified in 3.1.5.5.1.2.3; this assumes that effective smoothing time compensation is performed in the LGC, as defined in 3.1.5.5.1.2.3, note 5.

(b) Semi-Automatic and Manual Control Modes - The angular rates associated with normal landing site redesignations during the final approach of the DRM descent shall not exceed 10 degrees/ sec. In the manual mode during final approach or landing phases, the commanded angular rates shall not exceed 20 degrees/ sec. The error due to angular velocity shall not exceed ϵ_V ft. along each velocity beam and ϵ_R ft along the altimeter beam where: sec.

$$\epsilon_V = \tau \alpha_B$$

$$\epsilon_R = \tau R \frac{d\theta}{dt} \tan\theta$$

τ = [illegible] seconds for Phases II and III of DRM.

$$\alpha_B = \frac{d\gamma}{dt} \sin\gamma \, |V_t|$$

$|V_T|$ = magnitude total vector velocity

γ = angle between vector velocity and the individual beam (The error is calculated in radians)

θ = angle between local verticle and the individual beam (The error is calculated in radians)

R = Range along altitude beam feet

[redacted]

[redacted]

3.1.5.5.1.1.5 (Continued)

(b) (Continued)

The beam lag errors must be resolved into errors along the LR coordinate axes and shall be combined with the accuracy numbers specified in 3.1.5.5.1.2.3.

3.1.5.5.1.1.6 Angular Acceleration per Vehicle Axis. - Angular acceleration per vehicle axis shall be in accordance with the following:

$\pm 6^\circ/sec^2$ max for altitude $>$ 1000 ft.

$\pm 12^\circ/sec^2$ max for altitude $<$ 1000 ft.

NOTE: Angular acceleration may occur about each LEM vehicle axis independently.

3.1.5.5.1.2 LR Performance Requirements. -

3.1.5.5.1.2.1 Antenna Positions. - (See Figure 6)

Position 1: Antenna Angle:

The angle between the LEM minus X axis and Antenna Velocity Group Beam Center is approximately 51°.

Position 2: Antenna Angle:

The angle between the LEM minus X axis and the Antenna Velocity Group Beam Center is approximately 21°.

NOTES: (1) The angle between the LR Range Beam and the Antenna Velocity Group Beam Center and the LR Range Beam is approximately 21°.

(2) These angles will be accurately specified as constants of Table VII.

(3) Maximum Switching Time between Position 1 and Position 2: 7 sec.

3.1.5.5.1.2.2 LR Data Transfer to the GFE-PGNCS. - The LR data is presented to the GFE-PGNCS LGC in a form which is described in the following sections. (See Figure 7)

[redacted]

[redacted]

3.1.5.5.1.2.2.1 Velocity Measurement Data Format. -

(a) The velocity data furnished at the GFE-PGNCS LGC interface by the LR comprises three digital numbers representing the following frequencies.

$S_{xa} = (f_1 + f_3) + F_B$, corresponding to a velocity component along antenna axis X_A

$S_{ya} = (f_1 - f_2) + F_B$, corresponding to a velocity component along antenna axis Y_A

$S_{za} = (f_3 - f_2) + F_B$, corresponding to a velocity component along antenna axis Z_A

Where f_1, f_2, f_3 are beam doppler frequencies, F_B is a bias frequency, and counting time is determined by the LGC.

(b) Within the LGC, a digital number corresponding to the numerical value of F_B is subtracted from each of the LR interface signals, and the velocity along each antenna coordinate axis is computed by the following multiplication:

$V_{xa} = -K_X \ (f_1 + f_3)$

$V_{ya} = K_Y \ (f_1 - f_2)$

$V_{za} = K_Z \ (f_3 - f_2)$

Where K_X, K_Y, K_Z are positive, constant scale factors.

(c) Within the LGC, the velocity information is then resolved into components of the NAVBASE orthogonal coordinate system. The transformation requires knowledge of the angles between orthogonal LR antenna and NAVBASE coordinate systems represented by the 3 Euler angles defined in Figure 8. These angles are represented in a positive right-hand system in the order illustrated. The NAVBASE coordinate system is defined in GAEC-MIT ICD-LID-280-10004 and is shown in simplified form in Figure 9. The LR shall furnish the above V_{xa}, V_{ya}, and V_{za} data in the form of 15 bit digital words S_{xa}, S_{ya}, and S_{za} to the LGC.

[redacted]

3.1.5.5.1.2.2.2 Range Measurement Data Format. -

(a) The range along the range beam R is represented by the following equation.

$R = k\ r$

Where k is the bit weight and r is the range count

3.1.5.5.1.2.3 LR Accuracy Requirements. -

Range: 1.5% + 15 feet (3σ) 25,000 ft. to 2000 ft. altitude
1.5% + 5 feet (3σ) 2000 ft to 10 ft altitude

Velocity: The Table below is based on the DRM #1

TABLE VI

LR Accuracy Requirements

Velocity Component	Altitude Range		
	25K to 2K ft	2K to 200 ft.	200 to 5 ft.
	Antenna Position #1	Antenna Position #1	Antenna Position #2
	Accuracy (3σ)		
Vxa	1.5% or 1.5 ft/sec	1.5% or 1.5 ft/sec	1.5% or 1.5 ft/sec
Vya	2% or 2 ft/sec	3.5% or 3.5 ft/sec	2% or 1.5 ft/sec
Vza	2% or 2 ft/sec	3% or 3 ft/sec	2% or 1.5 ft/sec

NOTES: 1. Accuracy is defined as the greater of the two specified values.

2. The accuracy of the range data is based on a 0.2 sec. counting time.

3. The accuracy of the velocity data is based upon the following assumptions:

[redacted]

[redacted]

NOTE 3: (Continued)

(a) Smoothing consists of a tracker time-constant of the appropriate one of the following plus a total uninterrupted accumulated time of 0.4 sec. or its equivalent in the counter.

(1) 0.25 sec. max. between altitudes of 25K ft. and 2.5K ft.
(2) 0.15 sec. max. between altitudes of 2.5K ft. and 1.0K ft.
(3) 0.10 sec. max. below 1.0K ft.

(b) The accuracy is expressed as a percent of the vehicle total vector velocity and is a 3 sigma accuracy referred to the antenna axes which are specified with respect to the navigation base by the Euler angles of Table VII and shown in Figure 8.

4. Quantization errors are included in LR accuracy.

5. Accuracy applies to the digital word in the LGC register immediately following the end of a 0.4 second accumulation interval, when the word is compared to the actual velocity at a prior time, equal to one half the counting interval (0.2 sec.) plus 0.08 seconds for the velocity measurements, and one half the counting interval plus 0.1 second for range measurement.

3.1.5.5.1.2.4 LR Range Low Scale Factor Discrete. - The LR Low Scale Factor Discrete is issued at approximately 2500 feet range when the limits of the FM sweep in the LR are changed. Approximately one second delay is required after the change to allow the LR counter to stabilize. Switch over hysteresis shall be a minimum of 300 feet.

3.1.5.5.1.2.5 LR Data Good Discretes. - The Data Good discrete signals for altitude and velocity data from the LR are an indication to the LGC that the range and three velocity frequency trackers are locked on to a signal.

3.1.5.5.1.2.6 Acquisition Performance. -

(a) Acquisition Definition - Acquisition is defined as the condition in which all the velocity trackers and the range tracker have locked on to a signal and have commenced tracking.

[redacted]

3.1.5.5.1.2.6 (Continued)

(b) Acquisition Probability - Within the altitude interval of 25,000 ft. to 15,000 ft. and for the other operating limits specified in 3.1.5.5.1.1, the LR shall have an acquisition probability of at least 0.75 in any 12 second interval. At altitudes below 15,000 ft. and for the other operating limits of 3.1.5.5.1.1, the LR acquisition probability in any 12 second interval shall be at least 0.99.

These acquisition probabilities shall apply both to initial acquisition and to re-acquisition after loss of track.

3.1.5.5.1.2.7 False Alarm Rate. - A false alarm is defined as the acquisition by any of the LR tracking loops of a spurious signal which causes an interruption in the loop signal search of more than 1 second.

Within the limits specified in 3.1.5.5.1, the LR mean false alarm interval shall not be less than 20 minutes.

3.1.5.5.2 RR Performance Requirements and Constraints. -

3.1.5.5.2.1 Operating Limits. - The RR is required to measure and furnish data to the GFE-PGNCS within the operating limits listed below:

3.1.5.5.2.1.1 Range Limits. -

Max: 400 nm

Min: 500 ft

3.1.5.5.2.1.2 Range Rate Limits. -

Max: ± 4900 fps (closing or opening)

[redacted]

TABLE VII

GFE-PGNCS Required Data Processing Constants for LR Operation

No.		
1	F_B	Velocity Bias Frequency
2	K_X	Scale Factor to convert the doppler frequency sum $(f_1 + f_3)$ to velocity along LR antenna coordinate X_A
3	K_Y	Scale Factor to convert the doppler frequency difference $(f_1 - f_2)$ to velocity along LR antenna coordinate Y_A
4	K_Z	Scale Factor to convert the doppler frequency difference $(f_3 - f_2)$ to velocity along LR antenna coordinate Z_A
5	α_1	Respective Euler angles between the LR antenna coordinate system in Position 1 and the NAVBASE (Fig. 6)
6	β_1	
7	γ_1	
8	α_2	Respective Euler angles between the LR antenna coordinate system in Position 2 and the NAVBASE (Fig. 6)
9	β_2	
10	γ_2	
11	k_{r1}	Bit weight for long range scale: 2.158 ft/bit
12	k_{r2}	Bit weight for short range scale: 0.4318 ft/bit
13	ξ	Angles of range beam with respect to the LR antenna velocity group beam center line
14	ζ	

NOTES: (1) Final determination of these constants depends on MSC definition of flight trajectory and analysis of LR design verifications and flight test results.

(2) Items (11) and (12) refer to a counting interval of 0.2 seconds.

[redacted]

3.1.5.5.2.1.3 Range Acceleration Limits. -

Max: (a) 50 ft/sec^2 over range interval 500 ft. to 100 nm.

(b) $50\sqrt{\frac{100}{R}}$ ft/sec^2 over range interval R = 100 to 400 nm. where R is range in nautical miles

Min: 0 ft/sec^2

3.1.5.5.2.1.4 Inertial LOS Angular Velocity Limits. -

Max: 12 mr/sec (.687°/sec)

NOTE: (1) The above angular velocity limits refer to the total angular velocity of the LOS with respect to inertial space.

3.1.5.5.2.1.5 Vehicle Angular Velocity Limits. -

Max: 10°/sec per axis

NOTES: (1) The above limits refer to angular rates with respect to inertial space about the vehicle axes during LEM automatic LOS control modes.

(2) The maximum limit applies simultaneously about each axis.

3.1.5.5.2.1.6 Vehicle Impulsive Angular Acceleration Limits. -

Max: ± 0.75 radian/sec^2

NOTES: (1) The maximum limit refers to angular accelerations about each vehicle axis with respect to inertial space during LEM automatic LOS control modes.

(2) Angular accelerations may occur about vehicle axes simultaneously.

(3) Maximum angular accelerations occur during ascent coast.

(4) Total impulse per firing of 8.25 foot-pounds-seconds.

[redacted]

3.1.5.5.2.1.7 Angle Coverage Requirements. -

3.1.5.5.2.1.7.1 Antenna Reference Definitions. - The general configuration of the RR antenna assembly is illustrated in Figures 10 and 11. The notes below relate to this figure and define an antenna axis orientation, rotation conventions, and zero references:

(a) The antenna shaft axis is the outer gimbal axis and is nominally parallel to the LEM Y axis.

(b) The antenna trunnion axis is the inner gimbal axis and is orthogonal to the shaft axis.

(c) The electrical LOS is perpendicular to the trunnion axis.

(d) The zero shaft and trunnion axis angles place the electrical LOS parallel to the LEM +Z axis.

(e) Positive shaft rotation is clockwise motion of the antenna as viewed along the LEM +Y axis.

(f) Positive trunnion rotation is clockwise motion of the antenna with respect to the antenna reference coordinate system as viewed along the LEM +X axis when shaft angle =0°.

3.1.5.5.2.1.7.1 Angle Coverage Limits. - The RR antenna angle coverage requirements with respect to the LEM are illustrated in Figures 10 and 12. The required shaft axis coverage totals 225 degrees positioned with respect to the vehicle +Z axis shown. Throughout this shaft angle range, the radar must provide angle measurements to the full accuracies for trunnion LOS angles up to ± 55° with respect to the LEM X, Z plane. The current RR antenna design provides the specified angle coverage in two overlapping angle sector modes of operation as noted below.

[redacted]

3.1.5.5.2.1.7.1 (Continued)

Electrical Tracking Limits	LOS Angle		Resolver Angle	
Shaft Angle-Mode I	+60°	-70°	+60°	-70°
Shaft Angle-Mode II	+155°	+40°	-25°	-140°
Trunnion Angle-Mode I	+55°	-55°	+55°	-55°
Trunnion Angle-Mode II	+55°	-55°	+125°	-125°

Mechanical Gimbal Limits	LOS Angle (Limit Stop)	Resolver Angle (Limit Stop)
Shaft Angle-Mode I	+60°	+60°
Shaft Angle-Mode II	+40°	-140°
Trunnion Angle-Mode I	+70°	+70°
Trunnion Angle-Mode II	+70°	+110°

3.1.5.5.2.2 Bias Error Definition. - Bias error is the mean value of the error between the true value of the parameter and the indicated value within any 10 minute interval.

3.1.5.5.2.3 Random Error Definition. - Random Error is the variation about the mean of measured parameter taken in a 10 minute averaging interval for determining the mean.

3.1.5.5.2.4 Range Measurement Accuracy. - The required GFE-PGNCS range measurement accuracy from the RR/T over the operating limits specified in 3.1.5.5.2.1 is as follows:

[redacted]

[redacted]

3.1.5.5.2.4 (Continued)

Random uncertainty (3σ) = 1% or 80 feet whichever is greater

Maximum Bias = 500 ft. for ranges >50.8 nm

= 80 ft for ranges < 50.8 nm

NOTES: (1) The bias and random error definitions specified in 3.1.5.5.2.2 and 3.1.5.5.2.3 respectively apply.

(2) Measurement accuracy refers to the accuracy of the digital indication of true instantaneous range along the LOS by the digital word in the radar high speed counter at a point in time immediately following parallel transfer of data from data reversible counter to the radar high speed counter.

3.1.5.5.2.5 Range Rate Measurement Accuracy. - The required GFE-PGNCS range rate measurement accuracy from the RR over the operating limits specified in 3.1.5.5.2.1 is as follows:

Random uncertainty (3σ) = 1.3% or 1.3 fps whichever is greater

Bias Error: = 1 fps max.

NOTES: (1) The bias and random error definitions specified in 3.1.5.5.2.2 and 3.1.5.5.2.3 respectively apply.

(2) Velocity measured by the RR is represented by a number in the RR counter. Measurement accuracy refers to that portion of the number remaining when the number 17,000 is subtracted, and is referenced to a time midway in the 0.08 second counting interval.

(3) The random uncertainity specification includes quantization uncertainties in the RR.

[redacted]

[redacted]

3.1.5.5.2.6 Angle Measurement Requirements. - Angle measurement requirements shall be in accordance with the following table.

TABLE VIII

RR ANGULAR MEASUREMENT ACCURACIES REFERRED TO GFE-PGNCS

Range (NMI)	Angular Error Random mr (3 σ)	Angular Error Bias mr		Allowable Random Error Variation
400	5 (.286°)	15 (.86°)		
			....	Directly with Range
300	4 (.229°)	15 (.86°)		
			....	Directly with Range
200	3 (.172°)	15 (.86°)		
			....	Constant
5	3 (.172°)	15 (.86°)		
			....	Inversely with Range
2	6 (.344°)	15 (.86°)		
			....	Inversely with Range
1	11 (.630°)	15 (.86°)		
			....	Constant
80 feet	11 (.630°)	15 (.86°)		

NOTES: (1) The angle errors indicated are the difference between the true LOS with respect to the NAVBASE reference, and the LOS indicated by the RR gimbal resolver signals when referred to the NAVBASE coordinate system.

(2) The indicated accuracies must prevail for operating limits specified in 3.1.5.5.2.1 with the exception that vehicle Angular Velocity Limits are ± 1.0°/second maximum per axis and maximum durations of angular acceleration is less than 15 milliseconds in a 5 second interval.

(3) The angle bias error between the true LOS and the RR indicated LOS with respect to the NAVBASE reference shall not exceed 15 mr (.86°). Maximum variation in RR angle bias shall not exceed (0.5 mr) (.029°) in any 10 minute time period.

(4) During tracking of the CSM by the RR on the Lunar Surface, the 3 mr (.172°) figure is applied when tracking at angles greater than 25° from lunar horizon.

[redacted]

[redacted]

3.1.5.5.2.7 Gimbal Servo Performance. -

(a) The acceleration capability of the gimbal servos shall enable the inertial LOS angular rate to attain 90% of commanded rate within 0.2 seconds.

(b) Upon removal of an LGC rate command of no more than 6.0°/sec., the inertial LOS angle of the RR antenna shall not overshoot angular position in excess of 1.0 degree.

(c) When there is no command to drive the RR gimbals and the GFE-PGNCS CDU output noise is below 5 mv RMS, then the inertial rate of the antenna shall be less than 8.0 degrees per minute.

(d) Gimbal Slew rates are specified in LIS-370-10006.

3.1.5.5.2.8 Angle Interface. - The angle interface is specified in LIS-370-10006.

3.1.5.5.2.9 Range and Range-Rate Scale Factors. - Two range scales will be used to cover the required operating range specified in 3.1.5.5.2.1. The scale change occurs at 50.8 nm and the quantization bit sizes for the high and low range scales are 75.04 and 9.38 feet respectively. The range scale change from high to low shall be indicated by the RR to the LGC by a "Range Low Scale Factor" discrete signal, which is issued when the range counter is rescaled.

The quantization bit size for range rate shall bee 0.6278 ft./sec. per bit for a counting interval of 80.0 milliseconds.

3.1.5.5.2.10 Acquisition Performance. -

3.1.5.5.2.10.1 Acquisition Definition. - RR/T acquisition is defined as the condition in which the velocity trackers have commenced tracking a signal, the antenna gimbal servos are commanded by the angle error signals derived from the antenna microwave measurements (radar auto-track), and the range trackers have locked on signal and have commenced tracking. Acquisition probabilities specified subsequently shall apply both to the initial acquisition and to reacquisition after loss of track.

[redacted]

[redacted]

3.1.5.5.2.10.2 Acquisition Probability. - Provided the RR electrical boresight is held within 2° of the true LOS to the transponder and the Auto Angle Track Enable discrete signal has been issued, the RR/T acquisition probability in any 12 second interval shall not be less than .85 within th"e operating limits defined in 3.1.5.5.2.1.

3.1.5.5.2.10.3 False Alarm Rate. - A false alarm is defined as the acquisition by any of the RR tracking loops of a spurious signal from any source whatsoever, except interfering signals from other radars or similar sources of radiation, which is accompanied by internal switching of the gimbal servos to radar self-track.

Within the operating limits specified in 3.1.5.5.2.1, the RR mean false alarm interval shall not be less than 20 minutes.

3.1.5.5.2.11 Data Good Discrete Signal (Ref. LIS 540-10001). - The "Data Good" discrete signal from the RR is an indication to the LGC that the velocity and range trackers are locked on to a signal. Accurate angle data is available 2.5 seconds following presence of data good signal from the RR or Auto Track Enable from the GFE-PGNCS LGC, whichever is later.

3.1.5.5.2.12 RR Usage. -

3.1.5.5.2.12.1 Usage Time. - The RR shall be capable of operation to the specifications specified in 3.1.5.5.2.1 and 3.1.5.5.2.2 and within the crew safety and reliability requirements established by MSC for both intermittent and cumulative time intervals needed to complete the mission, including thee possibility of the severest LEM abort situation. (See Figure 13 for present usage profile).

Under certain sample trajectories currently being used by MIT in GFE-PGNCS analysis, LEM abort conditions may develop which require usage of the RR, in addition to normal descent tracking, of the types described below:

(a) Continuous or near-continuous tracking of the CSM by the LEM RR for periods of 45 to 60 minutes for LEM trajectory determination after abort injection.

[redacted]

3.1.5.5.2.12.1 (Continued)

(b) Continuous or near-continuous tracking for periods of 60 to 80 minutes during phasing angle monitoring and subsequent midcourse corrections and rendezvous.

(c) Total abort tracking time as much as $2\frac{1}{2}$ hours.

(d) Time lapse of up to 9 hours between the activity of Item (a) and that of Item (b).

3.1.5.6 Spacecraft Mass Properties. - The spacecraft shall be designed to provide the capability for a lunar orbit separation weight of 32,500 pounds based on a maximum translunar injection weight of 32,000 pounds. The ascent stage shall be designed for a launch weight of 10,820 pounds. Spacecraft moment of inertia versus weight is set forth in Figures 14 and 15 for descent and ascent respectively. Spacecraft X axis center of gravity is given in Figures 16 and 17 for descent and ascent respectively. The radial envelope of the center of gravity in the spacecraft Y - Z plane is given in Figure 18 for descent and Figure 19 for ascent. The spacecraft weight history is given in Table IX.

3.1.5.7 LOTS Performance Constraints. - (TBD)

3.1.6 Operability. -

3.1.6.1 Reliability. - The mission success reliability apportionment for the GFE-PGNCS shall not be less than .9969 from earth launch till hard dock with the CSM after lunar stay period, in accordance with NASA DRM.

3.1.6.2 Maintainability. -

3.1.6.2.1 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 GFE-PGNCS subsystem.

[redacted]

TABLE IX

SPACECRAFT WEIGHT HISTORY

	WEIGHT (EARTH LBS.)
TRANSLUNAR INJECTION	32000
LEM/CSM SEPARATION	32500
END INSERTION TO HOHMANN - DESCENT	32112
BEGIN HOVER	16947
- MINIMUM	14650
LUNAR TOUCHDOWN - NOMINAL	15021
- MAXIMUM	16200
LUNAR LAUNCH	10820
END INSERTION TO HOHMANN	5516
BURNOUT (DOCKING)	5322
COMPLETION OF CREW TRANSFER	4695

NOTE: WEIGHTS SHOWN ARE WITHIN ± 5%

[redacted]

[redacted]

3.1.6.2.2 Maintenance Concept. - Field maintenance of the GFE-PGNCS 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 removeable from the LEM 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 GFE-PGNCS subsystem.

3.1.6.3 Useful Life. -

3.1.6.3.1 Service Life. - The LEM GFE-PGNCS shall be capable of meeting the requirements of this specification for a minimum of 2000 system operating hours including the test time logged during all subsystem operations.

3.1.6.3.2 Storage Life. - Non-operating shelf-life of the GFE-PGNCS shall be a minimum of 36 months. Total useful life of the GFE-PGNCS from the time of delivery to the procuring agency shall be a minimum of 5 years with routine maintenance and servicing.

3.1.6.4 Natural Environment. - N/A

3.1.6.5 Ground Handling and Transportability. - Full design recognition shall be given to the durability requirements of the GFE-PGNCS 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.

[redacted]

[redacted]

3.1.6.6 Human Performance. -

3.1.6.6.1 Flight Crew. - The flight crew for the LEM shall consist of two men.

3.1.6.6.2 Crew Participation. - The flight crew shall have the capability to control the LEM through all flight modes. The flight crew shall participate in navigation, control, monitoring, and observation of the GFE-PGNCS as required. Status of the subsystem shall be displayed for crew monitoring, failure detection, and GFE-PGNCS guidance mode selection.

3.1.6.6.3 Abort Initiation. - Provision shall be made for crew initiation of all abort modes.

3.1.6.7 Safety. -

3.1.6.7.1 Hazard Proofing. - The design of the GFE-PGNCS subsystem and support equipment shall minimize the hazard of fire, explosion and toxicity to the crew, launch area personnel and facilities.

3.1.6.7.2 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.

3.1.6.7.3 Fail Safe. - Subsystem or component failure shall not propagate sequentially, that is, design shall be "fail safe".

3.1.6.8 Induced Environments. -

3.1.6.8.1 Exterior Mounted Equipment. - The required operation of the GFE-PGNCS mounted exterior to the crew cabin (IMU, PTA, AOT) shall not be adversely affected by short exposure (up to two weeks) to the following environmental conditions:

(a) Solar radiation at 360 BTU/ft^2/hr. for 6 hours per day.

[redacted]

3.1.6.8.1 (Continued)

(b) Rain up to 0.6 inches/hr. for 12 hours (not directly exposed).

(c) Humidity 95 ± 5% relative humidity, including possible condensation of water vapor on equipment.

(d) Sand and Dust as encountered in ocean-beach areas, equivalent to 140 mesh silica flour with particle velocity up to 500 feet per minute.

(e) Fungus as experienced in tropical climates. The use of non-nutrient materials is recommended wherever possible; where materials which are nutrients for fungi are used, such materials shall be treated with an approved fungicidal agent (Ref. Spec. MIL-E-4158C).

(f) Salt Spray atmosphere as encountered in coastal areas.

(g) Ozone exposure to 0.05 parts per million concentration.

3.1.6.8.2 Installed Ground Transportation. - The GFE-PGNCS shall be capable of withstanding without damage detrimental to operating requirements the environmental conditions, shock, vibration and acceleration levels experienced during installed ground transportation, as defined by ICD's LIS-510-10001 and LIS-520-10001.

3.1.6.8.3 Preflight. - The GFE-PGNCS shall be capable of withstanding without damage detrimental to the required operation, the environmental conditions, shock, vibration and acceleration levels experienced during preflight-checkout operations as defined in ICD's LIS-510-10001 and LIS-520-10001.

3.1.6.8.4 Flight. - The GFE-PGNCS shall be capable of operating within requirements when subjected to the induced flight environments specified in ICD's LIS-520-10001 and LIS-510-10001.

3.2 Interface Requirements. - The GFE-PGNCS spacecraft and spacecraft subsystem interfaces shall be as defined in the ICD's listed in the appendix.

3.3 Design and Construction. -

3.3.1 GFE-PGNCS Definition. - The GFE-PGNCS shall be an aided inertial subsystem utilizing CSM ephemeris data and MSFN tracking data transmitted by voice link, radar and optical sensor data to provide vehicle guidance, navigation, control, and status reporting. The subsystem shall have the capability for fully automatic and manual operations consistent with mission phase requirements. The GFE-PGNCS shall consist of the following assemblies:

(a) Inertial Measurement Unit (IMU)

(b) Power and Servo Assembly

(c) Pulse Torquing Assembly (PTA)

(d) Alignment Optical Telescope (AOT)

(e) Coupling Data Units (CDU)

(f) LEM Guidance Computer (LGC)

(g) Display and Keyboard (DSKY)

(h) Cable Harness Assembly A

(i) Cable Harness Assembly B

(j) AOT Control Unit

(k) Navigation Base (NVB)

(l) Signal Conditioning Assembly (SCA)

(m) LEM Optical Tracker Subsystem (LOTS)

The assemblies shall be arranged in accordance with the installation ICD's (LID-340-10000, LID-340-10010, LID-280-10004) and shall not protrude beyond the limiting envelope dimensions shown thereon.

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 Inertial Measurement Unit (IMU). - The IMU shall sense vehicle attitude and acceleration. The IMU shall consist of three single-degree-of-freedom gyros (IRIG) and three single-degree-of-freedom accelerometers (PIPA's) on a stable member isolated from vehicle orientation by a servo-driven three-degree-of-freedom gimbal system. The IMU shall be mounted on the navigation base.

3.3.1.1.2 Power and Servo Assembly (PSA). - The PSA shall consist of the electronic equipment that provides most of the support electronics, power supplies, IMU servos, and IMU temperature control. The PSA shall be made up of modules which plug into the PSA header assembly.

3.3.1.1.3 Pulse Torquing Assembly (PTA). - This assembly contains all the pulse torquing electronics for both the gyros and accelerometers.

3.3.1.1.4 Alignment Optical Telescope (AOT). - The AOT shall consist of a unity power telescope with a reticle graduated in such a manner that star position angles may be measured and manually read out. The AOT shall be mounted on the navigation base. A seal shall allow for relative motion between the AOT and LEM.

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

IMU gimbal angles (3)

Radar antenna angles (2) or LOTS gimbal angles (2)

3.3.1.1.5 (Continued)

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

IMU align (3)

Attitude errors (3)

RR gimbal servo drive (2) or LOTS servo drive (2)

Forward and lateral velocity (2)

3.3.1.1.6 LEM Guidance Computer (LGC). - The LGC shall be a digital computer with special capability for organizing simultaneous real time operations and control data processing for guidance and navigation. The basic memory shall be 36,864 words of fixed, wired ropes, and 2048 words of erasable memory. The basic word length shall be 15 bits plus-parity. Capability shall exist for double precision operation. Crewman operation of the computer shall be through the DSKY.

3.3.1.1.7 Display and Keyboard Unit (DSKY). - The DSKY shall provide the operating controls and display for the LGC. 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 and navigation equipment.

3.3.1.1.8 AOT Control Unit. - This unit will contain the dimmer control for the AOT reticle light, the MARK X, MARK Y AND MARK REJECT switches.

3.3.1.1.9 Navigation Base (NVB). - The navigation base shall be a rigid structure capable of supporting and maintaining the alignment of the IMU, the AOT and the ASA. The navigation base shall be hard mounted to a support frame on the ascent stage structure.

3.3.1.1.10 Signal Conditioning Assembly (SCA). - The signal conditioning assembly shall contain electronics to interface with the telemetry and GSE equipment.

3.3.1.1.11 LEM Optical Tracker Subsection (LOTS). - The LOTS is a visible light tracker capable of angle tracking either a constant or a modulated light source.

3.3.1.2 Design Criteria. -

3.3.1.2.1 Design Analysis Criteria. - The GFE-PGNCS shall be designed to be capable of operating at the limit load conditions contained in ICD LIS-520-10001.

3.3.1.2.2 Performance Margins. -

3.3.1.2.2.1 Multiple Failure. - The decision to design to accommodate 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 GFE-PGNCS 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 subsystem constraints which would impose excessive GFE-PGNCS subsystem requirements, subject to RCS fuel limitations and other attitude constraints.

3.3.1.2.2.4 Thermal Control. - Thermal design of the GFE-PGNCS subsystem shall normally use passive means of thermal control, such as insulation, coatings, and control of thermal resistances. Thermal design may incorporate the applications of cold plates. The GFE-PGNCS thermal interface is specified in ICD LIS-510-10001.

3.3.1.3 Weight and Power. - The control weight of the GFE-PGNCS including all assemblies, components, and parts shall be 240 pounds. The design load weight of the assemblies of GFE-PGNCS equipment shall not exceed the values specified in ICD LIS-490-10001. The power requirements of the GFE-PGNCS shall be as specified in ICD LIS-390-10002.

3.3.2 Selection of Specifications and Processes. - N/A

3.3.3 Materials, Parts and Processes. - Shall be in accordance with ICD LIS-520-10002.

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) will not be used in areas where the environment or condtions are such that combustion would take place.

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

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. - N/A

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 LEM. When used, fungus-nutrient materials shall be hermetically sealed or treated for fungus resistance and shall not adversely affect equipment performance or service life.

[redacted]

3.3.6 Corrosion of Metal Parts. - All metals shall be corrosion-resistant 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, alclad 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 Standard MS33586, 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. - N/A

3.3.8 Workmanship. - N/A

3.3.9 Electromagnetic Interference. - The GFE-PGNCS and the LEM vehicle equipment shall meet the requirements of MSC-ASPO-EMI-10A and MIL-I-26600. Bonding, wire configuration and shielding shall be provided in accordance with the applicable ICD's.

[redacted]

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4 QUALITY ASSURANCE

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

5 PREPARATION FOR DELIVERY

5.1 General. - NASA shall be responsible for the preparation and shipment of the GFE specified herein.

6 NOTES

[redacted]

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SPECIFICATION NO. LSP-370-3

APPENDIX

10 SCOPE

10.1 Scope. - The following is a list of pertinent interface documents.

20 Interface Control Documents. -

Document No.	Title
LID-280-10004	IMU-AOT-NVB PTA Installation
LID-280-14000	IMU-LOT-NVB-PTA Installation
LIS-280-14001	LOTS Field of View
LIS-300-10002	Abort Guidance Section Electrical Interface with GFE-PGNCS
LIS-340-10000	GFE-PGNCS LGC-CDU-PSA Signal Conditioner Installation
LID-340-10008	AOT Field of View
LID-340-10010	LEM DSKY Installation
LIS-350-10001	LEM GFE-PGNCS Electrical Interfaces for Total Attitude Signals, Attitude Error Signals, and IMU Cage Signal
LIS-350-10002	LEM GFE-PGNCS Lateral and Forward Velocity Electrical Interface
LIS-370-10003	LEM GFE-PGNCS Measurement Interface Provisions

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SPECIFICATION NO. LSP-370-3

20 (Continued)

LIS-370-10004	LGC-LEM Electrical Interface
LIS-370-10006	GFE-PGNCS to Rendezvous Radar Angle Electrical Interface
LIS-370-10007	LEM GFE-PGNCS 800 CPS Electrical Interfaces
LIS-370-14001	LEM-LOTS Measurements Interface Provisions
LIS-380-10001	S-Band Steerable Antenna Functional Interface with GFE-PGNCS
LID-390-10001	LEM Wiring Electrical Interface for GFE-PGNCS
LIS-390-10002	GFE-PGNCS Prime Power Requirements and Characteristics
LID-390-14000	LEM Wiring for GFE-PGNCS (LOTS)
LIS-390-14001	GFE-PGNCS Prime Power Requirements and Characteristics (LOTS)
LID-410-10002	Inertial Components Temperature Control System Interface
LID-410-10003	PSA Adapter Module Interface
LIS-420-10001	GFE-PGNCS Installation Fixtures and Procedures
LIS-420-14001	GFE-PGNCS Installation Fixtures and Procedures (LOTS)
LIS-490-10001	GFE-PGNCS Mass Properties

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20 (Continued).

LIS-490-14001	Weight Requirements for GFE/PGNCS Equipment (MIT-ACED-GAEC)
LIS-510-10001	Thermodynamic Requirements of Guidance and Navigation Equipment Grumman-MIT/IL
LIS-510-14001	Thermodynamic Requirements of LEM Optical Tracker (LOTS) Equipment ACED-GAEC
LIS-520-10001	LEM Design Environment
LIS-520-10002	Materials Compatibility Requirements Grumman-MIT/IL
LIS-520-14001	LEM Design Environment (LOTS)
LIS-520-14002	LEM Materials Compatibility (LOTS)
LID-540-10001	LEM GFE-PGNCS Functional Interface Flow Diagram
LIS-540-10001	LEM GFE-PGNCS Functional Interface Requirements
MH01-01388-416	Interior Lighting and Functional Criteria
MH01-05076-414	LEM/CSM Guidance and Navigation (IMU Alignment)
MH01-05174-414	Nomenclature, Markings and Color

[redacted]

[redacted]

TABLE X

LR(3σ) ERRORS vs. LEM PITCH - PHASE 1

COMPONENT	TIME SEC.	ALTITUDE FT.	TOTAL VELOCITY FPS	PITCH, DEG. FROM NOM. -10	-7.5	-5	-2.5	NOM	+2.5	+5	+7.5	+10
V_{XA}	174	40,000	3452	1.09	1.07	1.03	0.98	0.94	0.94	0.88	0.76	2.13
	270	25,000	2020	0.81	0.79	0.77	0.74	0.65	0.71	1.36	-	1.56
	325	15,000	1150	0.73	0.69	0.64	0.58	0.67	0.89	1.28	2.11	2.47
	348	10,800	798	0.68	0.64	0.59	0.60	0.70	0.86	1.11	1.54	1.33
V_{YA}	174	40,000	3452	1.32	1.31	1.30	1.31	1.32	1.34	1.34	1.27	1.47
	270	25,000	2020	1.29	1.30	1.30	1.31	1.32	1.32	1.34	-	1.47
	325	15,000	1150	1.35	1.36	1.36	1.37	1.38	1.40	1.47	1.92	2.37
	348	10,800	798	1.44	1.45	1.45	1.47	1.49	1.51	1.58	1.81	2.99
V_{ZA}	174	40,000	3452	1.67	1.61	1.55	1.50	1.47	1.36	1.42	2.57	[illegible].16
	270	25,000	2020	1.14	1.11	1.10	1.16	1.39	1.97	3.71	-	2.59
	325	15,000	1150	1.08	1.14	1.26	1.44	1.77	2.35	3.45	5.78	5.25
	348	10,800	798	1.21	1.30	1.44	1.63	1.91	2.34	3.05	4.30	3.87
RANGE	174	40,000	3452	2.08	1.90	1.72	1.57	1.43	1.25	1.11	1.51	3.15
	270	25,000	2020	1.09	1.04	0.97	0.93	0.90	1.02	1.69	2.68	1.94
	325	15,000	1150									
	348	10,800	798									

[redacted]

(ERRORS IN PERCENT OF TOTAL VELOCITY OR RANGE UNLESS NOTED)

TABLE XI

LR(3σ) ERRORS vs. LEM YAW - PHASE 1

COMPONENT	TIME SEC.	ALTITUDE FT.	TOTAL VELOCITY FPS	-10	-7.5	-5	-2.5	NOM	+2.5	+5	+7.5	+10
				YAW DEGREES FROM NOM.								
V_{XA}	174	40,000	3452	1.05	1.01	0.98	0.96	0.94	0.93	0.92	0.91	0.92
	270	25,000	2020	0.65	0.63	0.64	0.64	0.65	0.67	0.70	0.73	0.77
	325	15,000	1150	0.70	0.70	0.69	0.68	0.67	0.65	0.62	0.59	0.59
	348	10,800	798	0.73	0.73	0.72	0.71	0.70	0.69	0.68	0.66	0.64
V_{YA}	174	40,000	3452	1.69	1.58	1.48	1.39	1.32	1.39	1.48	1.58	1.69
	270	25,000	2020	1.76	1.69	1.54	1.43	1.32	1.43	1.54	1.69	1.76
	325	15,000	1150	1.87	1.90	1.64	1.50	1.38	1.50	1.64	1.90	1.87
	348	10,800	798	1.77	1.72	1.62	1.55	1.49	1.55	1.62	1.72	1.77
V_{ZA}	174	40,000	3452	1.64	1.60	1.56	1.52	1.47	1.42	1.35	1.28	1.21
	270	25,000	2020	1.18	1.23	1.29	1.35	1.39	1.41	1.41	1.43	1.41
	325	15,000	1150	1.52	1.51	1.66	1.72	1.77	1.81	1.84	1.86	1.86
	348	10,800	798	1.78	1.81	1.84	1.88	1.91	1.93	1.95	1.99	2.00
RANGE	174	40,000	3452	1.70	1.57	1.50	1.43	1.45	1.50	1.57	1.69	1.09
	270	25,000	2020	1.11	1.03	0.97	0.92	0.90	0.92	0.96	1.03	1.10
	325	15,000	1150									
	348	10,800	798									

(ERRORS IN PERCENT OF TOTAL VELOCITY OR RANGE UNLESS NOTED)

[redacted]

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TABLE XII

(To be supplied at a later date)

TABLE XIII

LR(3σ) ERRORS vs LEM PITCH - PHASE 2

COMPONENT	TIME SEC.	ALTITUDE FT.	TOTAL VELOCITY FPS	PITCH, DEGREES FROM NOMINAL -30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30
V_{XA}	352	10,100	749	0.61	0.85	1.49	2.16	1.23	0.84	0.67	0.79	0.87	1.08	1.55	1.44	1.04
	380	5,800	555	0.64	0.86	1.31	0.83	1.38	0.95	0.74	0.74	0.83	1.03	1.44	2.12	1.22
	410	2,600	374	0.73	0.95	1.28	0.80	1.24	0.98	0.79	0.73	0.85	1.04	1.39	1.71	1.19
	416.5	2,150	318	0.78	0.97	1.29	1.34	1.36	1.04	0.88	0.74	0.85	1.04	1.33	1.66	1.25
	430	1,200	202	0.83	0.99	1.15	1.32	1.16	1.13	0.96	0.83	0.91	1.06	1.25	1.46	1.24
	450	500	82.0	0.81FPS	0.90FPS	0.96FPS	0.97FPS	0.99FPS	0.86FPS	0.87FPS	0.82FPS	0.86FPS	0.94FPS	1.03FPS	1.09FPS	1.16FPS
	460	250	44.2	0.54FPS	0.57FPS	0.58FPS	0.80FPS	0.57FPS	0.55FPS	0.56FPS	0.58FPS	0.58FPS	0.60FPS	0.63FPS	0.74FPS	0.56FPS
V_{YA}	352	10,100	749	1.48	1.54	1.82	3.05	1.78	1.63	1.61	1.63	1.62	1.64	1.66	1.70	1.77
	380	5,800	555	1.57	1.62	1.83	3.28	1.99	1.75	1.69	1.69	1.68	1.69	1.72	1.76	1.83
	410	2,600	374	1.75	1.81	2.04	2.96	2.20	1.95	1.86	1.82	1.81	1.80	1.81	1.83	1.89
	416.5	2,150	318	2.39	2.39	2.37	2.86	2.34	2.36	2.35	1.97	1.94	1.94	1.94	1.97	2.02
	430	1,200	202	2.52	2.54	2.54	2.53	2.66	2.53	[illegible]	2.46	2.42	2.36	2.28	2.21	2.13
	450	500	82.0	2.70FPS	2.73FPS	2.75FPS	2.77FPS	2.90FPS	2.76FPS	2.74FPS	2.70FPS	2.66FPS	2.61FPS	2.56FPS	2.50FPS	2.43FPS
	460	250	44.2	1.93FPS	1.95FPS	1.95FPS	2.01FPS	1.91FPS	1.94FPS	1.92FPS	[illegible]	1.87FPS	1.84FPS	1.80FPS	1.76FPS	1.71FPS
V_{ZA}	352	10,100	749	1.68	2.35	4.19	4.53	1.90	1.21	1.61	1.75	1.42	1.13	2.32	2.17	3.47
	380	5,800	555	1.83	2.43	3.71	2.42	2.42	1.26	1.35	1.48	1.20	1.37	2.30	3.96	4.08
	410	2,600	374	2.02	2.59	3.57	2.19	2.23	1.54	1.25	1.30	1.31	[illegible]	2.54	3.26	3.62
	416.5	2,150	318	2.20	2.72	3.63	3.73	2.58	1.79	1.64	1.31	1.47	[illegible]	2.49	3.22	3.71
	430	1.200	202	2.30	2.71	3.22	3.57	2.22	2.16	1.84	1.73	1.92	2.18	2.51	2.80	3.50
	450	500	82.0	2.21FPS	2.45FPS	2.64FPS	2.60FPS	2.56FPS	1.80FPS	1.84FPS	1.88FPS	[illegible]	2.19FPS	2.28FPS	2.21FPS	2.26FPS
	460	250	44.2	1.44FPS	1.53FPS	1.59FPS	2.13FPS	1.30FPS	1.38FPS	1.32FPS	[illegible]	1.30FPS	1.37FPS	1.38FPS	1.56FPS	1.56FPS
RANGE	380	5,800	555	1.22	1.24	1.79	1.26	2.05	1.57	1.06	0.94	0.95	0.99	1.03	1.34	1.62
	410	2,600	374	2.10	2.10	2.64	1.89	2.79	2.11	1.69	1.48	1.40	1.37	1.38	1.48	1.64

[redacted]

(ERRORS IN PERCENT OF TOTAL VELOCITY OR RANGE UNLESS NOTED)

TABLE XIV

LR(3σ) ERRORS vs LEM YAW - PHASE 2

COMPONENT	TIME SEC.	ALTITUDE FT.	TOTAL VELOCITY FPS	YAW DEGREES FROM NOMINAL -30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30
V_{XA}	352	10,100	749	0.85	0.78	0.72	0.68	0.66	0.66	0.67	0.69	0.75	0.85	0.98	1.22	1.52
	380	5,800	555	0.93	0.85	0.78	0.74	0.71	0.73	0.74	0.78	0.85	0.85	1.12	1.34	1.58
	410	2,600	374	0.98	0.91	0.84	0.79	0.77	0.78	0.79	0.82	0.89	0.99	1.14	1.32	1.57
	416.5	2,150	318	1.02	0.95	0.88	0.84	0.87	0.87	0.85	0.91	0.97	1.05	1.20	1.38	1.35
	430	1,200	202	1.16	1.09	1.02	0.98	0.96	0.95	0.96	1.00	1.05	1.15	1.26	1.38	1.50
	450	500	82.0	0.99FPS	0.95FPS	0.91FPS	0.89FPS	0.87FPS	0.87FPS	0.87FPS	[illegible]	0.90FPS	0.95FPS	1.00FPS	1.04FPS	1.11FPS
	460	250	44.2	0.62FPS	0.59FPS	0.57FPS	0.56FPS	0.56FPS	0.56FPS	0.56FPS	0.56FPS	0.57FPS	0.60FPS	0.62FPS	0.65FPS	0.68FPS
V_{YA}	352	10,100	749	4.33	3.43	2.74	2.39	2.02	1.76	1.61	1.76	2.02	2.39	2.74	3.43	4.33
	380	5,800	555	4.29	3.65	3.09	2.21	2.28	1.93	1.69	1.93	2.28	2.21	3.09	3.65	4.29
	410	2,600	374	4.22	3.54	3.06	2.64	2.33	2.06	1.86	2.06	2.33	2.64	3.06	3.54	4.22
	416.5	2,150	318	3.38	3.75	3.27	2.87	2.74	[illegible]	2.35	2.52	2.74	2.87	3.27	3.75	3.38
	430	1,200	202	3.75	3.62	3.40	3.16	2.88	2.67	2.50	2.67	2.88	3.15	3.40	3.62	3.75
	450	500	82.0	3.06FPS	2.96FPS	2.98FPS	2.94FPS	2.38FPS	2.77FPS	2.74FPS	2.77FPS	2.83FPS	2.94FPS	2.98FPS	2.96FPS	3.06FPS
	460	250	44.2	2.14FPS	2.13FPS	2.11FPS	2.07FPS	2.00FPS	1.95FPS	1.92FPS	1.95FPS	2.00FPS	2.07FPS	[illegible]	2.13FPS	2.14FPS
V_{ZA}	352	10,100	749	2.13	1.50	1.19	1.31	1.47	1.59	1.61	1.64	1.66	1.70	1.77	1.86	1.93
	380	5,800	555	2.50	2.00	1.58	1.34	1.15	1.27	1.35	1.40	1.49	1.52	1.58	1.60	1.63
	410	2,600	374	2.70	2.18	1.84	1.56	1.38	1.23	1.25	1.29	1.33	1.37	1.41	1.46	1.49
	416.5	2,150	318	2.22	2.43	2.09	1.82	1.64	1.57	1.64	[illegible]	[illegible]	1.35	1.39	1.43	1.47
	430	1,200	202	2.65	2.50	2.34	2.18	2.02	1.91	1.84	[illegible]	1.81	1.83	1.84	1.88	1.96
	450	500	82.0	2.00FPS	1.94FPS	1.96FPS	1.94FPS	1.88FPS	[illegible]	1.84FPS	1.85FPS	1.85FPS	1.85FPS	1.89FPS	1.95FPS	2.01FPS
	460	250	44.2	1.36FPS	1.34FPS	1.32FPS	1.32FPS	1.35FPS	1.37FPS	[illegible]	1.39FPS	1.41FPS	1.44FPS	1.47FPS	1.51FPS	1.56FPS
RANGE	380	5,800	555	1.31	1.17	1.12	1.03	1.08	1.09	1.08	1.08	1.08	1.02	1.11	1.16	1.30
	410	2,600	374	2.07	1.87	1.81	1.75	1.72	1.70	1.69	1.70	1.72	1.75	1.80	1.86	2.06

[redacted]

(ERRORS IN PERCENT OF TOTAL VELOCITY OR RANGE UNLESS NOTED)

TABLE XV

LR(3σ) ERRORS vs LEM ROLL - PHASE 2

COMPONENT	TIME SEC.	ALTITUDE FT.	TOTAL VELOCITY FPS	ROLL, DEGREES FROM NOMINAL -30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30
V_{XA}	352	10,100	749	0.88	0.77	0.72	0.68	0.68	0.68	0.67	0.67	0.68	0.71	0.76	0.85	0.94
	380	5,800	555	0.81	0.71	0.70	0.76	0.76	0.74	0.75	0.73	0.72	0.70	0.78	0.85	0.91
	410	2,600	374	0.80	0.72	0.78	0.82	0.81	0.81	0.79	0.77	0.75	0.73	0.78	0.88	0.96
	416.5	2,150	218	0.80	0.74	0.90	0.93	0.91	0.91	0.88	0.86	0.85	0.83	0.89	0.86	0.93
	430	1,200	202	0.91	0.94	0.99	1.01	1.00	0.99	0.96	0.95	0.94	0.93	0.91	0.93	0.98
	450	500	82.0	0.88FPS	0.92FPS	0.95FPS	0.95FPS	0.93FPS	0.90FPS	0.87FPS	0.83FPS	0.85FPS	0.91FPS	0.99FPS	1.09FPS	1.14FPS
	460	250	44.2	0.64FPS	0.59FPS	0.58FPS	0.59FPS	0.58FPS	0.56FPS	0.56FPS	0.58FPS	0.61FPS	0.64FPS	0.68FPS	0.72FPS	0.74FPS
V_{YA}	352	10,100	749	2.81	2.66	2.63	2.37	2.21	1.89	1.61	1.89	2.21	2.37	2.63	2.66	2.81
	380	5,800	555	2.93	2.71	2.61	2.48	2.32	2.11	1.69	2.11	2.32	2.48	2.61	2.71	2.93
	410	2,600	374	3.00	2.85	2.74	2.62	2.50	2.17	1.86	2.17	2.50	2.62	2.74	2.85	3.00
	416.5	2,150	318	3.28	3.27	3.32	3.14	2.94	2.65	2.35	2.66	2.94	3.14	3.33	3.27	3.28
	430	1,200	202	4.02	3.80	3.58	3.38	3.15	2.83	2.50	2.84	3.16	3.38	3.59	3.80	4.02
	450	500	82.0	3.08FPS	3.05FPS	3.03FPS	3.02FPS	2.99FPS	2.87FPS	2.74FPS	2.87FPS	2.99FPS	3.02FPS	3.03FPS	[illegible]	3.08FPS
	460	250	44.2	2.12FPS	2.08FPS	2.08FPS	2.07FPS	2.05FPS	1.99FPS	1.92FPS	1.99FPS	2.05FPS	2.07FPS	2.08FPS	2.08FPS	2.12FPS
V_{ZA}	352	10,100	749	1.17	1.35	1.54	1.67	1.72	1.70	1.62	1.59	1.61	1.54	1.52	1.28	1.25
	380	5,800	555	1.54	1.22	1.39	1.42	1.45	1.41	1.35	1.37	1.29	1.20	1.20	1.54	1.79
	410	2,600	374	1.91	1.61	1.36	1.33	1.38	1.32	1.25	1.21	1.26	1.45	1.70	2.02	2.28
	416.5	2,150	318	2.21	1.89	1.73	1.77	1.78	1.72	1.64	1.59	[illegible]	1.81	2.09	2.18	2.49
	430	1,200	202	2.89	2.52	2.17	1.93	1.79	1.79	1.84	1.93	2.02	2.22	2.51	2.85	3.04
	450	500	82.0	2.33FPS	2.08FPS	1.93FPS	1.98FPS	1.94FPS	1.85FPS	1.84FPS	1.96FPS	2.08FPS	2.28FPS	2.55FPS	2.83FPS	2.99FPS
	460	250	44.2	1.43FPS	1.45FPS	1.49FPS	1.50FPS	1.48FPS	1.43FPS	1.38FPS	1.34FPS	1.32FPS	1.39FPS	1.51FPS	1.63FPS	1.69FPS
RANGE	380	5,800	555	1.06	1.06	1.04	1.07	1.07	1.07	1.08	1.08	1.08	1.09	1.06	1.09	1.10
	410	2,600	374	1.79	1.77	1.75	1.71	1.68	1.69	1.69	1.70	1.70	1.74	1.79	1.82	1.86

(ERRORS IN PERCENT OF TOTAL VELOCITY OR RANGE UNLESS NOTED)

[redacted]

SPECIFICATION NO. 370-3

TABLE XVI

PHASE 3 PITCH

(To be supplied at a later date)

SPECIFICATION NO. 370-3

TABLE XVII

PHASE 3 YAW

(To be supplied at a later date)

TABLE XVIII

PHASE 3 ROLL

(To be supplied at a later date)

TABLE XIX

Antenna in Position One

ALTITUDE IN FEET	LEM Y-AXIS PITCH		LEM X-AXIS YAW		LEM Z-AXIS ROLL	
	VEL Only	4 Beams	VEL Only	4 Beams	VEL Only	4 Beams
25K	-12° to +17° +27° to +75°	+12° to +16° +29° to +60°	-25° to -25°	-5° to +5°	-4° to +4°	-4° to +4°
19.5K	TBD	TBD	TBD	TBD	TBD	TBD
15K	TBD	TBD	TBD	TBD	TBD	TBD
10.8K	-17° to +21° +40° to +66° +82° to +85°	-12° to +21° +43° to +66°	-30° to +30°	-10° to +10°	-5° to +3°	-3° to +3°
10.1K	-17° to +21° +38° to +67° +83° to +85°	-12° to +21° +43° to +67°	-11° to +11°	-11° to +11°	-7° to +7°	-7° to +7°
8.0K	-18° to +20° +38° to +67°	-8° to +20° +43° to +67°	-10° to +10°	-10° to +10°	-5° to +5°	-5° to +5°
5.8K	-17° to +20° +37° to +67°	+47° to +67°	-7° to +7°	-7° to +7°	-3° to +3°	-3° to +3°
2.6K	-17° to +17° +38° to +64°	OUT	-5° to +5°	NONE	-3° to +3°	NONE
2150	-25° to -15°	OUT	NONE	NONE	NONE	NONE
1900	-26° to +22° +34° to +67° +79° to +95°	TBD	-12° to +12°	-12° to +12°	-8° to +8°	-8° to +8°
1200	-25° to +26° +41° to +79°	-25° to +26° +41° to +70°	-9° to +12°	-9° to +12°	-7° to +7°	-7° to +7°
250	-25° to +100°	-17° to +55°	-30° to +30°	-28° to +28°	-60° to +60°	-52° to +52°
200	-25° to +100°	-22° to +61°	-30° to +30°	-30° to +30°	-60° to +60°	-60° to +60°

Allowable LEM Attitude Deviations From DRM

For LR Accuracy

[redacted]

SPECIFICATION NO. LSP-370-3

[redacted]

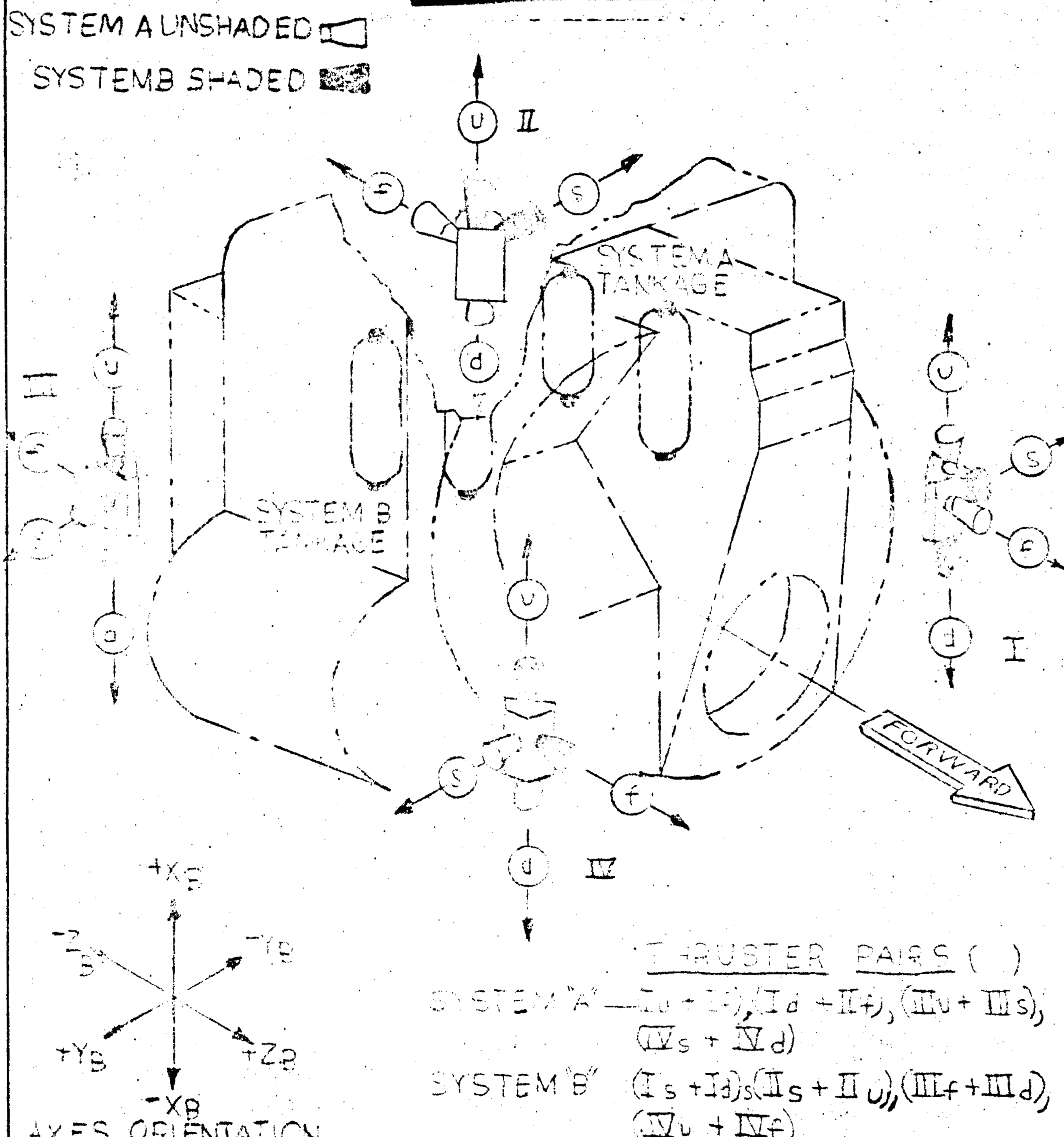


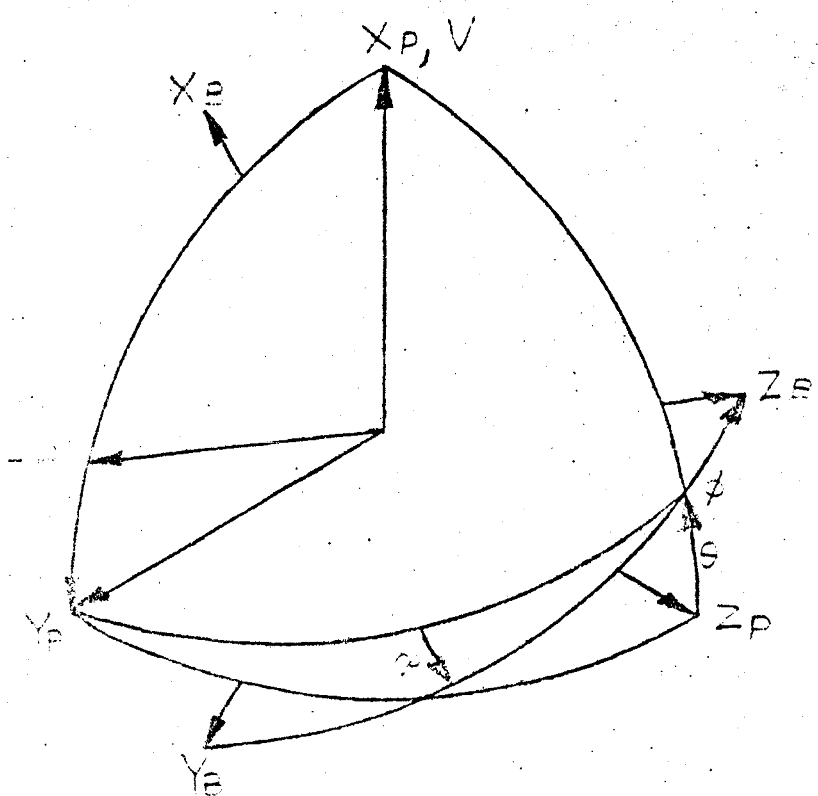
FIGURE 1
RCS THRUSTER LOCATION AND IDENTIFICATION

[redacted]

[redacted]

SPECIFICATION NO. LSP-370-3

PGNS IMU ALIGNMENT



AXES:

-H = NEGATIVE CSM ORBITAL ANGULAR MOMENTUM VECTOR
V = LANDING POINT VERTICAL
X_P = PGNS IMU STABLE MEMBER X AXIS.
Y_P = " " " " Y
Z_P = " " " " Z
X_B = LEM BODY X AXIS REFERENCED TO NAV. BASE ATT. PT.
Y_B = " " Y " " " "
Z_B = " " Z " " " " "

ANGLES

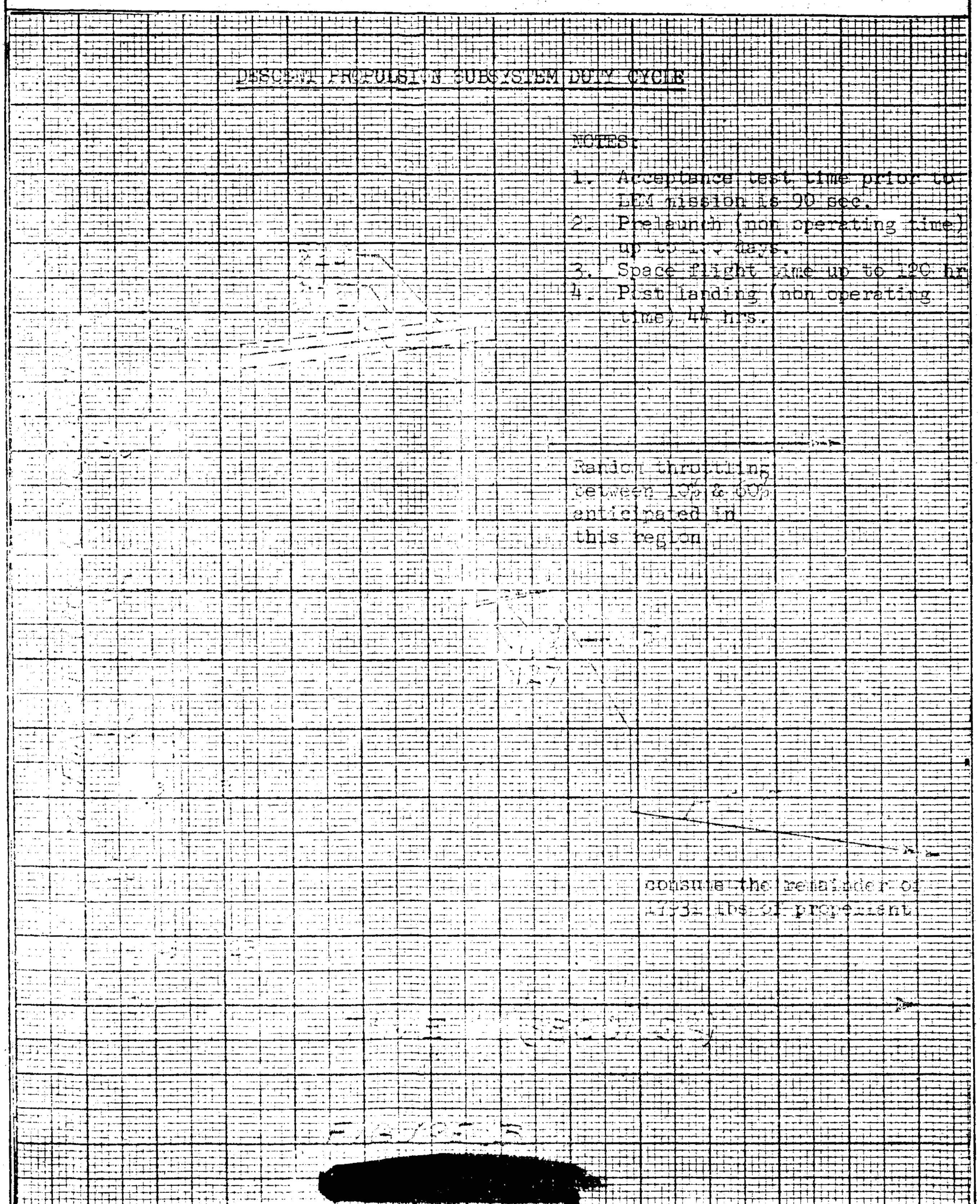
θ = +AIG IMU INNER GIMBAL ANGLE.
ψ = +AMG " MIDDLE " " .
φ = +AOG " OUTER " " .

FIGURE 2

[redacted]

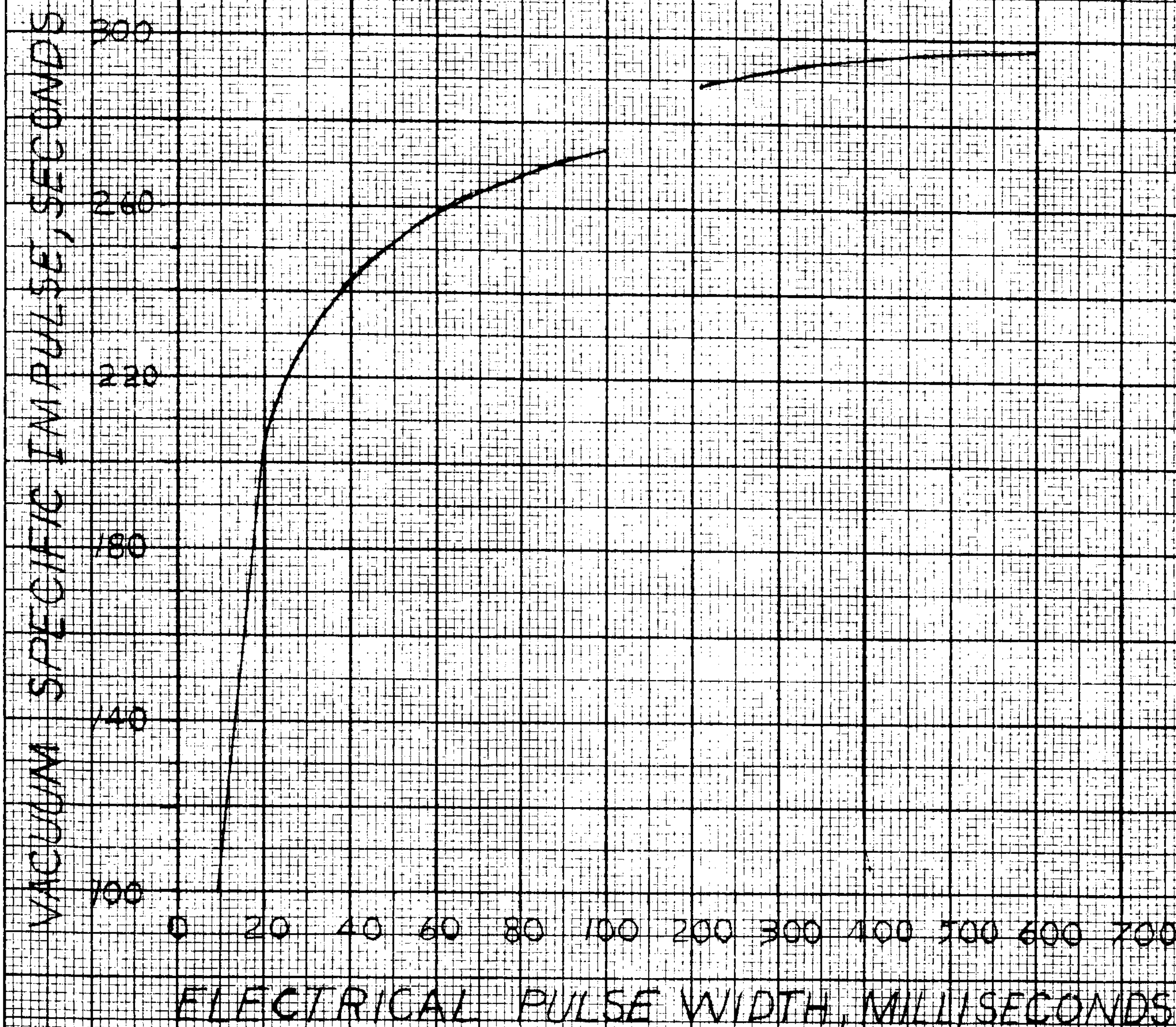
[redacted]

SPECIFICATION NO. LSP-370-3



[redacted]

[redacted]

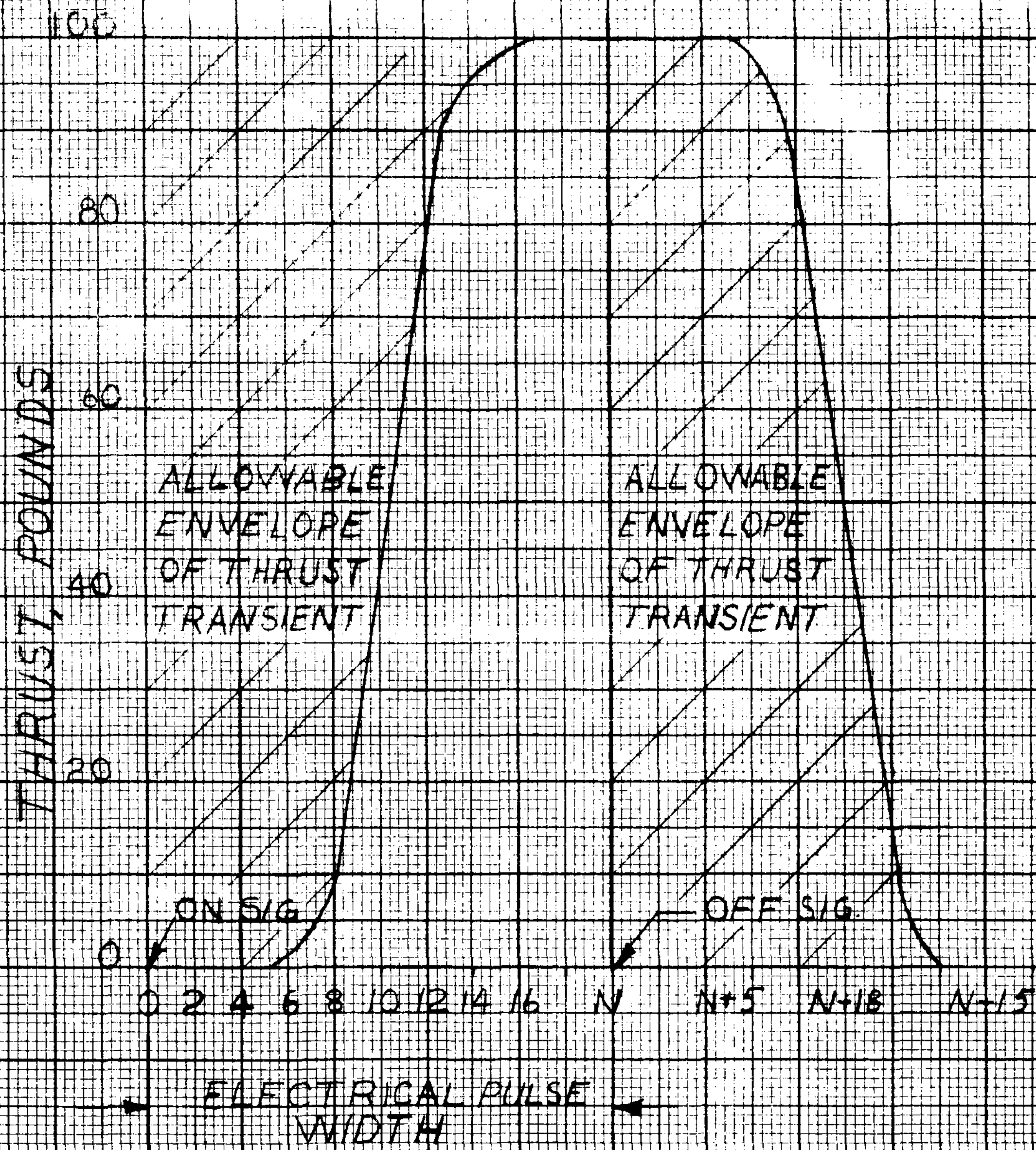


VACUUM SPECIFIC IMPULSE VS. ELECTRICAL PULSE WIDTH

REFER TO PARA. NO. 3.1.5.3.6.3.3.

[redacted] FIGURE 4

[redacted]



THRUST VS. TIME

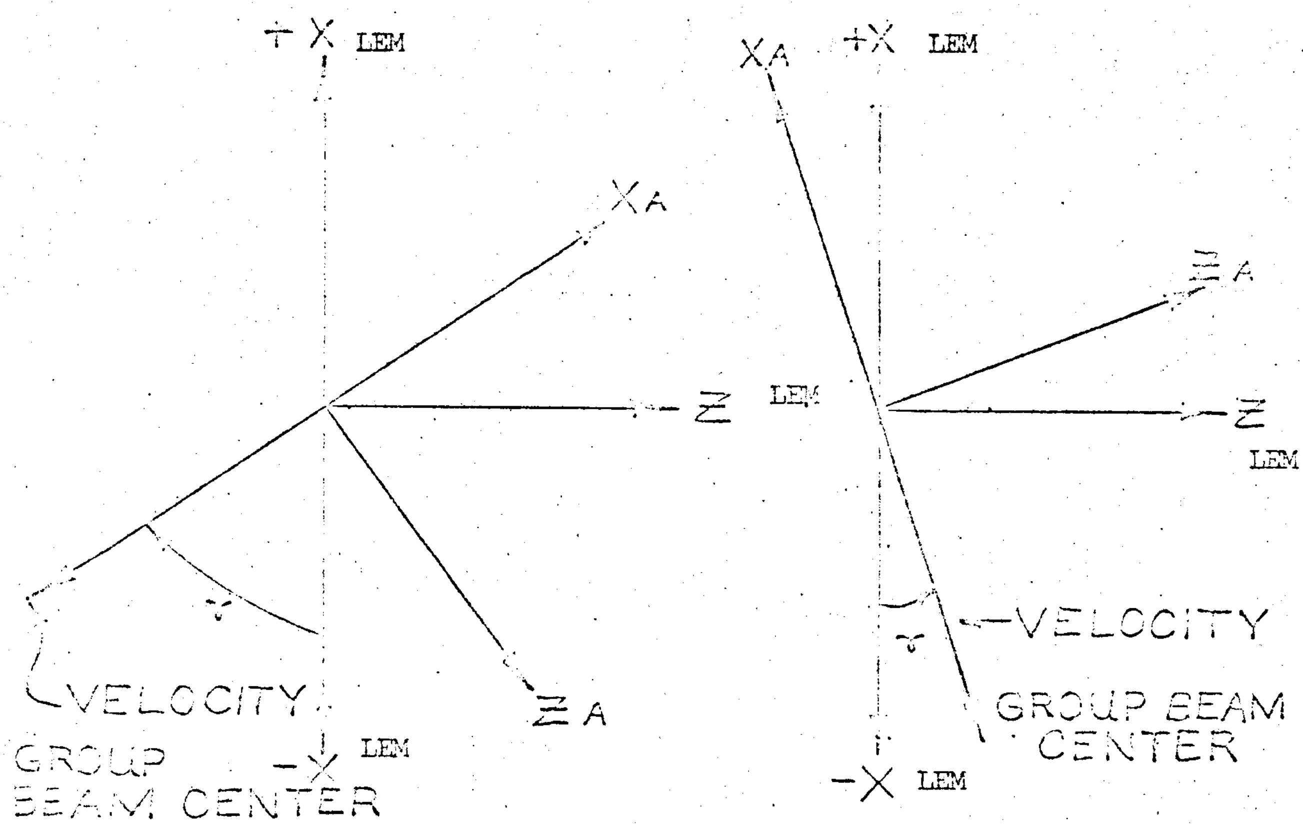
REFER TO PARA. 3.1.5.3.6.3.4 FIGURE 5

[redacted]

[redacted]

SPECIFICATION NO. LSP-370-3

LANDING RADAR ANTENNA POSITIONS



POSITION 1 (POWERED DESCENT)

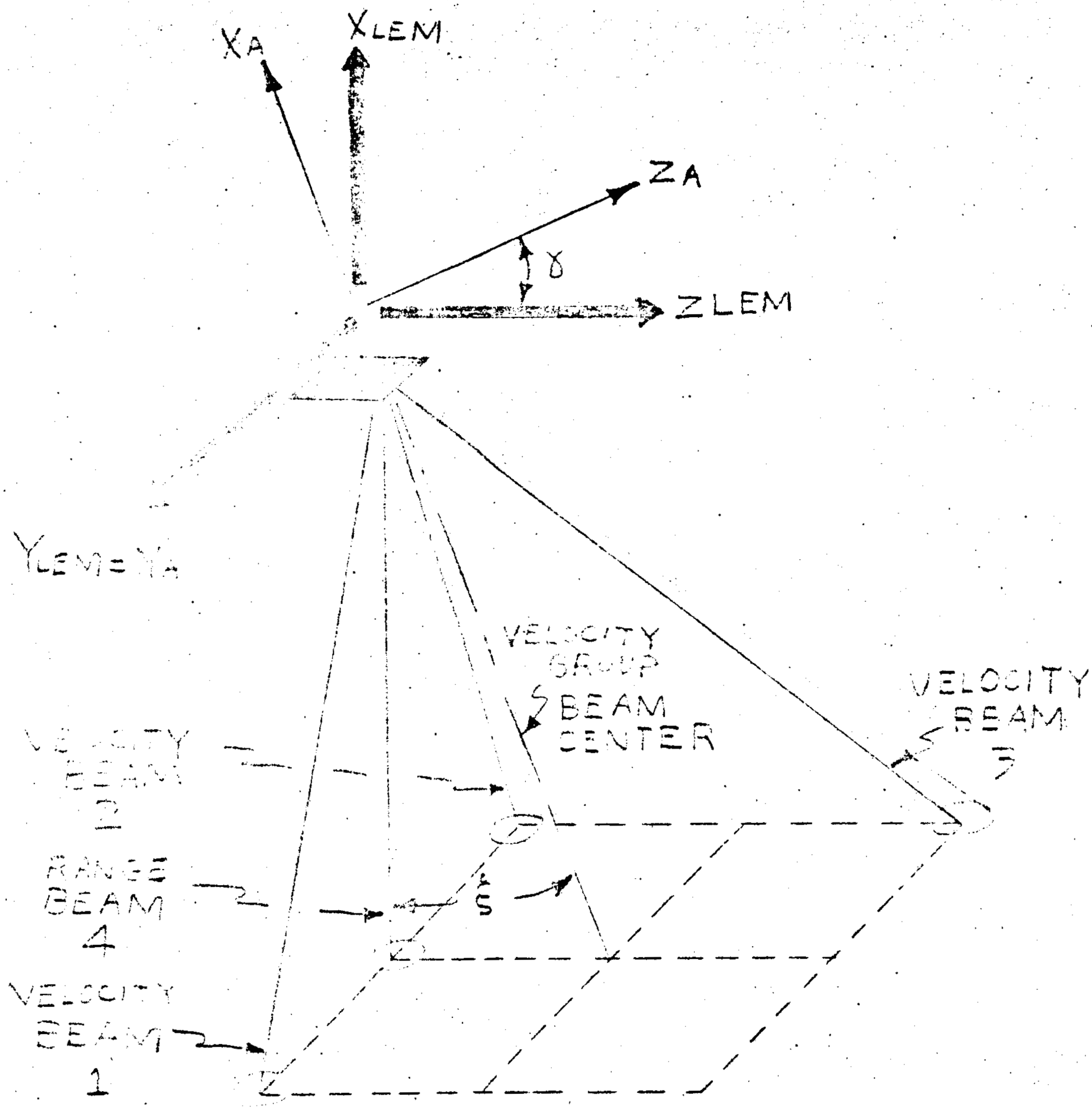
POSITION 2 (FINAL APPROACH)

FIGURE 6

[redacted]

[redacted]

SPECIFICATION NO. LSP-370-3



Xlem, Ylem Zlem: Spacecraft Axes
Xa, Ya, Za: LR Antenna Axes
LR antenna is shown in Position 2.

LANDING RADAR ANTENNA COORDINATE SYSTEM

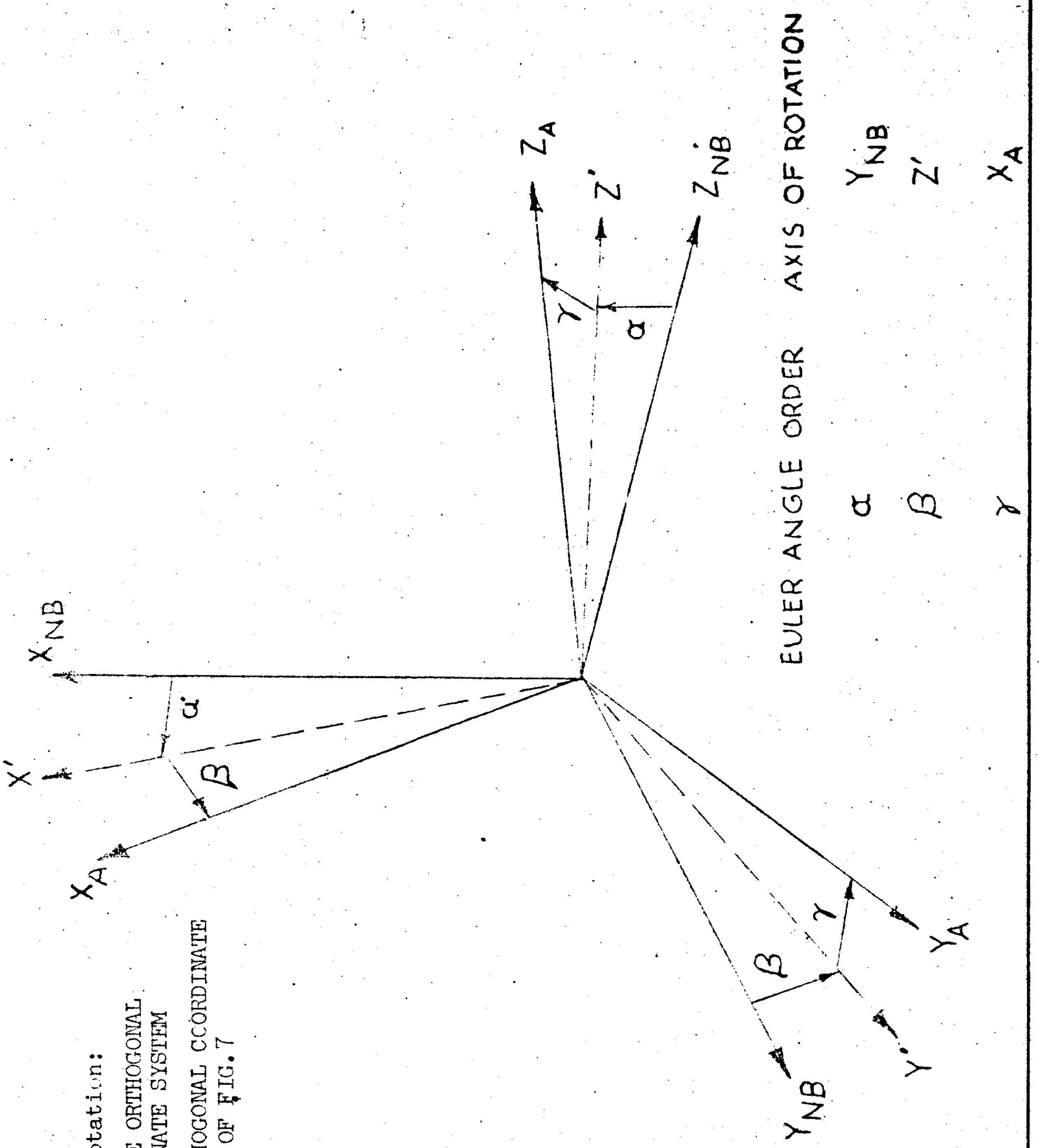
FIGURE 7

[redacted]

[redacted]

SPECIFICATION NO. LSP-370-3

EULER ANGLE DEFINITION BETWEEN NAVBASE & LR ANTENNA COORDINATE SYSTEM



Subscript Notation:

NB = NAVBASE ORTHOGONAL COORDINATE SYSTEM

A = LR ORTHOGONAL COORDINATE SYSTEM OF FIG. 7

FIGURE 8

[redacted]

PGNCS REFERENCE NAVBASE COORDINATE SYSTEM

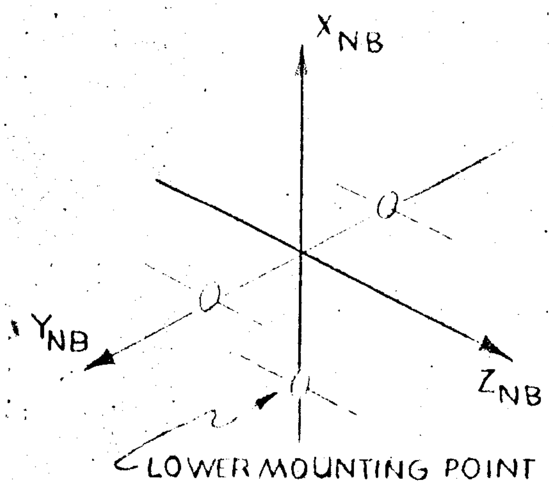


FIGURE 9

DEFINITIONS AND COMMENTS

1. The NAVBASE reference coordinate system is defined by the 3 mounting points in the LEM ascent stage specified in Grumman_MIT ICD-280-10004 Sections G-G and F-F:

   (a) $+Y_{NB}$ is defined by the centers of the two upper mounting points with the positive direction in the same general sense as the LEM +Y vehicle axis.

   (b) $+X_{NB}$ is defined by a line through the center of the lower mounting point and perpendicular to the Y_{NB} axis. Positive direction is in the same general sense as the LEM +X vehicle axis.

   (c) $+Z_{NB}$ is defined as the right hand vector cross product of $X_{NB} \times Y_{NB}$.

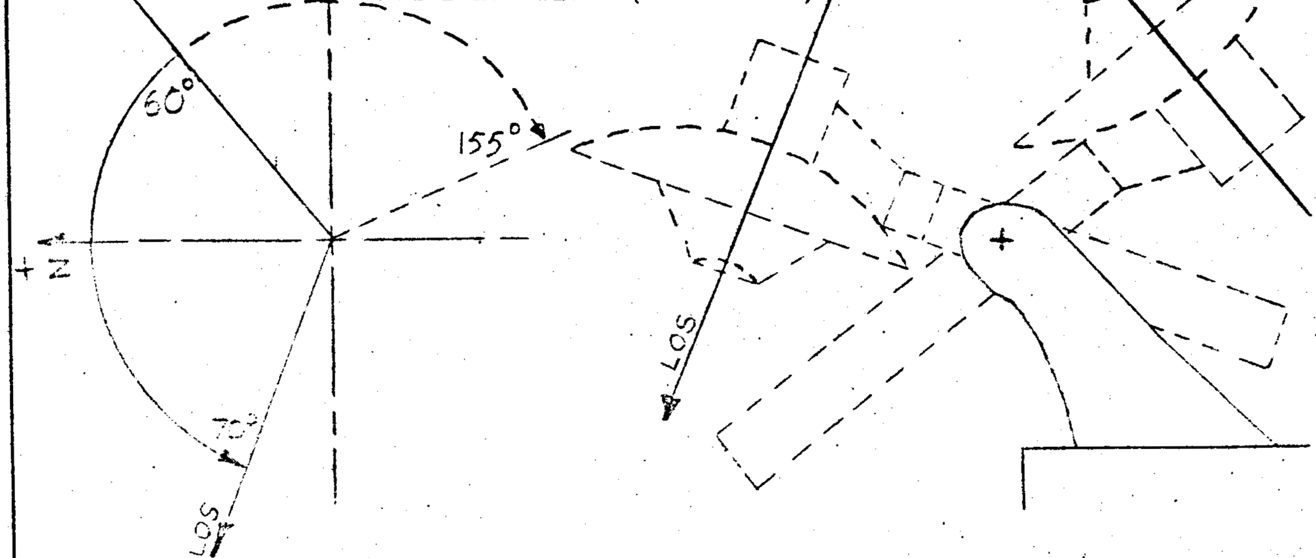
2. The NAVBASE coordinate system is roughly parallel with the LEM vehicle axis system.

[redacted]

[redacted]

SPECIFICATION NO. LSP-370-3

DEMONSTRATION OF R/R ANTENNA DUAL MODE OPERATION AND SWITCH POINT LOCATIONS (SHAFT AXIS)



MODE I OPERATION: RENDEZVOUS AND LUNAR BEACON TRACKING

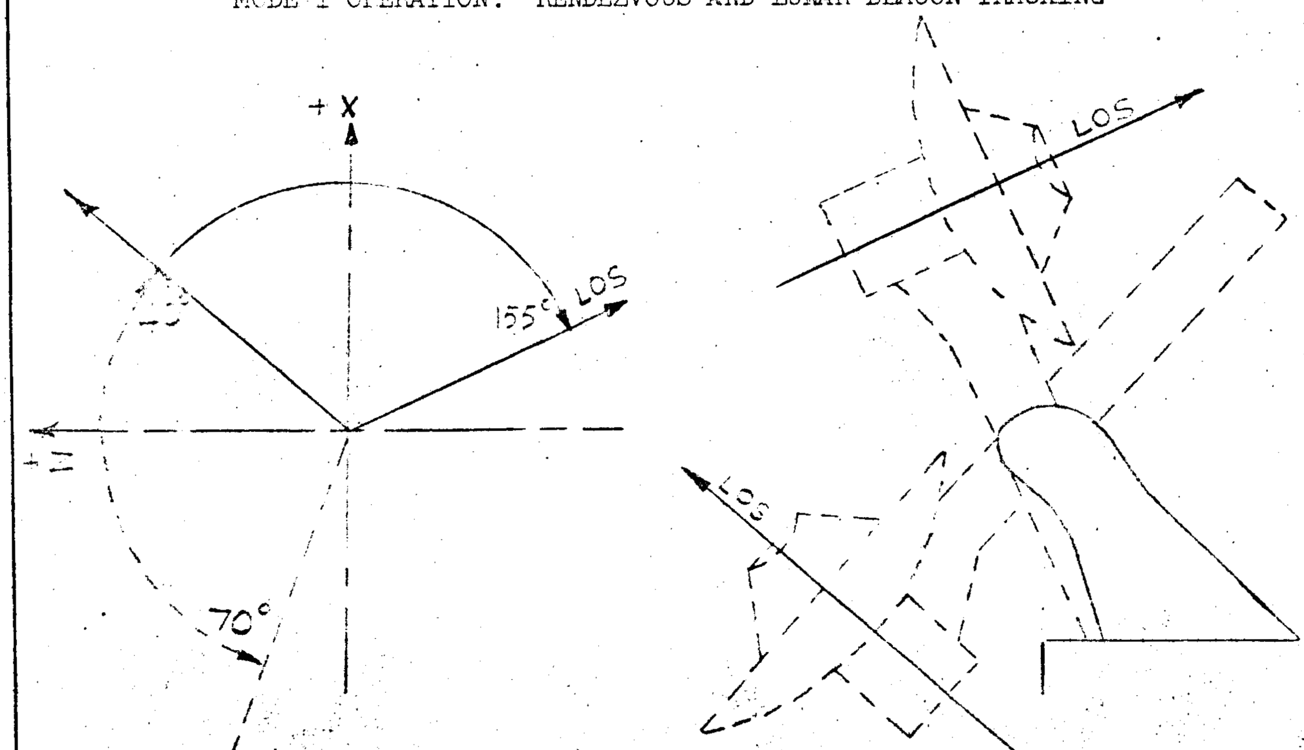


FIGURE 10

MODE II OPERATION: CSM TRACKING

[redacted]

[redacted]

SPECIFICATION NO. LSP-370-3

ANTENNA ASSEMBLY LEM RR ANGLE CONVENTIONS

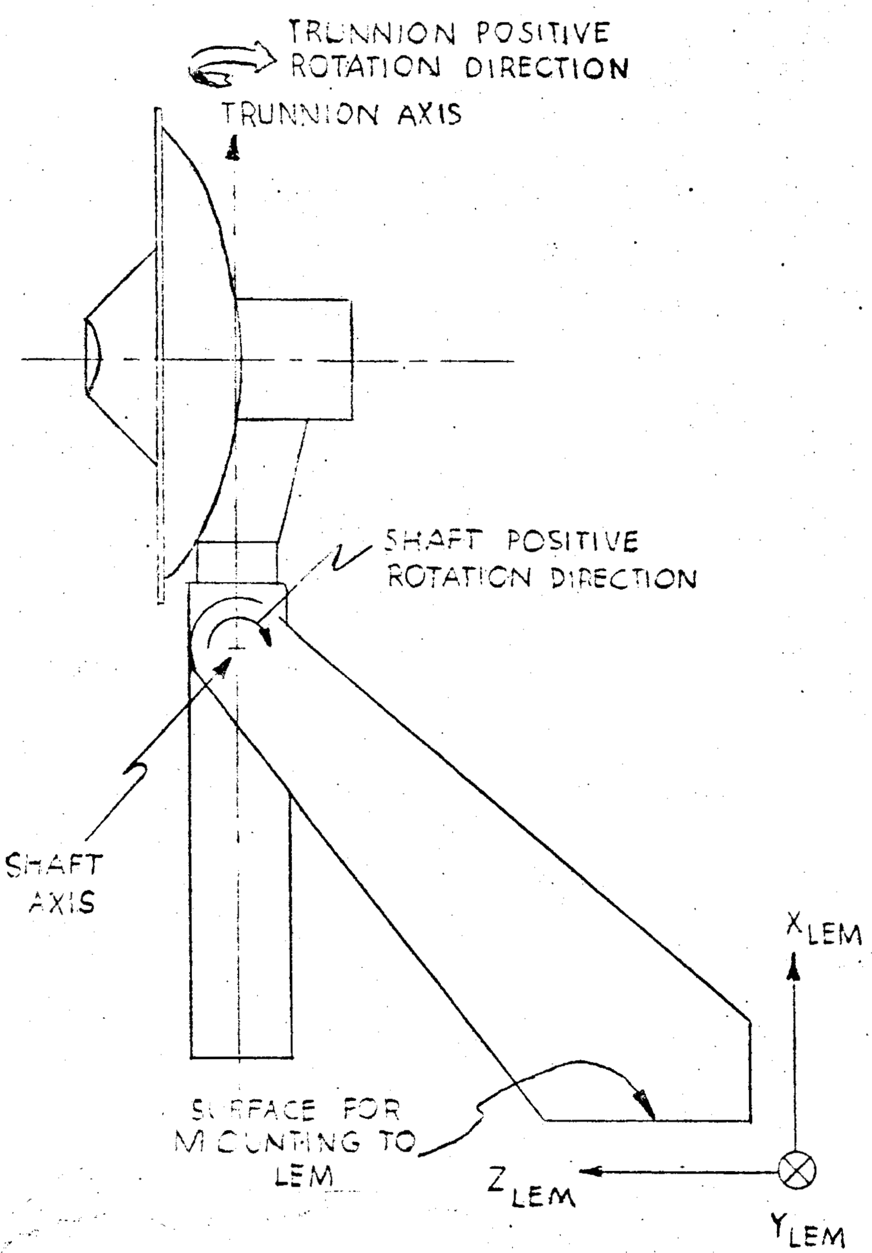


FIGURE 11

[redacted]

[redacted]

SPECIFICATION NO. LSP-370-3

REQUIRED RR ANTENNA ANGLE COVERAGE

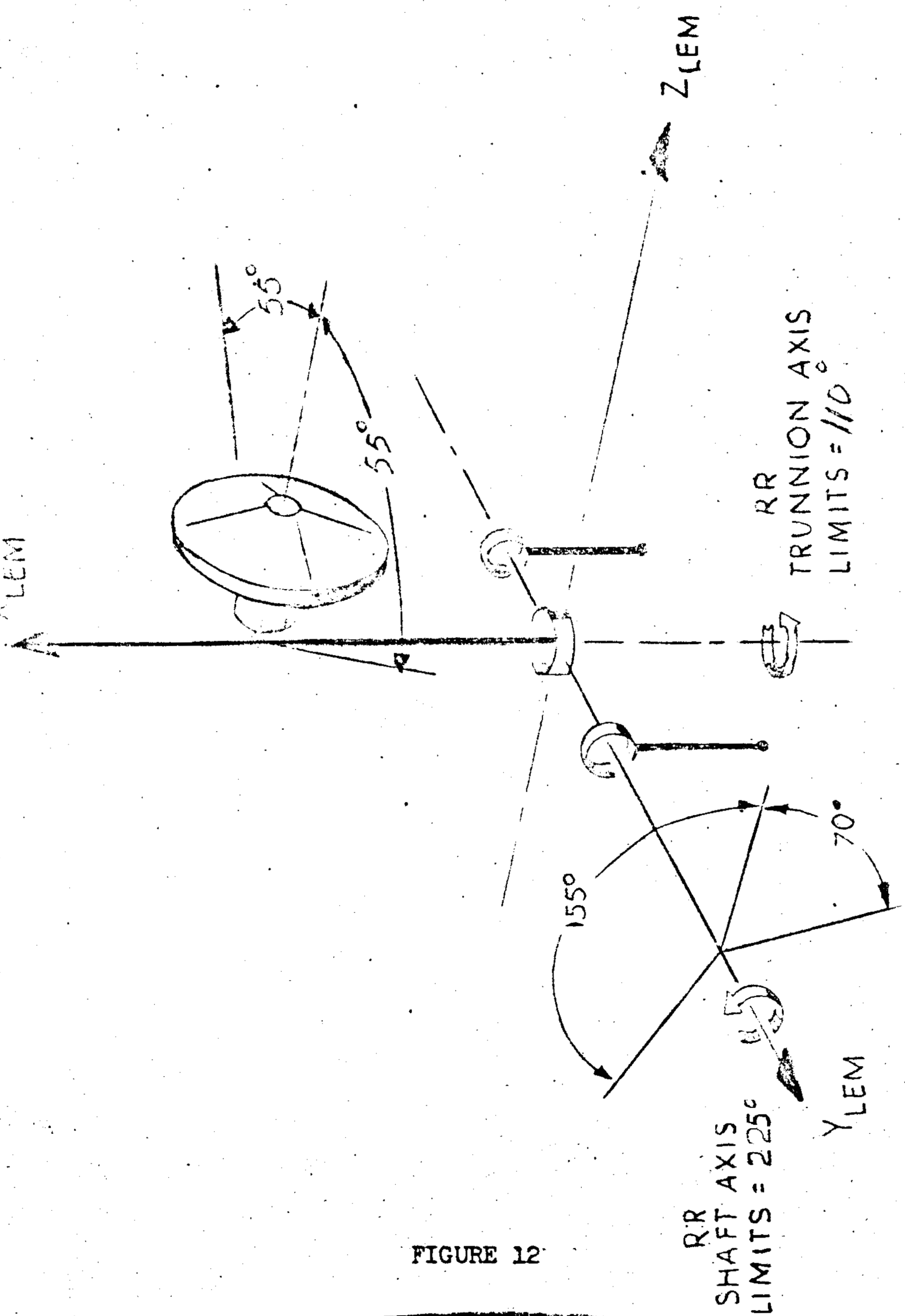
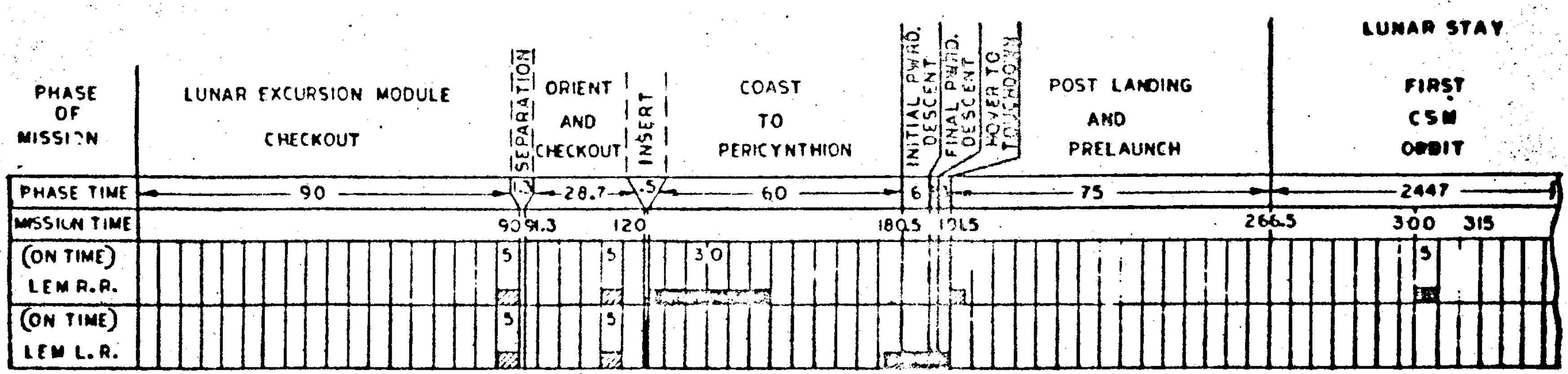


FIGURE 12

[redacted]

C [redacted]



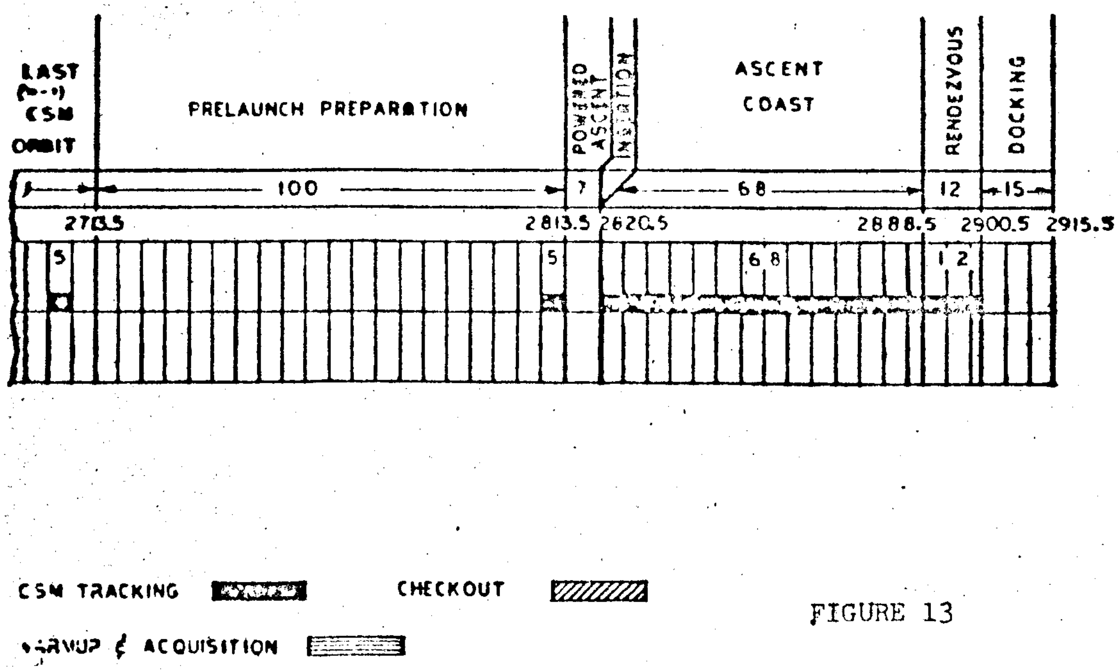


FIGURE 13

NOTES

1. TIME INTERVALS SHOWN ARE IN MINUTES
2. MISSION TIMES INDICATED ARE FROM START OF LEM CHECKOUT (90 MINUTES PRIOR TO SEPARATION)
3. WARMUP AND ACQUISITION TIME OF RADARS IS ASSUMED TO BE 1.5 MINUTES.

* 4. L.R. ON TIME WHEN LEM IS LANDING TO A SURFACE BEACON IS REDUCED TO 6.5 MINUTES.

** SYSTEMS ANALYSIS' REQUIREMENTS FOR A NOMINAL MAXIMUM-TIME MISSION.

GRUMMAN AIRCRAFT ENGRG CORP., BETHPAGE, L. I., NEW YORK		
SIZE C	CODE IDENT NO. 26512	LEM RADAR USAGE ** TIME LINE
SCALE		SHEET

GRUMMAN AIRCRAFT ENGINEERING CORPORATION
Bethpage, L. I., N. Y.
CODE IDENT 26512

[redacted]

SPECIFICATION NO. LSP-370-3

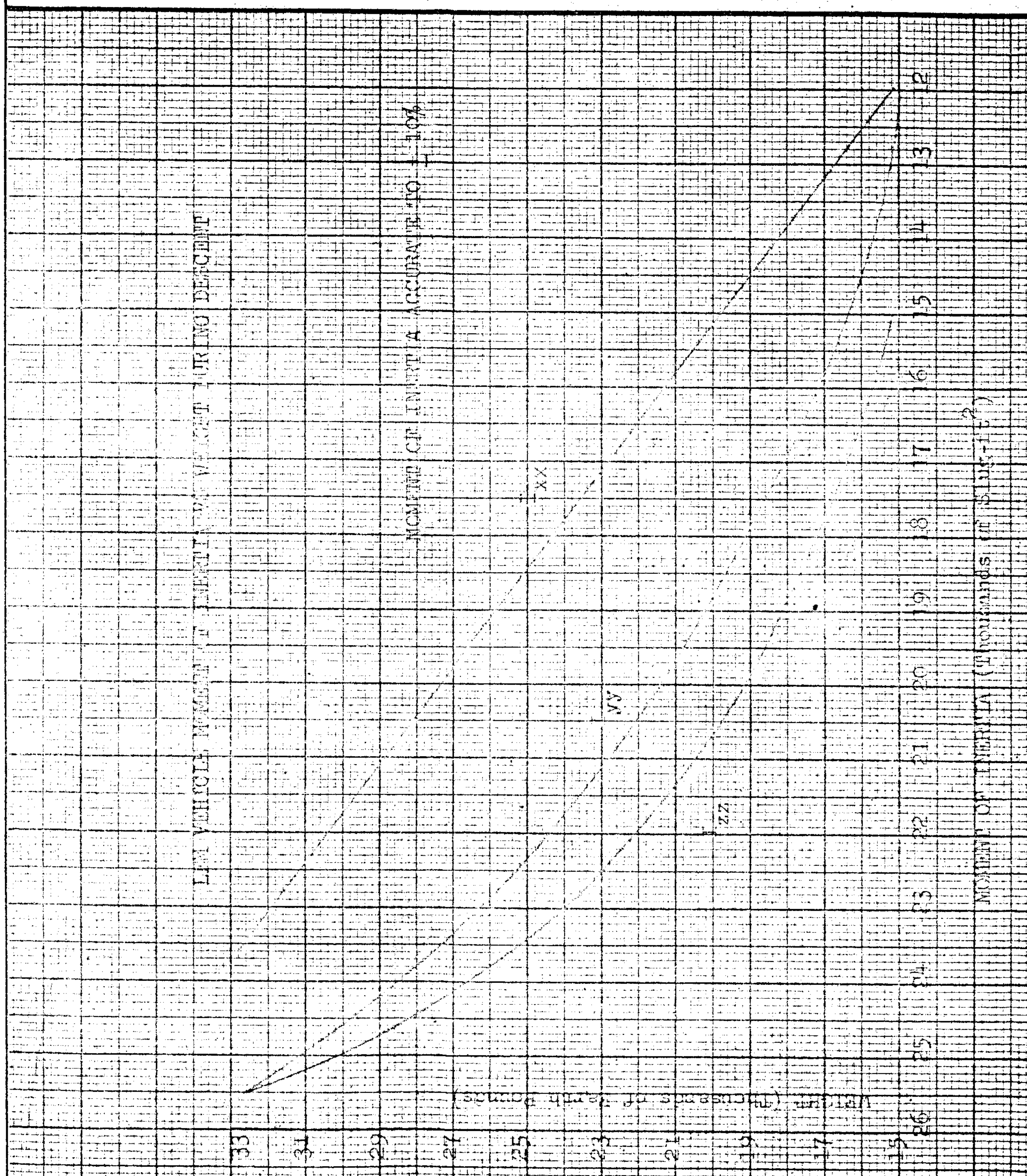


FIGURE 14

[redacted]

Eng 200.7 3-65

GRUMMAN AIRCRAFT ENGINEERING CORPORATION
Bethpage, L. I., N. Y.
CODE IDENT 26512

[redacted]

SPECIFICATION NO. LSP-370-3

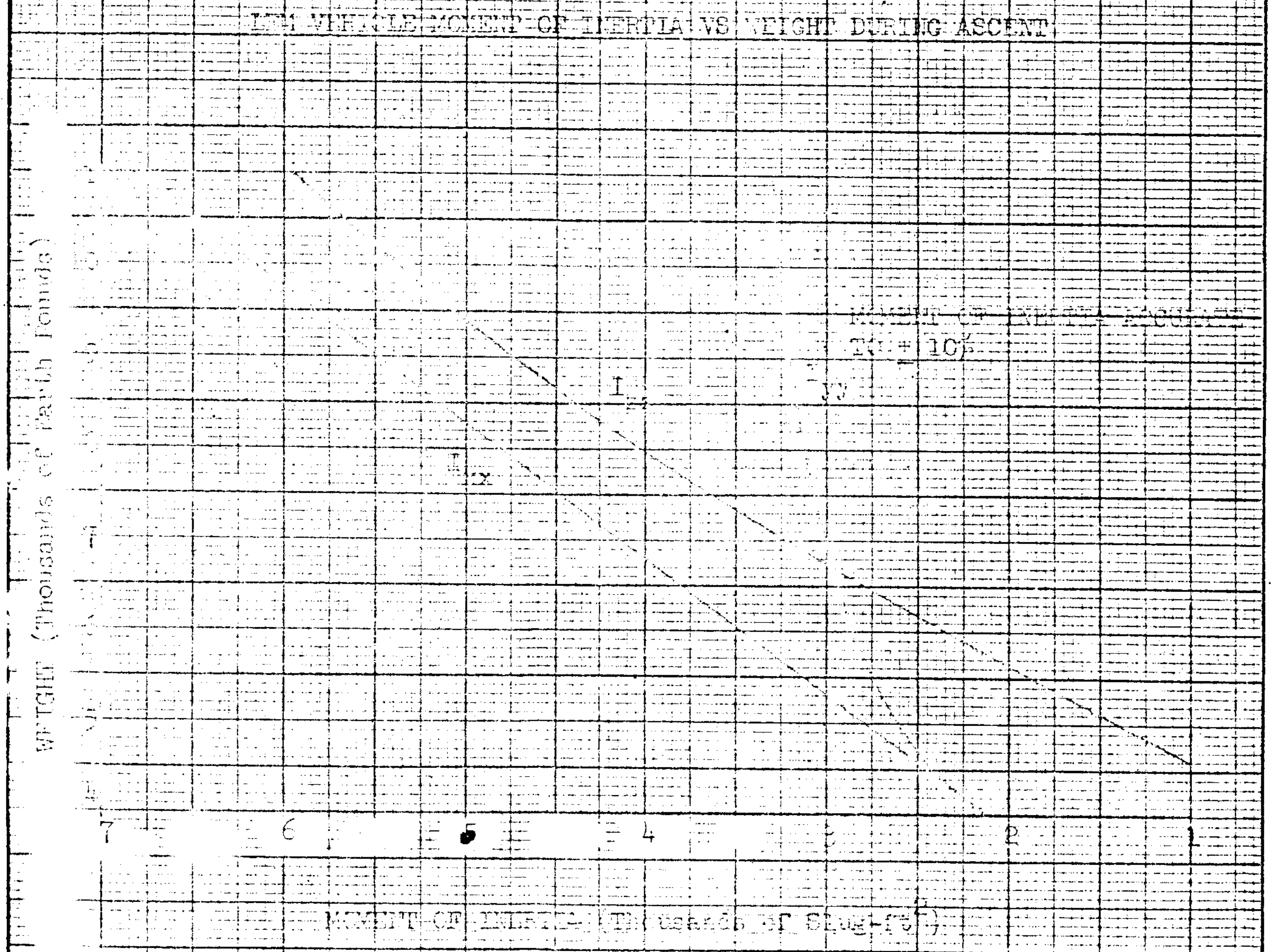


FIGURE 15

[redacted]

Eng 200.7 3-65

[redacted]

SPECIFICATION NO. LSP-370-3

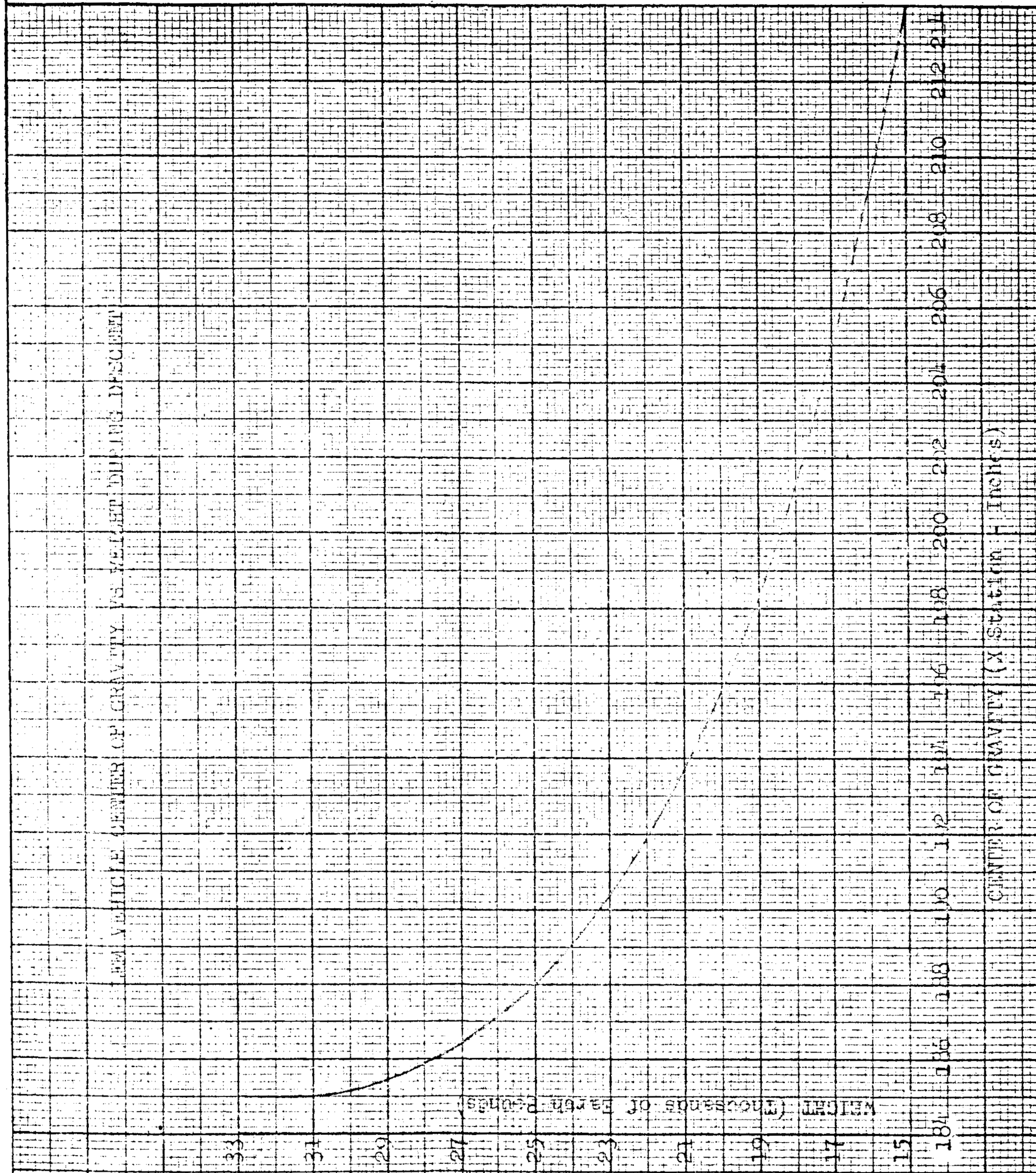


FIGURE 16

[redacted]

[redacted]

SPECIFICATION NO. LSP-370-3

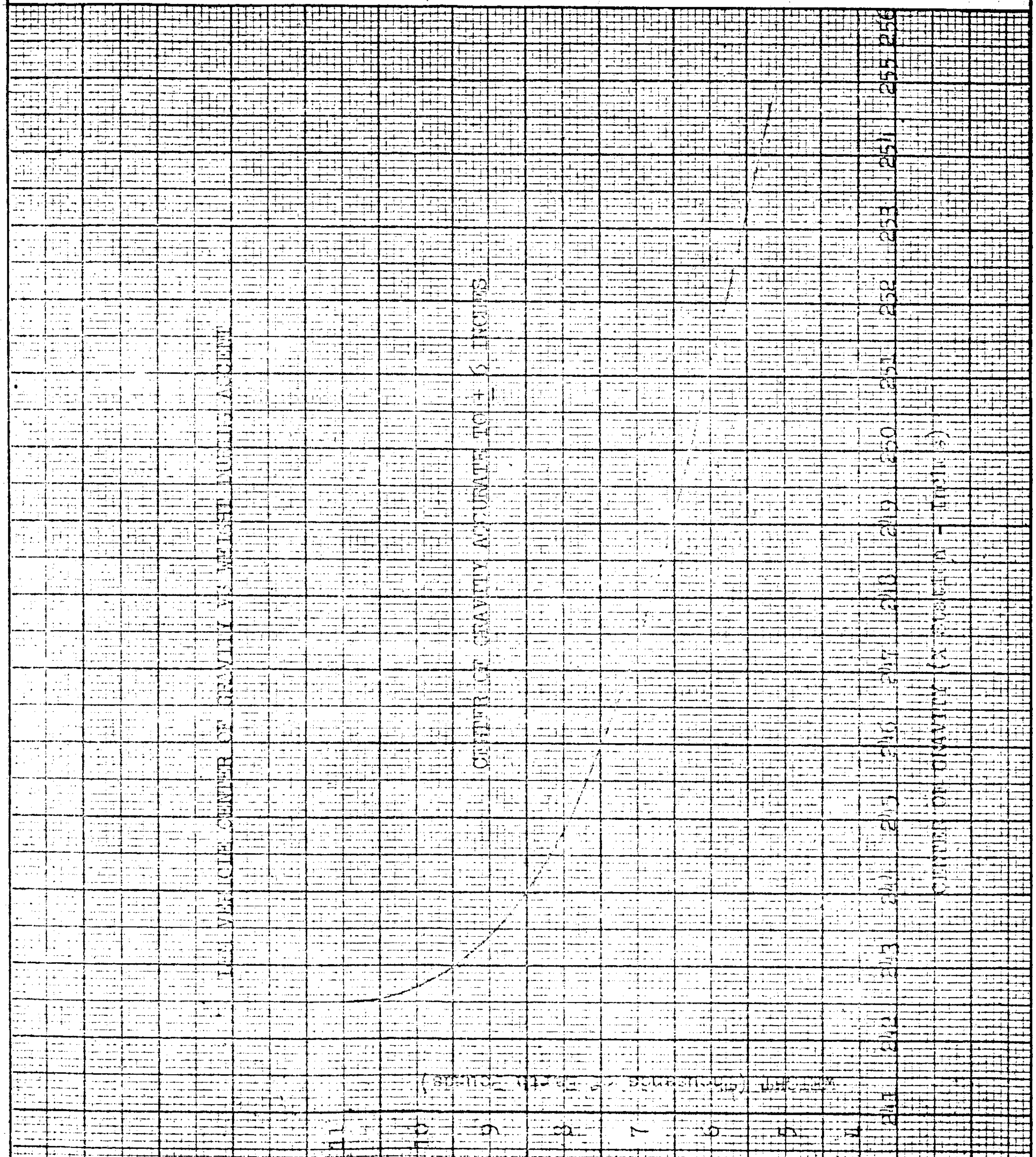


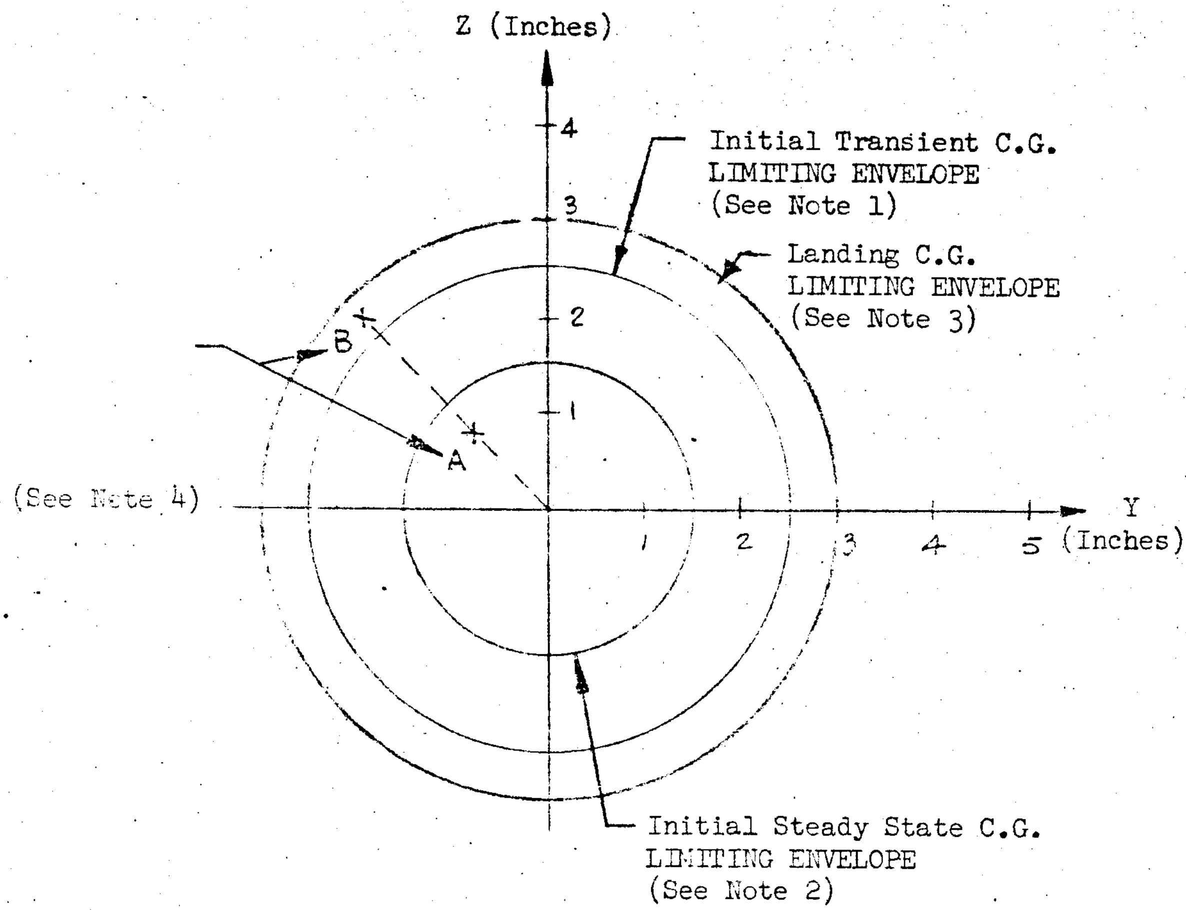
FIGURE 17

[redacted]

[redacted]

SPECIFICATION NO. LSP-370-3

RADIAL ENVELOPE OF CENTER OF GRAVITY IN SPACECRAFT Y-Z PLANE FOR DESCENT



NOTES:

(1) At engine start spacecraft C.G. is established by fixed weight C.G. plus the shift of propellant between the interconnected descent tanks. Total spacecraft C.G. will be within the initial transient C.G. LIMITING ENVELOPE shown above.

(2) After engine start the propellant in the descent tanks will be brought to a balanced condition by engine thrust. In this balanced condition spacecraft C.G. will be within the initial steady state C.G. LIMITING ENVELOPE set forth above.

(3) At landing with the propellant in a balanced condition spacecraft C.G. will be within the landing C.G. LIMITING ENVELOPE shown above.

(4) Spacecraft C.G. will nominally move along a radial line from the initial steady stage C.G. (Point A) to the final landing C.G. (Point B) as propellant is expended.

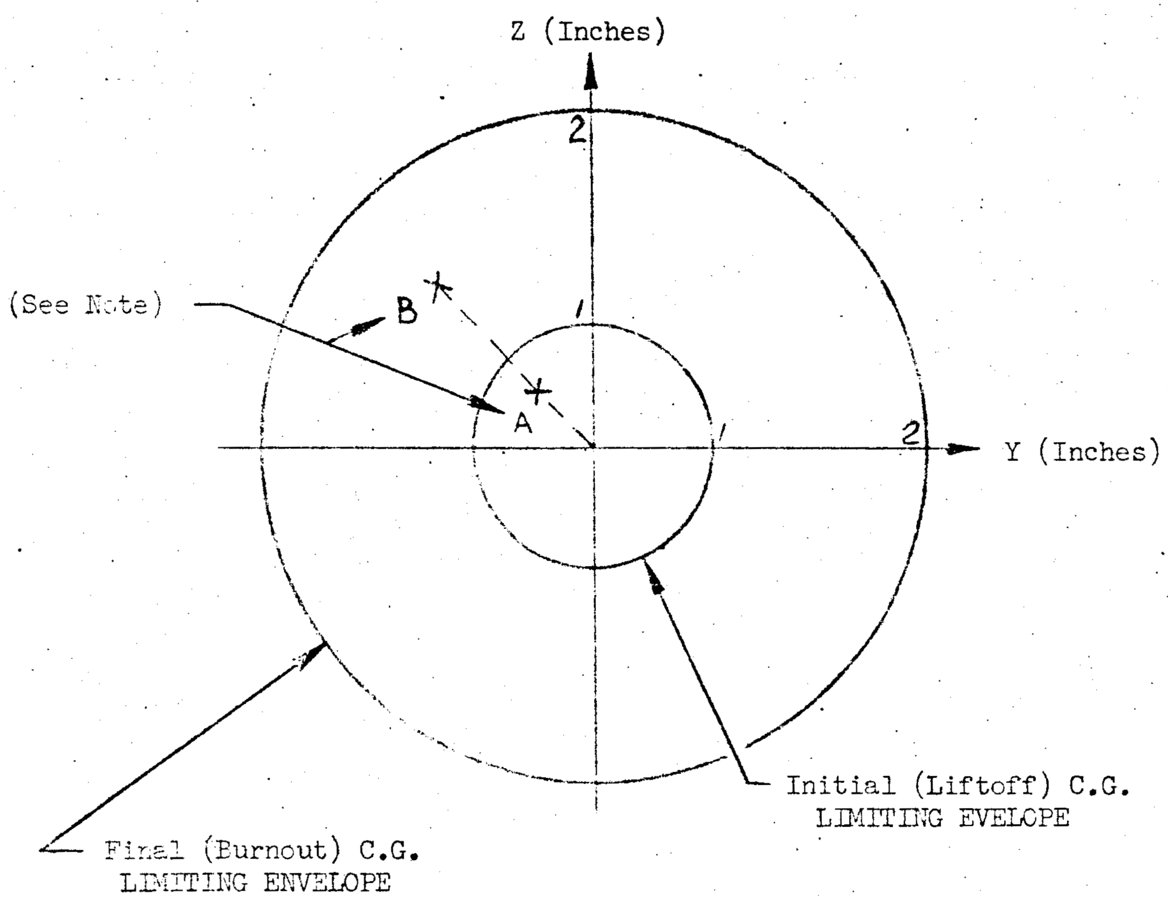
FIGURE 18

[redacted]

[redacted]

SPECIFICATION NO. LSP-370-3

RADIAL ENVELOPE OF CENTER OF GRAVITY IN SPACECRAFT Y-Z PLANE FOR ASCENT



NOTE: Spacecraft C.G. will nominally move along a radial line from the initial C.G. (Point A) to the final C.G. (Point B) as propellant is expended.

FIGURE 19

[redacted]