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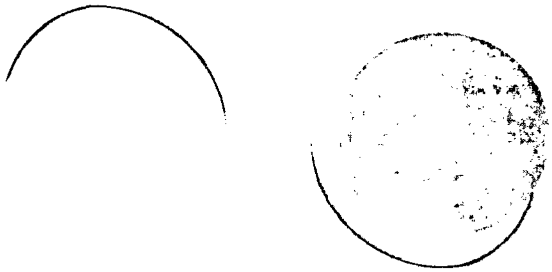

Apollo Extension Systems—Lunar Excursion Module
Phase B Final Report

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Vol. VII Truck Design Analysis Summary

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Apollo Extension Systems — Lunar Excursion Module
Phase B Final Report

to

National Aeronautics and Space Administration
Manned Spacecraft Center
Advanced Spacecraft Technology Division
Houston, Texas 77058

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Vol. VII Truck Design Analysis Summary

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Preface

This report presents the results of the Phase "B" Preliminary Definition Study (Contract NAS 9-4983) of the Lunar Excursion Module (LEM) and its modifications and additions, as necessary, for use in the Apollo Extension Systems (AES). This use includes a Laboratory for Earth and lunar orbital missions, and a Shelter, a Taxi and a Truck for extended-stay lunar surface missions. The overall objective of this study was to conduct sufficient analyses to provide a basis for selection by NASA of a single concept for each mission for final definition and development.

The study results are distributed in the volumes listed below in the following manner: Volume I contains a summary of the Preliminary Project Development Plan (PDP) with emphasis on estimates of the program costs and schedules. This volume was submitted on 30 October 1965, one month in advance of the remaining final documentation. Volume II is a brief summary of the overall study. Volumes III through XVI contain the design analyses, preliminary specifications, and operations analyses for each of the AES/LEM vehicle types. Volumes XVII through XXVI contain preliminary project planning data in the areas of management, manufacturing, development testing, and support.

It was necessary to base the preliminary project planning data, including estimated costs, on a single configuration for each of the AES/LEM vehicle types. Since these PDP data were required by the end of October, the configurations had to be selected at the mid-point of the study, before the configuration studies had been completed. These configurations have been called "baseline" configurations. The continuing design analyses in the second half of the study have resulted in recommended changes to the baseline configurations. Volumes III through VI describe the "recommended" configurations, the baseline configurations, and some additional alternates which were studied. It is anticipated that NASA will make a selection from these configurations, and that these selections will then be the new baseline configurations for the next phase of AES definition studies.

The scope of this study included integration of the experimental payloads with the Shelter and Taxi, but did not include study of the integration on individual LEM Laboratory flights. At approximately the mid-point of the study, an addendum was written with the objective of providing support to the NASA Mission Planning Task Force for study of the Phase I Laboratory flights. The schedule for the addendum calls for completion of these mission planning studies in January, 1966. Therefore, the addendum efforts are not described in this report.

The volumes which comprise this report are as follows:

I	*Phase B Preliminary Definition Plan (30 Oct 1965)*
II	*Preliminary Definition Studies Summary*
III	*Phase I Laboratory Design Analysis Summary*
IV	*Phase II Laboratory Design Analysis Summary*
V	*Shelter Design Analysis Summary*
VI	*Taxi Design Analysis Summary*
VII	*Truck Design Analysis Summary*
VIII	*Phase I Laboratory Master End Item Specification*
IX	*Phase II Laboratory Master End Item Specification*
X	*Shelter Master End Item Specification*
XI	*Taxi Master End Item Specification*
XII	*Phase I Laboratory Experimental Payload Performance & Interface Specification*
XIII	*Phase II Laboratory Experimental Payload Performance & Interface Specification*
XIV	*Shelter Experimental Payload Performance & Interface Specification*
XV	*Taxi Experimental Payload Performance & Interface Specification*
XVI	*Prelaunch & Mission Operations*
XVII	*Manufacturing Plan*
XVIII	*AES Modifications to LEM Quality Control Program Plan*
XIX	*Ground Development Test Plan*
XX	*Support Equipment Specification*
XXI	*Facilities Plan*
XXII	*Support Plan*
XXIII	*Transportation Plan*
XXIV	*Training Equipment Requirements*
XXV	*Support Equipment Requirements*
XXVI	*Management Plan*

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1. INTRODUCTION

1.1 BACKGROUND

Extended lunar exploration capability can be achieved by supplementing a manned landing with a LEM Truck, consisting of a modified LEM descent stage capable of an unmanned automatic landing from lunar orbit with a large payload. Additional components, including appropriate ascent stage subsystems, are integrated into the descent stage to meet the mission requirements.

The first Grumman studies of LEM Truck missions were accomplished as part of the Lunar Logistics System effort. Report PDR-344-3b, 22 March 1963, (contract NASW-528, Supplement 1) discussed the payload/staytime tradeoffs and provided a packaging study of specific payloads deemed most useful for early lunar exploration.

The current LEM Truck effort is part of a continuous monitoring process throughout all Phases of the AES study, to maintain the Truck consistent in concept with the other vehicles, particularly the Shelter. This volume updates the Phase A Truck report, reflecting the recommended Phase B Shelter concepts where applicable, and incorporating recent information from the basic LEM. A Reference Configuration and subsystem alternates are developed. In the areas of guidance, navigation and control, instrumentation, propulsion, communications and structure (descent stage only), the "recommended" Shelter concepts are used in the Reference Truck. Conversely, the Environmental Control and Electrical Power Subsystems reflect the differences between the Truck and Shelter missions.

In the Vehicle Design section, the Phase A conceptual design has been updated and expanded to include possible docking structures, which may also serve to support subsystem components in preferred locations.

1.2 STUDY OBJECTIVES

The continuing objectives of the Truck study are to:

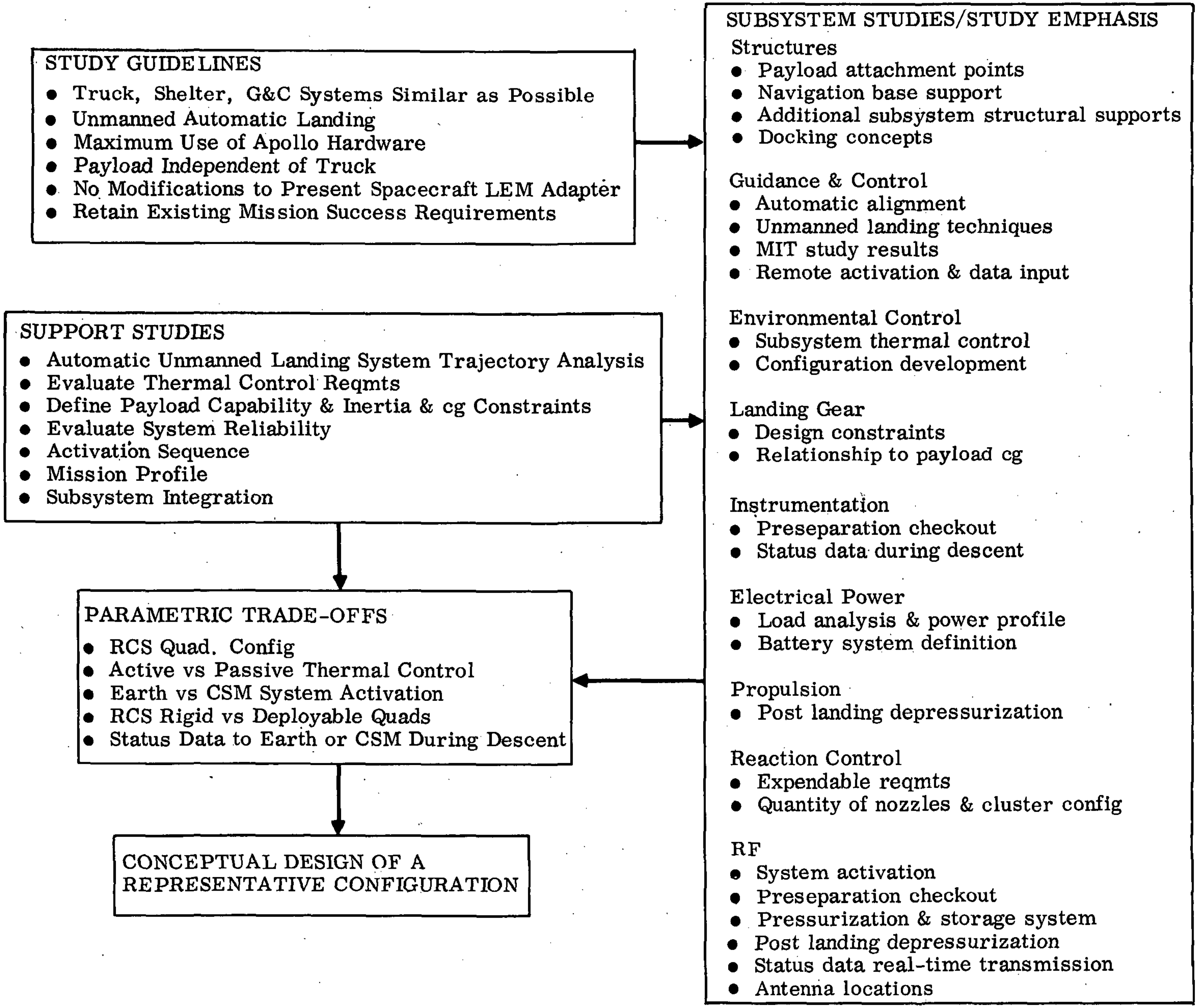
- Determine the capability of present LEM subsystems and components to perform the Truck mission
- Determine required modifications and additions to these subsystems
- Determine feasible subsystem and system configurations
- Determine weight and power profiles
- Determine payload capability.

1.3 STUDY APPROACH

The approach used in the study is indicated in Fig. 1-1. The guidelines specified in Paragraph 6.1.10 of the Statement of Work are listed at the upper left in the diagram. In addition, the following assumptions were made to develop a single conceptual design:

- Landing area is clear of obstacles and severe slopes
- Guidance and Control system can keep the descent and touchdown within the landing gear design envelope
- Status monitoring with real-time transmission is required from separation to touchdown for failure analysis
- CSM supplies electrical power to the Truck during translunar flight (a change from the Phase A assumption)
- Truck is deactivated following post-landing checkout.

Alternative assumptions which lead to a differing subsystem designs are discussed in the appropriate subsystem sections of this report.



STUDY GUIDELINES
- Truck, Shelter, G&C Systems Similar as Possible
- Unmanned Automatic Landing
- Maximum Use of Apollo Hardware
- Payload Independent of Truck
- No Modifications to Present Spacecraft LEM Adapter
- Retain Existing Mission Success Requirements

SUPPORT STUDIES
- Automatic Unmanned Landing System Trajectory Analysis
- Evaluate Thermal Control Reqmts
- Define Payload Capability & Inertia & cg Constraints
- Evaluate System Reliability
- Activation Sequence
- Mission Profile
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SUBSYSTEM STUDIES/STUDY EMPHASIS

Structures
- Payload attachment points
- Navigation base support
- Additional subsystem structural supports
- Docking concepts

Guidance & Control
- Automatic alignment
- Unmanned landing techniques
- MIT study results
- Remote activation & data input

Environmental Control
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- Configuration development

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- Relationship to payload cg

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- Status data during descent

Electrical Power
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- Battery system definition

Propulsion
- Post landing depressurization

Reaction Control
- Expendable reqmts
- Quantity of nozzles & cluster config

RF
- System activation
- Preseparation checkout
- Pressurization & storage system
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- Status data real-time transmission
- Antenna locations

PARAMETRIC TRADE-OFFS
- RCS Quad. Config
- Active vs Passive Thermal Control
- Earth vs CSM System Activation
- RCS Rigid vs Deployable Quads
- Status Data to Earth or CSM During Descent

CONCEPTUAL DESIGN OF A
REPRESENTATIVE CONFIGURATION

Fig. 1-1 Truck Study Approach

2. CONFIGURATION SUMMARY

Using the LEM Truck concept, a payload of approximately 1900 cu ft and 10,000 lb can be delivered to the lunar surface. The Truck is a LEM descent stage, modified primarily by adding selected ascent stage subsystem hardware to the descent stage. These modifications in no way degrade the primary structure.

2.1 SCOPE

The conceptual design presented in this volume is termed the "Reference" Truck, to avoid confusion with the terms "Baseline" and "Recommended", which have special meanings in the Design Analysis Summary reports for the other AES vehicles. For some Truck subsystems a single approach can be recommended; these are so labeled. However, in most areas, the work necessary to arrive at subsystem recommendations is beyond the scope of a "minimum design study effort." In these cases, various approaches are discussed, including their advantages, disadvantages and conditions favoring them, and one is referenced for use in the weight statement and vehicle configuration drawing.

2.2 CONFIGURATION DESCRIPTION

The LEM descent stage used for the Truck is a complete descent stage to which is added reaction control, communications, guidance and navigation equipment normally carried in the ascent stage. Appropriate additions are also made to the descent stage Environmental Control Subsystem to accommodate these relocated components. Principal non-LEM equipments are the Program Coupler and Digital Coder Assemblies and the Automatic Star Tracker (LEM Optical Rendezvous System). The first two are similar to components of the Mission Programmer designed for the unmanned LEM test flight. The Star Tracker is the same as that used on the Shelter.

In addition to the ground rule specifying use of LEM hardware, and the physical constraints of the Spacecraft LEM Adapter (SLA), the Truck configuration is influenced by the following events in the mission profile:

- Transposition and docking: This maneuver requires appropriate structure to join the CSM and Truck, keeping the combined cg along the SM engine thrust line, and to provide an umbilical for the supply of translunar flight electric power to the Truck.
- Truck activation and checkout: Capability must be provided to accomplish this remotely, by umbilical or by communications link.
- Unmanned descent and landing: Involves automatic updating of the IMU (requiring Star Tracker), automatic landing capability, and automatic accomplishment of post-landing activities.

The Reference Truck is summarized relative to the basic LEM in Table 2-1, which also includes subsystem alternates where applicable. Remarks concerning the Reference Truck subsystems are presented below.

- Stabilization and Control: As in the Shelter, the Rate Gyro Assembly and Abort Guidance System are removed.

- Navigation and Guidance: Rendezvous Radar is removed and communication equipment is added to permit control from Earth during the unmanned descent, touchdown, and post-landing assessment.
- Environmental Control: An active system, employing glycol loop and water boiler, is used. The heat rejected is equivalent to 5 kw-hr, and approximately 20 lb of water is required.
- Landing Gear: No change from the present LEM is required.
- Instrumentation: Existing LEM components are used, except that the data storage capability is removed, as well as one of the two chassis of the SCEA. The remaining chassis can handle the measurements anticipated for the Truck, but some rewiring of its input-output routings and new subassembly configurations are required.
- Electric Power: Two redundant primary batteries, similar to those used in the LEM ascent stage, an inverter, and associated power supply and distribution equipment are used.
- Descent Propulsion: All LEM components are retained. In addition, squib-actuated vent valves are installed for post-landing depressurization.
- Reaction Control: Thruster locations are indexed between the landing gear supports. An eight-nozzle configuration is used, in which the upward firing nozzles are canted outboard to avoid plume impingement on the payload volume.
- Communications: LEM components are used for all functions except those associated with the automatic landing, in which case the Shelter concepts are employed.

TABLE 2-1

REFERENCE TRUCK SUMMARY

With Respect To LEM					Alternates (with respect to Reference Configuration)
Item	Change	Removed	Modified	Added	
1.0	Structure	Ascent Stage Stage Separation System Egress Platform		RCS Thruster Supports Equipment Brackets Navigation Base	
2.0	Stabilization & Control	Rate Gyro Assembly Abort Guidance System			
3.0	Navigation & Guidance	Rendezvous Radar AOT		S-Band Ant X-Y Scanner Transponder Program Coupler Assy Auto Tracker Assy	Add Rendezvous Radar
4.0	Crew Provisions	All Crew Provisions Removed (Not Applicable to Truck)			
5.0	Environmental Control*	All Life Support	Glycol Pump Cold Plates		Semi-Active Cooling System
6.0	Landing Gear		No Change		
7.0	Instrumentation	Data Storage LEM Scientific Equipment	Sensors SCEA		
8.0	Electrical Power Supply**	Descent Batteries Inverters (except one)	ECA	Redundant Ascent Battery & ECA	Remove Redundant Battery and ECA New 5-kw-hr Battery Add Redundant 5kw-hr Battery & ECA

Table 2-1 (Cont.)

With Respect to LEM					Alternates (with respect to Reference Configuration)
Item	Change	Removed	Modified	Added	
9.0	Propulsion	Ascent Propulsion System		Vent Valves to Descent Propulsion Plumbing	
10.0	Reaction Control	336-lb Propellant One Fuel Tank One Oxidizer Tank One Set Plumbing One Helium Tank 50% Helium 50% Press. Plumbing 8 Thruster Assys 50% Cluster Hardware	Cant Angle of Two Nozzles	Vent Valves to Plumbing	8 Thruster Config-uncanted 16 Thruster Config-4 canted Extendible Clusters
11.0	Communications	Television		Command Decoder DCA Antenna Switching Matrix	Beacon Landing
12.0	Controls & Displays	All Controls and Displays		Automatic Controls	

* Items moved to Descent Stage: Water Tank, Glycol Accumulator, Water Boiler, Coolant Recirculation Assy.

** LEM ascent batteries relocated to Descent Stage.

3. MISSION ANALYSIS

3.1 OBJECTIVES

The objective of the AES Truck mission is the delivery of a payload to the lunar surface to support Taxi/Shelter type missions. The Truck is an unmanned vehicle which can be landed before, after, or concurrent with the Shelter. By supplying additional expendables and experimental equipment, the Truck can extend the duration of the Taxi/Shelter type mission and enhance the scientific investigations of the lunar surface.

3.2 GROUND RULES AND ASSUMPTIONS

- Truck shall be capable of a preprogrammed automatic landing at a predesignated lunar landing site
- Truck shall have the capability to perform the descent portion of the mission independent of ground based information and command
- Any requirements for storage will be determined, and satisfied, by the payload
- Truck shall be designed so that all operations may be accomplished independent of the illumination
- Payload shall be designed for access and operation by crew members in pressurized suits.

3.3 ANALYSIS

3.3.1 General

An important consideration in the analysis of the Truck mission is the dispersion distance allowable between the Truck and the Shelter. If the Shelter does not contain an LSSM, the farthest distance that the Truck can land from the Shelter is about 1000 ft (based on an astronaut's round trip walking time, plus useful work time, which total must not exceed the allowable PLSS time). Therefore, the Truck must "home-in" on the Shelter or vice versa, depending on the sequence of launch. This implies an aided landing, using rendezvous radar and a beacon.

If an LSSM is available on the Shelter, the maximum dispersion is determined by the maximum time allowed on the lunar surface at one time, which is 6 hr. Assuming 1 to 2 hr to load the LSSM, about 2 hr remain for the trip out and 2 hr for the return. Assuming an LSSM speed of about 5 km/hr, this gives a maximum dispersion distance of 10 km. However, at such large distances the ability to obtain and hold line-of-sight becomes difficult, if not impossible. An optical or electrical device would be necessary for the astronaut on the LSSM to "home-in" on the Truck.

3.3.2 Mission Programmer

The Truck is operable in many different modes, submodes, and subsystem configurations. Switching between modes is required during many phases of the Truck mission.

An automatic means, designated the Mission Programmer, must be provided to perform this switching function. The phases of the mission requiring programmer action are descent, and post-landing checkout.

Functions that occur at a specified time and in a fixed sequence may be pre-programmed in the LEM Guidance Computer (LGC). The Reference Truck permits Earth initiation of any functions for which it is mandatory or desirable to have an option on occurrence, timing or sequencing. Table 3-1 lists the switching functions that must be performed. In some cases the normal method of switching is in a preprogrammed sequence but a command option is retained.

It is anticipated that portions of the LEM Mission Programmer (LMP) can be used to perform command functions for the Truck. The main elements of the LMP that are considered for the Truck are the LEM Guidance Computer (LGC), the Digital Coder Assembly (DCA), and the Program Coupler Assembly (PCA). The LGC provides the means for storage of pre-programmed information. The DCA is the uplink receiver and decoder for Earth commands. The PCA provides the relay switching for the execution of commands. The limiting item in the LMP design is the PCA. It must contain a sufficient number of relays to handle all the functions required for the Truck mission.

The PCA contains a 16 by 16 relay matrix that is used for commands from the LGC. Each set of two relays provides a complete on-off function with latching. The matrix therefore can handle 127 on-off functions in unitary correspondence. A 16 by 6 matrix is provided to operate with the DCA. This allows 48 functions to be performed by earth command.

The minimum number of relay pairs needed to perform the functions in Table 3-1 was estimated. Some of the functions require more than two switch positions. The minimum number of relay pairs required to synthesize m-position switching is calculated by setting the maximum number of switching positions for n relay pairs equal to $2^n - (n-1)$. The minimum n was selected such that $2^n - (n-1) > m$. Using this method of estimating, the equivalent number of functions to be performed by each relay group is then derived in the following manner.

The count of functions that are to be performed by pre-programmed commands is 43. The count for Earth command is 33. Comparing these numbers with the number of switching operations available, it appears that the LMP has the functional capacity to handle the Truck mission. In addition, a comfortable growth potential exists. It is possible that detail design requirements may dictate some redesign of the LMP. Such design factors as internal rewiring of the relay matrix and current carrying capacity of the relays must be considered.

3.4 MISSION DESCRIPTION

Description of the Truck mission depends on both the sequence of launch of the Truck and Shelter and their payloads. Possible payloads for the Truck include:

- Scientific equipment, additional LSSM or MFS, or possible MOLAB vehicle.
- Life support equipment and expendables to lengthen the duration of a nominal Shelter/Taxi mission

- Combination payload of life expendables and scientific equipment, thus enabling one extended mission to achieve results of many shorter missions at less cost.

The possible missions are:

- Truck lands before the Shelter. The Shelter is not launched until verification of safe Truck landing is obtained. A landing aid on the Truck might be necessary to assure that the Shelter landing is in the immediate vicinity of the Truck.
- Truck lands at about the same time as the Shelter and is stored for up to 3 months with the Shelter. Upon the arrival of the Taxi, the Shelter is occupied and an LSSM sortie to the Truck is initiated. Payload modules on the Truck can be transported to the Shelter by the LSSM.
- Truck lands after the Shelter. This type of mission increases the lifetime of a nominal Taxi/Shelter mission while also being capable of landing any special items required to satisfy needs originally unknown, or to replace failed equipment. An example would be a failure of the LSSM initially aboard the Shelter. Since the Shelter mission depends heavily upon this mobility aid, a degraded mission would result. By informing Earth, a new LSSM could be delivered by the Truck, and the original mission completed.

3.5 MISSION PROFILE

A mission profile was prepared to determine subsystem operational conditions and performance requirements. The profile is outlined in Table 3-2 which lists the primary mission phases and corresponding durations. The Design Reference Mission (prepared by the AMPTF) and the Critical Design Reference Mission for the Electrical Power Subsystem on the LEM Program, were used as references in establishing the mission profile.

The durations shown provide a conservative input to the subsystems where quantity of expendables is a function of time. A 90-min period for Truck activation and checkout appears adequate. A detailed time line, which would include communication windows with Earth, may indicate the advisability of increasing this to one or more orbital periods, or commencing the phase during translunar flight.

Table 3-1

PROGRAMMED SWITCHING FUNCTIONS

Phase	Functions
Prelaunch	Check out all subsystems - activate IMU heater (assume 10-w heater required) - place all subsystems in off position.
Launch thru translunar insertion	IMU heater on, all other subsystems off.
Transposition & S-IVB separation	IMU heater on, all other subsystems off; connect hard line between Truck and CM to provide electrical power to Truck and for S-IVB separation command.
Translunar	All subsystems off - IMU heater on; spacecraft makes 2.5 rev/hr for thermal balance
Lunar orbit insertion	All subsystems off - IMU heater on
Lunar orbit coast	No change
Lunar orbit checkout; prepare for Truck separation	1. Start instrumentation 2. Start communications 3. Deploy antennas 4. Check battery status 5. Start ECS 6. Activate pyro circuit 7. Deploy landing gear 8. Start S&C 9. Start N&G 10. Align N&G IMU 11. Arm RCS pyro circuit 12. Pressurize RCS 13. Check RCS 14. Arm descent engine propellant section 15. Press. descent engine propellant section 16. Check descent engine propellant section 17. Perform all self-test programs 18. Insert lunar orbit parameters in computer 19. Arm event timer or mission programmer 20. Disengage umbilicals to Truck 21. Separate from CSM; move to 750-ft range; yaw & pitch to correct orientation for transfer orbit insertion using RCS jets
Transfer orbit insertion	Fire descent engine at 10% thrust, gimbal engine to balance cg misalignment
Coast	Update IMU at 60, 40, 20 n.mi altitude; maintain attitude hold with RCS jets; rotate Truck as necessary for star sightings
Powered descent to touchdown	All systems operate as required to perform mission
Post-landing activities	Final status data; report propellant venting of descent propulsion and RCS. (A timed sequential triggering of venting valves); subsystem shutdown

Table 3-2

MISSION PROFILE

Mission Phase	Phase Duration, min	Accum. Time, min
Countdown	600.0	600.0
Launch to transposition	347.0	947.0
Translunar flight to coast in lunar orbit	6696.0	7643.0
Truck activation and checkout	90.0	7733.0
Separation	1.3	7734.3
Attitude orientation	28.7	7763.0
Transfer orbit insertion	0.5	7763.5
Coast to pericynthion	60.0	7823.5
Initial powered descent	6.0	7829.5
Final powered descent	2.0	7831.5
Hover to touchdown	3.0	7834.5

4. SYSTEMS ENGINEERING

4.1 THERMODYNAMICS

4.1.1 Asumptions

The following assumptions are used in evaluating Truck thermodynamic design concepts and associated performance:

- Truck will have the same vehicle restrictions as the present LEM during translunar flight, i.e., rotation about its axis with the sun never more than ±20 deg from a perpendicular to the X axis of the vehicle.
- Truck descent stage is thermally isolated from the payload.
- Payload will have its own thermal control system, independent of the Truck.

4.1.2 Backround Data

4.1.2.1 Structural Temperature Analysis

The Truck consists of structure, electronic equipment, fuel tanks, water tank and batteries thermally coupled. Total Truck weight is approximately 22,000 lb. This large mass is protected from the external environment by the insulated vehicle skins. The temperature transients of the descent stage during translunar flight will be damped by the thermal inertia of this large insulated mass. Rotation of the vehicle during translunar flight further minimizes the temperature extremes by limiting the time in sun for any given skin section. Figure 4.1-1 shows the temperature history of the inner and outer structure, electronic equipment, fuel tanks, and batteries during translunar flight. The batteries and electronic equipment are insulated from the outer structure. This design, plus the use of the glycol cooling loop during checkout/separation to lunar landing, keeps the equipment within its design limits. In addition, the glycol loop will absorb the added heat soaked back to the equipment during the engine firing phase of the mission.

4.1.2.2 Special Requirements

4.1.2.2.1 IMU Heater Requirements (Docking Structure Location). For unmanned lunar landing, the Truck requires the addition of an optical star tracker. The tracker is located outside the vehicle. One configuration considered is to attach the tracker to the IMU in the location of the present AOT, using the present LEM navigation base mounted in the docking structure. The ASA is removed. When the tracker is operating, it dissipates approximately 40 w and cooling is required. This is accomplished by extending the coolant loop to the tracker heat-dissipating areas. During translunar flight, the tracker will be turned off (no internal heat generated). In this mode, heat will be lost from the IMU to the colder tracker, and in turn radiated to space (approximately 3.5 sq ft of tracker area is exposed to space). This heat drain will increase the output of the IMU proportional heater. Heater power is required by the IMU to maintain its accelerometers above their calibration temperature (120°F). At present, temperature control is accomplished by utilizing the cooling loop as well as the heaters. This mode of operation causes excess heater power, since the proportional heater has to over-drive the coolant loop. For the Truck, a by-pass valve will be incorporated into the coolant loop to bypass the IMU when it is not operating. The two main modes of heat loss from the IMU are as follows:

- Heat lost through the navigation base to the docking structure.
- Heat lost to the auto tracker, and out to space

The heat lost to the docking structure is presented as a function of temperature in Fig. 4.1-2. Heat lost to the auto tracker is primarily a function of the conductive coupling between tracker and IMU, the percent time in sunlight for the tracker, and the absorptance to emittance ratio (α/ϵ) of the ablated CSM skin which is viewed by the tracker. Figure 4.1-3 presents tracker temperature and IMU heater power as a function of percent tracker time in sunlight for two values of CSM skin, ($\alpha/\epsilon = 0.4$ and 1.0, the expected range after ablation). The conductive coupling between IMU and tracker used is 0.7 btu/hr°F. The radiative heat loss is minimized by insulating between the IMU and vehicle skin, and providing an insulated cover over the outer tracker telescope. Imposing the present LEM restrictions on vehicle orientation during translunar flight, the most probable values of percent time in sunlight for the tracker will be between 35 to 50%. Thus, as shown in Fig. 4.1-3, the heater power needed to maintain the IMU at 135°F will be between 20 to 25 w (for heat loss to tracker). The total heater power required, including the heat leak to the docking structure, is as follows for two docking structure temperatures.

Average Docking Structure Temperature (°F)	Total Heater Power (w)
70	35
40	39

4.1.2.2.2 IMU and Star Tracker Requirements (Reference Truck Location). In the Reference Truck, the IMU and star tracker are located on top of the landing gear truss, the tracker has a viewing field of space of 120 deg in elevation and ±90 deg in azimuth. Since a new structural support system is required, care would be taken to design the system so as to minimize IMU heater requirements. The following would be incorporated into the design:

- Minimization of the conductive path between the IMU and star tracker by use of low-conductive supports, such as titanium tubing
- Minimization of the conductive path between IMU and outer structure (also considering titanium tubing)
- Insulation of the tracker assembly below the thermal shield and provision of a protective cover over the outer tracker telescope to minimize heat leakage to space
- Insulation between IMU and vehicle skin.

If the above design were implemented, the heater requirement for the IMU under the worst flight conditions would be under 20 w. This compares favorably with the IMU heater requirement of under 40 w when in the docking structure location, but requires a completely new design. A trade-off, considering all phases of the design, will have to be performed before a configuration can be selected.

4.1.2.2.3 RCS Temperature Control. During translunar flight, RCS injection plate temperature must be kept below 150°F. In the LEM, the RCS clusters are mounted on the ascent stage and are coupled thermally to the ascent stage structure. This coupling stabilizing the RCS injector temperatures by absorbing heat gains or making up heat losses by radiation from the ascent stage structure. With the RCS moved to the descent stage, as it is in the Reference Truck, the effective conductive coupling between the RCS injector and descent stage should be above 0.6 btu/hr °F to prevent the injector from going above 150°F. Figure 4.1-4 presents injector temperature as a function of this effective conductive coupling for the two extremes of descent stage temperature (40 and 90°F).

4.1.2.2.4 S-Band Steerable Antenna. This antenna, when not in use and receiving solar energy, requires heater power to maintain the antenna's steering components above their low-temperature survival limits. Components, such as servomotors, electronic equipment, and the gimbal mechanism must be maintained above -65°F. If the antenna is to be relocated in the descent stage, it should not be located such that it will be eclipsed from the sun by the vehicle. If the unit is not receiving any external heat flux, 5 w of heater power will be required to maintain it above its survival temperature.

4.1.3 Recommended Configuration

During translunar flight there is a minimum of on-board activity. In addition, the descent heat loss is sufficiently small that active cooling is not required. From checkout through lunar landing the glycol system will provide all the necessary cooling. The heat absorbed by the glycol system will be transferred to a LEM type water boiler. The total water required for this phase of the mission is 13.5 lb. The distribution of the cooling load is as follows:

	Average cooling Load (w)
Descent Bay High-Temperature Electronics	630
Descent Bay Low-Temperature Electronics	500
+10% For Power Peaks	110

4.1.4 Alternate Configuration - Utilization of Passive Cooling Capabilities

The Truck has passive cooling capabilities when in translunar flight or in lunar orbit. This potential can be utilized to cool equipment. The methods considered, in increasing order of complexity and weight, that are feasible for the Truck are:

- Equipment radiates its dissipated heat to a low α/ϵ skin, which in turn radiates to space.
- The above scheme, with a thermostatically operated internal shutter, whose movement exposes more or less of the radiating surface, thus raising or lowering the heat rejection capabilities of the equipment to the external skin.
- Equipment radiates directly to space with a shade that is thermostatically controlled to open or close exposing more or less equipment surface area directly to space. The equipment surface is painted with a low α/ϵ paint, such as LTV 602.

The capabilities of the above approaches are tabulated below. The left column indicates the maximum wattage that the equipment can dissipate, when in a maximum external heat flux orientation, and still be below 135°F. Having designed for the maximum wattage, then the right column is the heat that must be dissipated by equipment to remain above 35°F when in a minimum heat flux orientation. Truck equipment heat dissipation data is presented below for the extremes of two flight conditions: translunar, and lunar orbit.

	Translunar		Lunar Orbit	
	Full Sun Q Max 135°F (w)	No Sun Q Min 35°F (w)	Q Max 135°F (w)	Q Min 35°F (w)
Radiation to skin	14.6	12.0	13.8	9.5
Radiation to skin with internal Shutter	14.6	4.4	13.8	2.9
Radiation to space with external Shade	23.0	4.6	22.5	3.1

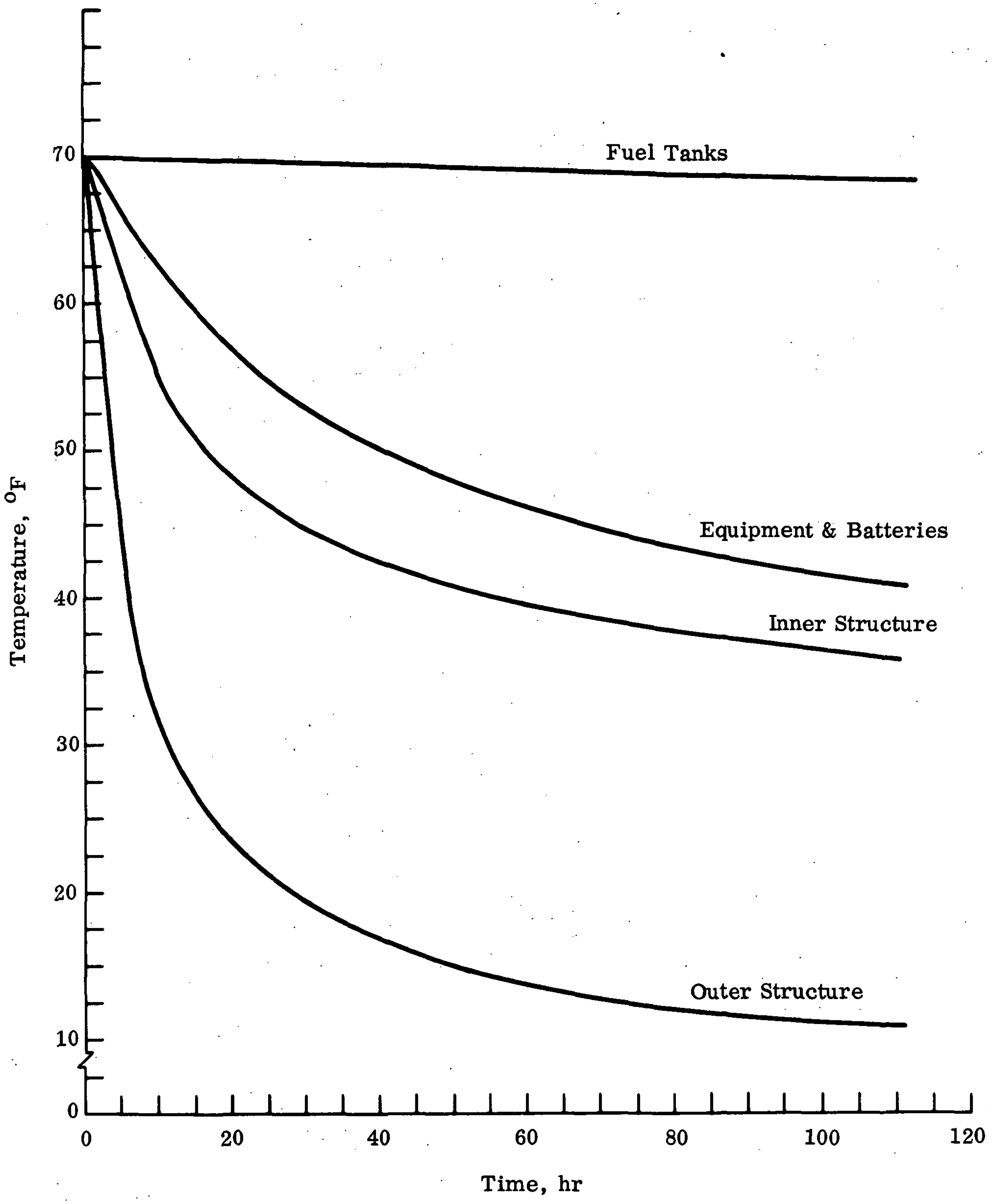


Fig. 4.1-1 Equipment Temperature History

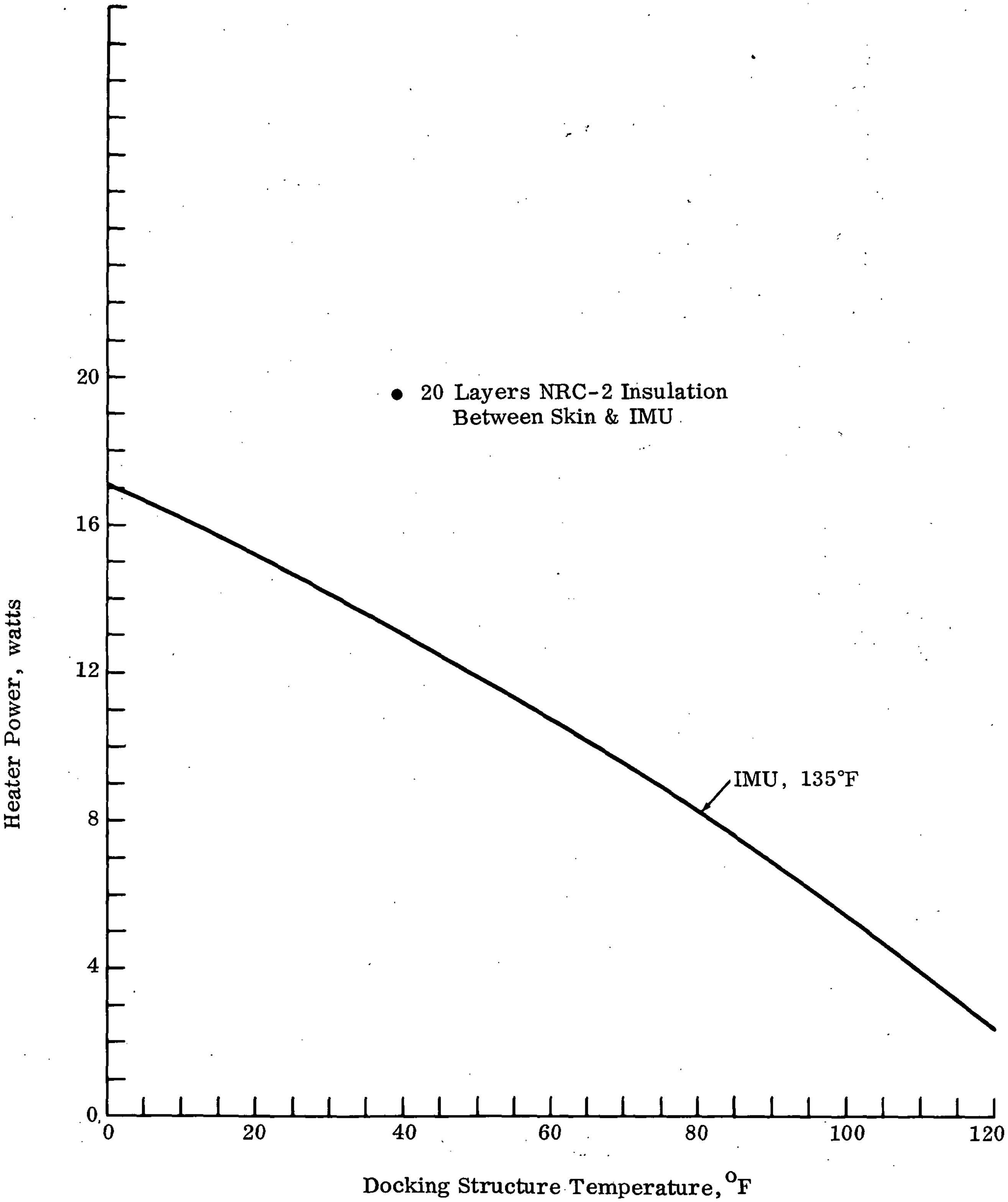


Fig. 4.1-2 IMU Heater Requirements

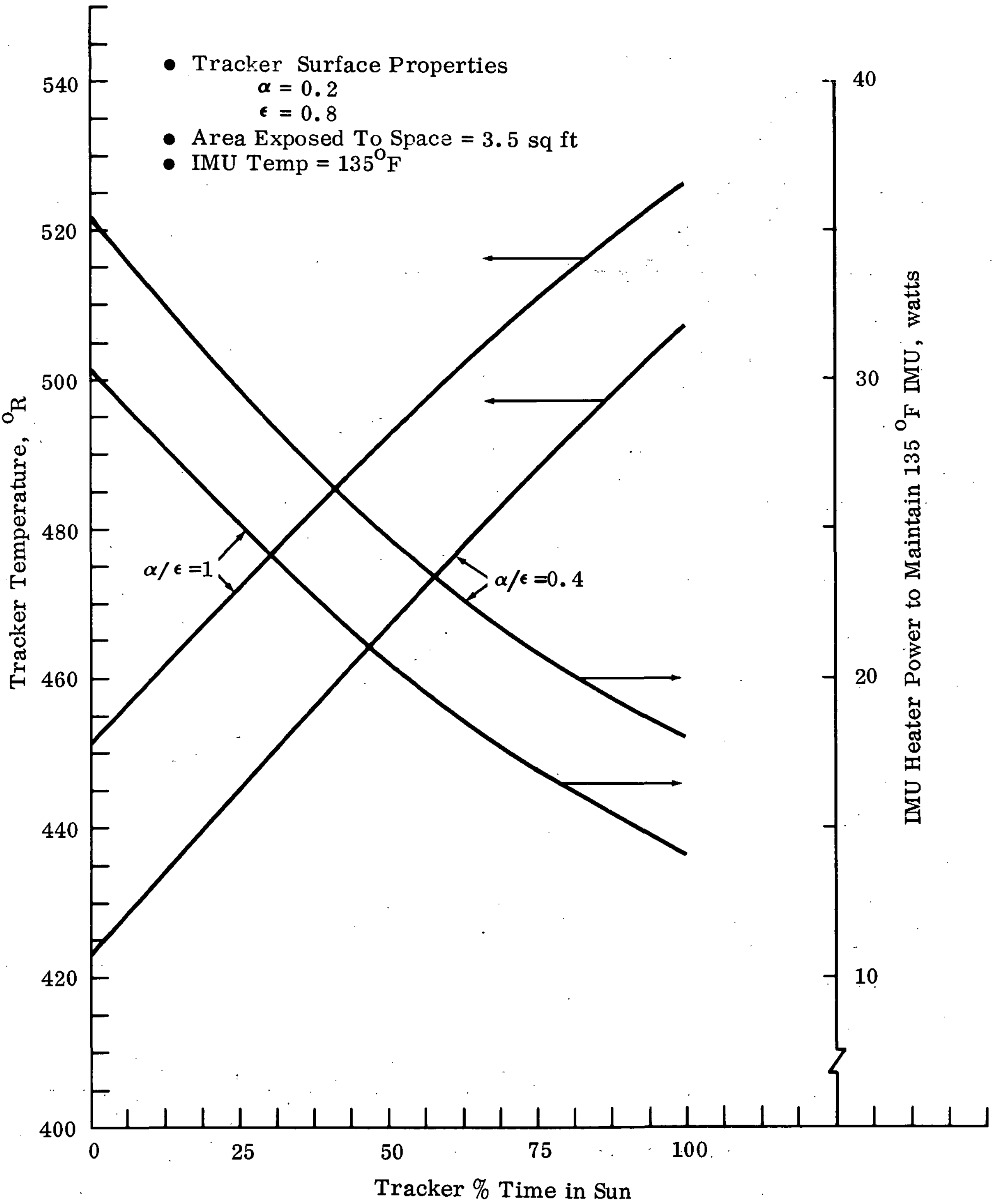


Fig. 4.1-3 IMU Heater Requirements vs % Time in Sunlight

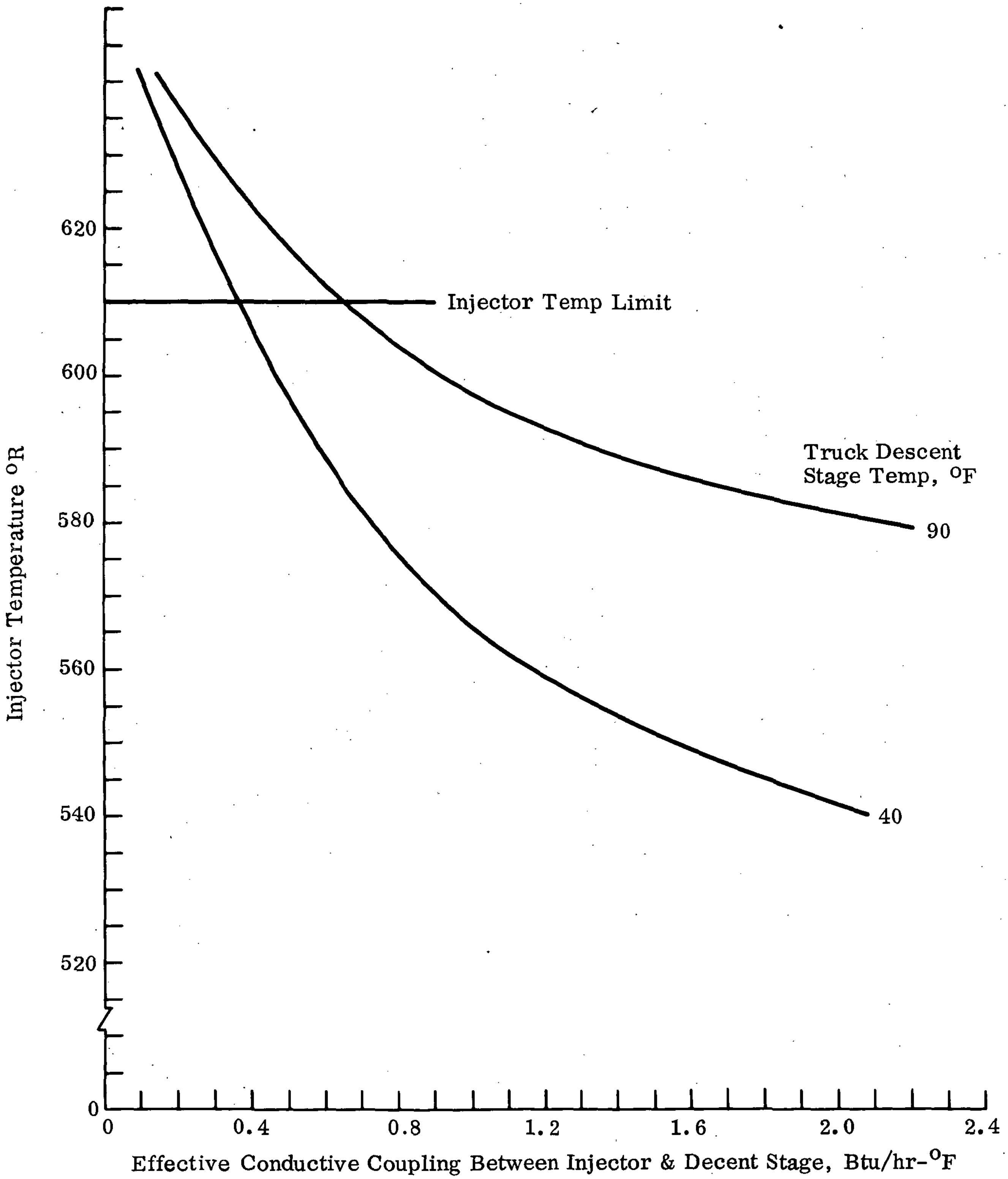


Fig. 4.1-4 RCS Injector Temperature

4.2 INTEGRATED GUIDANCE & CONTROL

4.2.1 Ground Rules

- Truck shall have the capability to make a preprogrammed unmanned automatic landing using the PNGCS
- Design for an 80-n.mi Hohmann trajectory; study effects of direct descent trajectory.

4.2.2 Direct Descent vs Hohmann Transfer

Figure 4.2-1 is a comparative time line of the major GN&C events associated with the two descent techniques considered here. The following advantages can be gained from the direct descent:

- Lower CEP at landing (decrease in position uncertainty)
- Higher reliability (decrease in probability of GN&C system failure)
- Fewer major GN&C events (4 as proposed to 7)
- Fewer descent propulsion system (DPS) ignitions (1 as opposed to 2)

The advantages of the Hohmann technique as compared to the direct are as follows:

- Minimum change to current LEM GN&C guidance equations (software)
- Truck will be visible to the CSM at touchdown (of questionable value).

In computing the CEP, the uncertainties resulting from the MIT Model 4 orbit navigation scheme as applied to the nominal LEM Hohmann descent were used for the initial condition uncertainties (position and velocity) for both trajectories.

The analysis assumed that sufficient time existed before the initiation of powered descent to allow for an additional onboard landmark sighting, or to allow for a final navigation update from Earth based MSFN tracking data transmitted to the Truck via the data link. This additional potential for improving the accuracy of the GN&C system can only exist if the data uplink capabilities of the PGNCS are modified to allow automatic update.

Preliminary reliability figures were computed for a GN&C configuration which replaced the rendezvous radar and alignment optical telescope with the LEM optical rendezvous system. The estimates obtained were 0.9940992 for the direct descent case, and 0.992568 for the Hohmann descent. The lower reliability figure for the Hohmann transfer case is essentially due to the longer operating time of all the equipment.

The errors in velocity to be expected at touchdown, and the time at which the DPS will be performing at high thrust levels, will be approximately the same for both techniuqes.

4.2.2.1 Δ V Requirements

Figure 4.2-2 indicates the minimum ΔV required to perform the Truck landing using either a direct powered descent or a Hohmann transfer technique, as a function of CSM parking orbit altitude. The ΔV values used to generate this figure were taken from Ref. 4-1 and 4-2 assuming an initial T/W of 0.323. It should be noted that these ΔV values represent the minimum fuel expenditure required to perform a braking maneuver between two specified conditions of position and velocity. Additional fuel expenditure will be required over and above that quoted in Fig. 4.2-2 to provide flexibility for guidance and control uncertainties and operational requirements.

Typical ΔV expenditures for Hohmann and direct descents, including allowance for performing a direct descent from 20 n.mi are 5919 and 6017 fps, respectively. (Note that these values exceed those shown in Fig. 4.2-2 by the amount of allowance made for contingencies -- relative values are not affected, nor are the resulting conclusions different.)

Compared with the current LEM Hohmann approach (i.e., transfer from 80 n.mi to 50,000-ft pericynthion altitude), a direct descent from 20 n.mi would save approximately 100-fps ΔV in the LEM budget. To achieve a comparable Truck ΔV savings using the Hohmann technique, the parking orbit altitude must be lowered to 44 n.mi. The SPS ΔV required to lower the CSM parking orbit from 80 to 20 n.mi, during insertion from the translunar trajectory, would be approximately 37 fps. The additional SPS propellant requirement is available from the 680-fps ΔV allocated for CSM rescue of LEM (Ref 4-3). In the Truck mission, no CSM rescue requirements are foreseen and therefore these additional propellants should be available for modifying the mission to increase payload.

A direct descent from 20 n.mi would require approximately the same engine duty cycle as that for a 80-n.mi Hohmann descent. A unique advantage of the direct approach is the requirement for only one engine ignition as opposed to two required in the Hohmann approach.

4.2.2.2 Guidance

To determine the CEP attained by the 80-n.mi Hohmann using an AST, a statistical error analysis was performed along the Truck descent trajectory. The statistical analysis included the effects of the 1σ uncertainties of the IMU, the Landing Radar and the 1σ uncertainty involved in the CSM orbit navigation technique. Based on this analysis, it was found that the CEP for the 80-n.mi Hohmann was 2704 ft.

uncertainty of 792 ft. In addition to CEP, the thrust and attitude deviations commanded by the guidance law to correct the trajectory wer determined. Fig. 4.2-3 is a time history of thrust deviations, and Fig. 4.2-3 is a time history of both pitch and yaw attitude deviations during powered descent. Both curves show that the thrust and attitude deviations are within the capability of the vehicle performance, i.e.: a) the maximum 1σ thrust command uncertainty is 134 lb of thrust at a throttle setting of 9888 lb (max thrust possible is 10,500 lb); and b) the maximum attitude deviation is 2.8 deg at a rate for which it is possible to compensate within the vehicle rate limit of 10 deg/sec. Examination of Fig. 4.2-2 and 4.2-3 shows a 10-sec region between the end of Phase 1 radar update and start of Phase 2 radar update. The reason for this gap is that as the velocity-to-be-gained to reach the end conditions goes to zero, the attitude commands would become extremely large. Therefore, a constant attitude phase is shown at the end of each phase to avoid erratic attitude commands.

An error performance analysis was made for the 20-n.mi direct powered descent, assuming:

- Automatic alignment via Star Tracker (coarse and fine) prior to initiation of powered descent.
- Powered descent maneuver and guidance law for powered descent similar to that for powered descent portion of Hohmann transfer trajectory.

The computed value of CEP for the 20-n.mi direct descent was 1732 ft. This represents a considerable improvement over the value computed using the Hohmann transfer prior to powered descent.

4.2.3 Eight vs Sixteen Jets RCS Configuration

The 16-jet RCS configuration for the LEM provides optimum performance and reliability for all requirements of the manned mission. The abort consideration calls for torques requiring four-jet control about certain axes in contingency situations and (manual) handling quality considerations play a major role in establishing the need for and location of the 16 jets.

However, for the Truck, neither abort nor handling qualities considerations are applicable. Two-jet rotational control can adequately meet dynamic control requirements. Translation is required only along vehicle X-axis for separation and ullage. Thus, a single system with eight RCS jets becomes a feasible configuration, if reliability is not degraded and other mechanization changes necessitated do not outweigh the savings resulting from the RCS simplification.

Two eight-jet configurations have been considered, they are:

1) Retain four of eight jets which lie in Y-Z plane for yaw control with pure couples, and retain four of eight jets aligned with X axis to generate pure couples about pitch and roll.
2) Use two -X jets for separation only (these jets will be canted to eliminate payload impingement); retain four +X jets to generate rotation about pitch and roll (no pure couple), and use two jets to generate yaw rotations (no pure couple).

Table 4.2-1 presents the operational capability of various eight-jet RCS configurations in 1 above. All possible combinations of the jets lying in the Y-Z plane were considered, assuming removal of the eight System-A jets (Fig. 4.2-4). Note that removal of System-B would result in the same control capability because of symmetry.

When one system of eight jets is removed, there are only four jets lying in the Y-Z plane, each of which can have two possible locations. Therefore, there are 16 possible Y-Z RCS jet configurations. Only 15 combinations are given in Table 4.2-1, because rotating all four jets simultaneously to their alternate positions yields the existing System-A RCS configuration.

From Table 4.2-1 it is apparent that full capability is available for response to pitch (Q), roll (R), and X translation commands if System-A is removed. It is also apparent that full capability cannot be generated by any possible configuration of the four jets lying in the Y-Z plane. However, response to yaw (P) and Y or Z translation commands can be performed, thus all Truck functional requirements can be satisfied.

Since no requirement for Y or Z translations exists for the descent trajectory, rotation of jet 7 to 8 and jet 3 to 4, or rotation of jet 12 to 11 and jet 16 to 15 will yield satisfactory performance during descent. However, it should be noted that with any of the eight-jet configurations tabulated in Table 4.2-1, failure of a single X-aligned jet will preclude completion of the Truck mission.

Utilization of the eight-jet RCS described in 2 above will impart a translation to the vehicle whenever a rotation is commanded because pure couples are not used to generate the desired control torque. Also, depending on the location of the vehicle cg, rotational coupling into the other body axis may be generated (the X axis cg is of particular concern). Additional analysis will be required to determine the effect of undesired translations and rotational coupling.

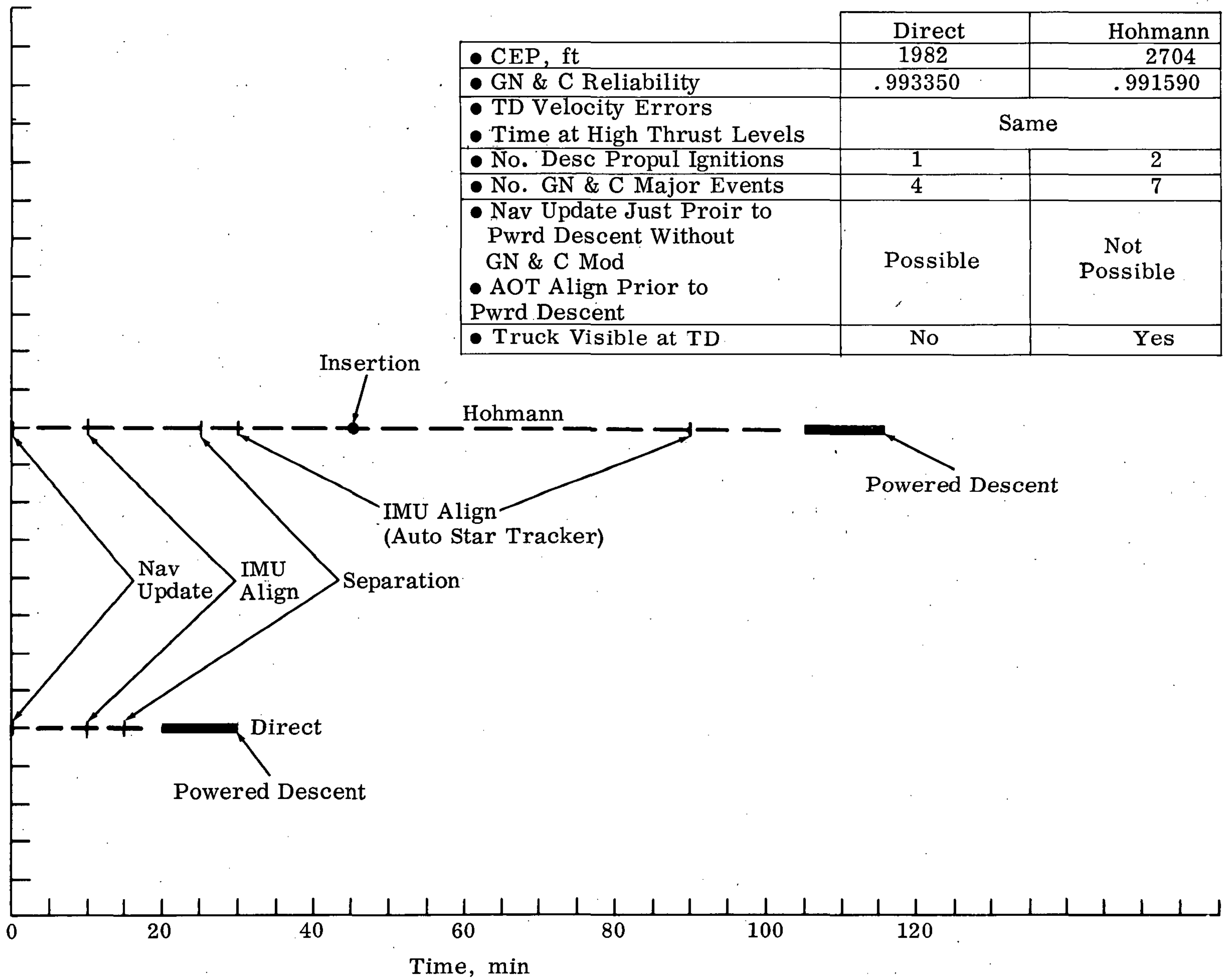
Reliability analyses have indicated very little advantage for the 16-jet configuration over an eight-jet configuration. However, going to eight jets may require modification (software) of jet logic in the LGC. The ability to use alternate jet combinations in the 16-jet configuration requires the ability to detect jet failures, and select alternate paths either manually or automatically. This requires a more thorough failure effect analysis than has been performed to date.

Table 4.2-1 Operational Capability - 8 JET RCS

Rotation or Translation Commanded	Exist'g Posit'n	Rotate Jets from___ to___													
		7 to 8 3 to 4	7 to 8 16 to 15	7 to 8 12 to 11	3 to 4 16 to 15	3 to 4 12 to 11	12 to 11 16 to 15	7 to 8	3 to 4	16 to 15	12 to 11	7 to 8 3 to 4 16 to 15	7 to 8 3 to 4 12 to 11	7 to 8 16 to 15 12 to 11	3 to 4 16 to 15 12 to 11
		Jets Used to Accomplish Rotation or Translation													
Q1	(9,14)														
Q2	(1,6)														
R1	(14,1)														
R2	(9,6)														
X1	(6,14)														
X2	(1,9)														
P1	NPC	(3,12)	NPC	NC	(7,16) or (3,12)	NPC	(7,16)	NPC	(3,12)	(7,16)	NPC	(3,12)	NPC	NPC	(7,16)
P2	NPC	(16,7)	NPC	(3,12) or (7,16)	NC	NPC	(3,12)	(7,16)	NPC	NPC	(3,12)	NPC	(7,16)	(3,12)	NC
Y1	(12,16)	(16,12)	NC	NC	NC	NC	NC	(16,12)	(16,12)	NC	NC	NC	NC	NC	NC
Y2	NC	(7,3)	NC	NC	NC	NC	NC	NC	NC	NC	NC	(3,7)	(3,7)	NC	NC
Z1	NC	NC	NC	NC	NC	(7,12)	(7,12)	NC	NC	NC	(7,12)	NC	NC	NC	(7,12)
Z2	NC	NC	(3,16)	NC	NC	NC	(3,16)	NC	NC	(3,16)	NC	NC	NC	(3,16)	NC

NC: No capability

NPC: No pure couple



	Direct	Hohmann
● CEP, ft	1982	2704
● GN & C Reliability	.993350	.991590
● TD Velocity Errors ● Time at High Thrust Levels	Same	
● No. Desc Propul Ignitions	1	2
● No. GN & C Major Events	4	7
● Nav Update Just Proir to Pwrd Descent Without GN & C Mod ● AOT Align Prior to Pwrd Descent	Possible	Not Possible
● Truck Visible at TD	No	Yes

Fig. 4.2-1 Hohmann/Direct Descent Comparison

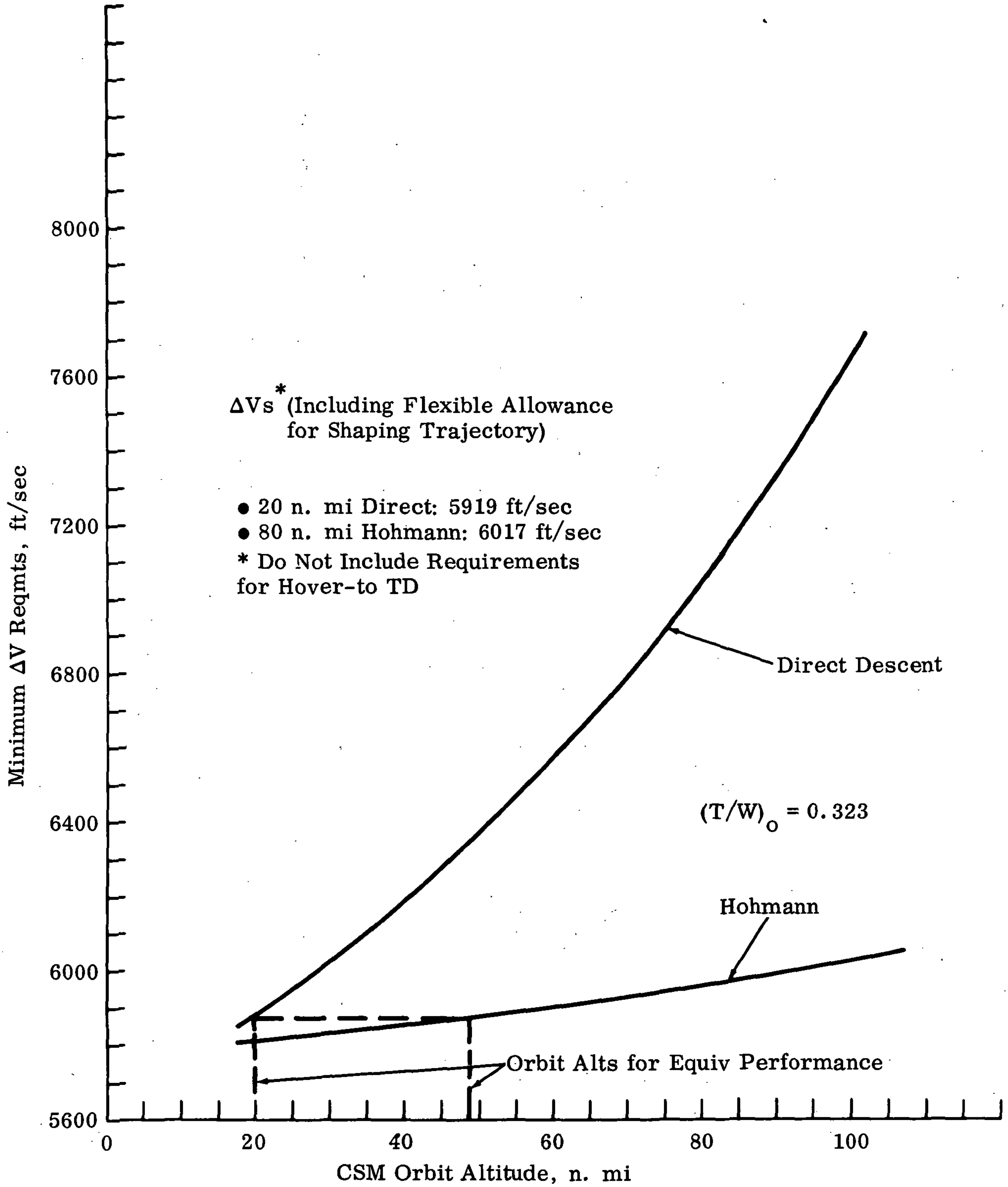


Fig. 4. 2-2 Hohmann/Direct Descent - Minimum V Requirements

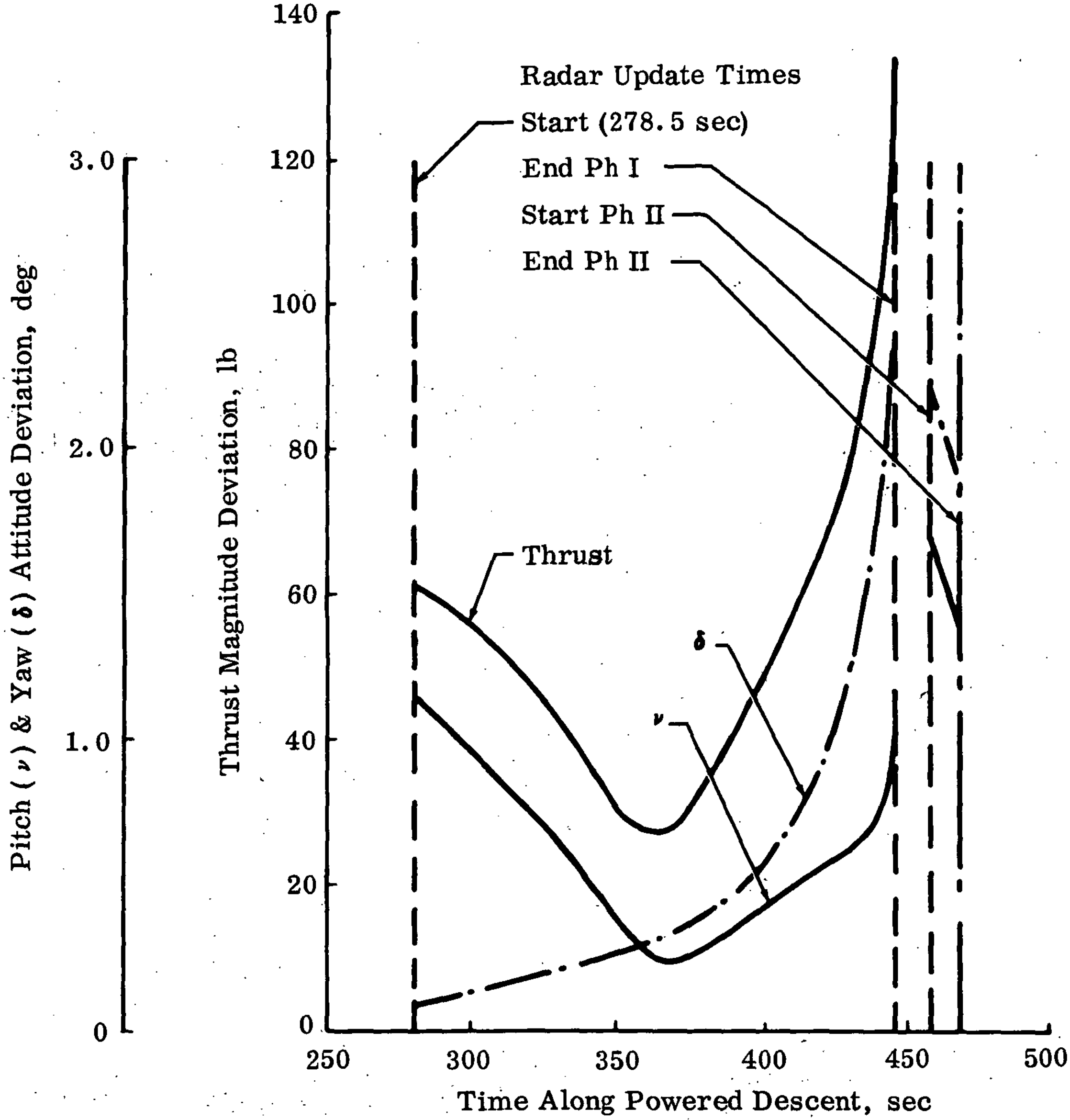


Fig. 4.2-3 Time History of Thrust Deviations and Pitch and Yaw Attitude

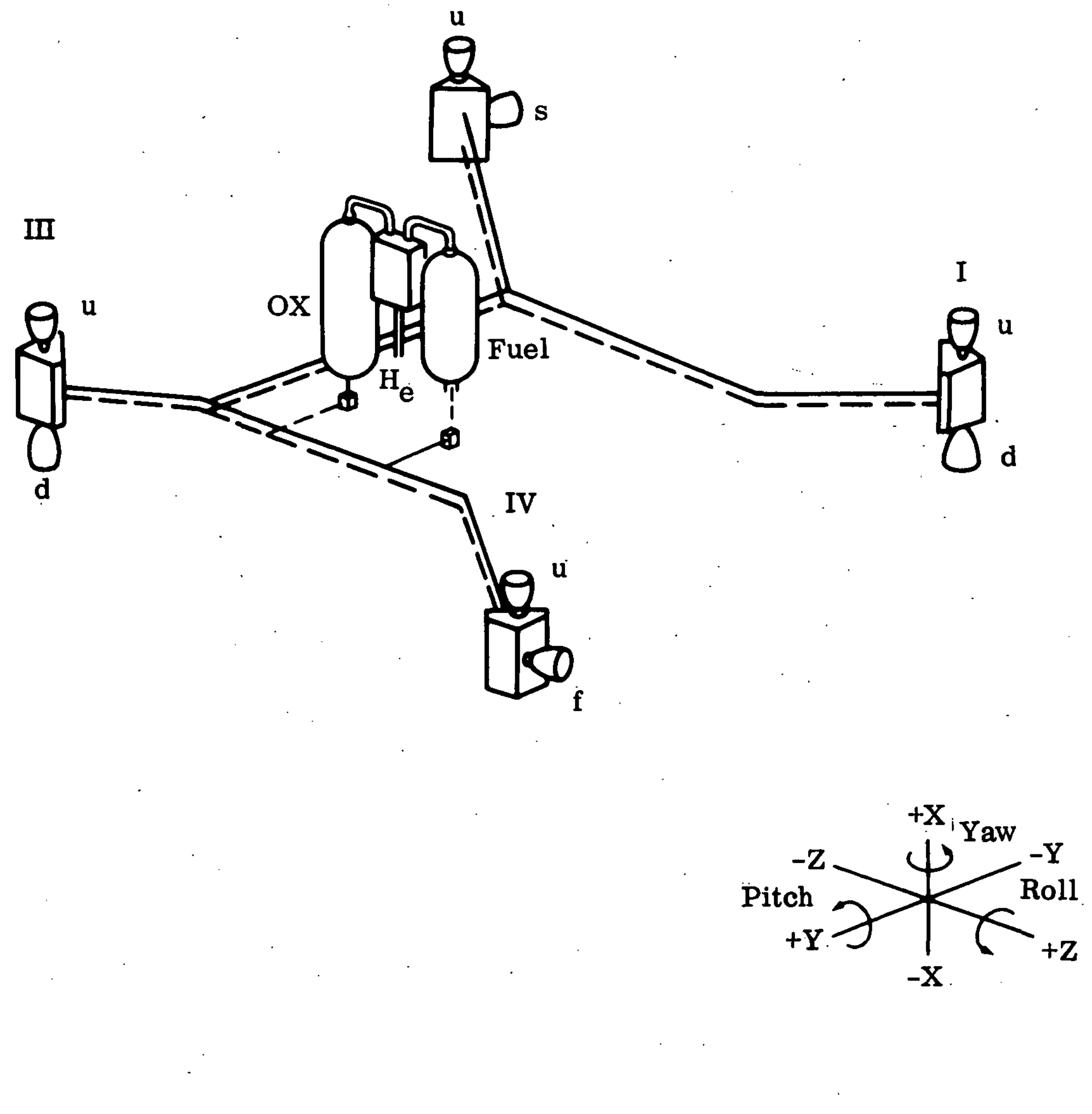


Fig. 4.2-4 Typical 8 Jet RCS Configuration

4.3 REACTION CONTROL AND PROPULSION ANALYSIS

4.3.1 Ground Rules

- An 80-n.mi Hohmann descent shall be the primary mode of descent to the lunar surface
- Direct, fully-powered descents will be studied as alternates to the primary mode.

4.3.2 Assumptions and Background Data

The following descent engine characteristics were assumed:

- Time-averaged specific impulse for all modes of descent considered in this analysis is 300 sec.
- Maximum descent engine spec operating life at near maximum thrust is 417 sec.
- When the descent propulsion system is used for SPS backup, the maximum demonstrated operating life is 512 sec.

4.3.3 Reference Configuration

The reference trajectory for the Truck employs a Hohmann descent from 80 n.mi, as described in Paragraph 4.2.

The main propulsion in the Truck is identical to the LEM descent propulsion subsystem with the exception of three additional vent valves provided for depressurizing the propellant tanks after lunar landing.

An eight-jet Reaction Control System (RCS) is used in the Reference Truck. It is similar to that recommended for the Shelter except that the two upward-firing thrusters are canted outboard, to avoid jet impingement on the payload, and are used only to separate the Truck from the CSM. This configuration and alternatives are discussed in Paragraph 5.4.

4.3.4 Alternate Configuration

4.3.4.1 Direct Descent Trajectory

An alternate mode of descent is a fully-powered 20-n.mi direct descent. Figure 4.3-1 shows that a 153-lb payload advantage can be obtained by using this mode of descent compared with an 80-n.mi Hohmann descent. Figure 4.3-2 shows that a descent engine burn time of 447 sec at near-maximum thrust is required for a direct descent from 20 n.mi. This long burn time at maximum thrust is the result of reducing the visibility phase from 115 sec for the LEM, to 20 sec for an unmanned automatic descent.

This burn time exceeds the current spec limit on the descent engine operating life (417 sec) at maximum thrust. However, when descent propulsion is used for SPS backup, the engine is required to demonstrate a lifetime of approximately 512 sec at near maximum thrust. This is an "over-stress" condition and corresponds to burning a full load of propellant at near maximum thrust. Therefore, from Figure 4.3-2, direct descents must be restricted to altitudes below 74 n.mi. Descents from higher CSM altitudes would require re-qualification of the descent engine for greater engine life at maximum thrust, larger propellant tanks, and more helium for pressurization.

4.3.4.2 Sixteen-Jet RCS

A 16-jet RCS configuration, with one set of oxidizer tanks and a single pressurization system, was considered as an alternate configuration. This configuration is discussed in Paragraph 5.4.

4.3.5 Discussion of Configuration Choice - Hohmann vs Direct Descent Landing Technique

Figure 4.3-1 shows the change in Truck payload for direct descents from various CSM parking orbit altitudes as compared with Hohmann descents. The ΔV values used to generate the curve are given in Paragraph 4.2 (Figure 4.2-2). Although these ΔV values neglect flexibility allowances for guidance and control uncertainties and operational requirements, they do represent a realistic estimate of the change in ΔV that would be required for descents employing either of the two landing techniques. It is apparent that direct descent from 20 n.mi results in an increase in Truck payload of approximately 150 lb over that which could be achieved using an 80-n.mi Hohmann descent. For a direct descent from 26 n.mi, the change in payload is zero, while direct descents from higher CSM altitudes result in a net loss in payload over that achievable using an 80-n.mi Hohmann descent.

A direct descent from 20 n.mi would require approximately the same engine duty cycle as that for an 80-n.mi Hohmann descent. With the direct descent, only one ignition of the engine is required, as opposed to two required in the Hohmann approach.

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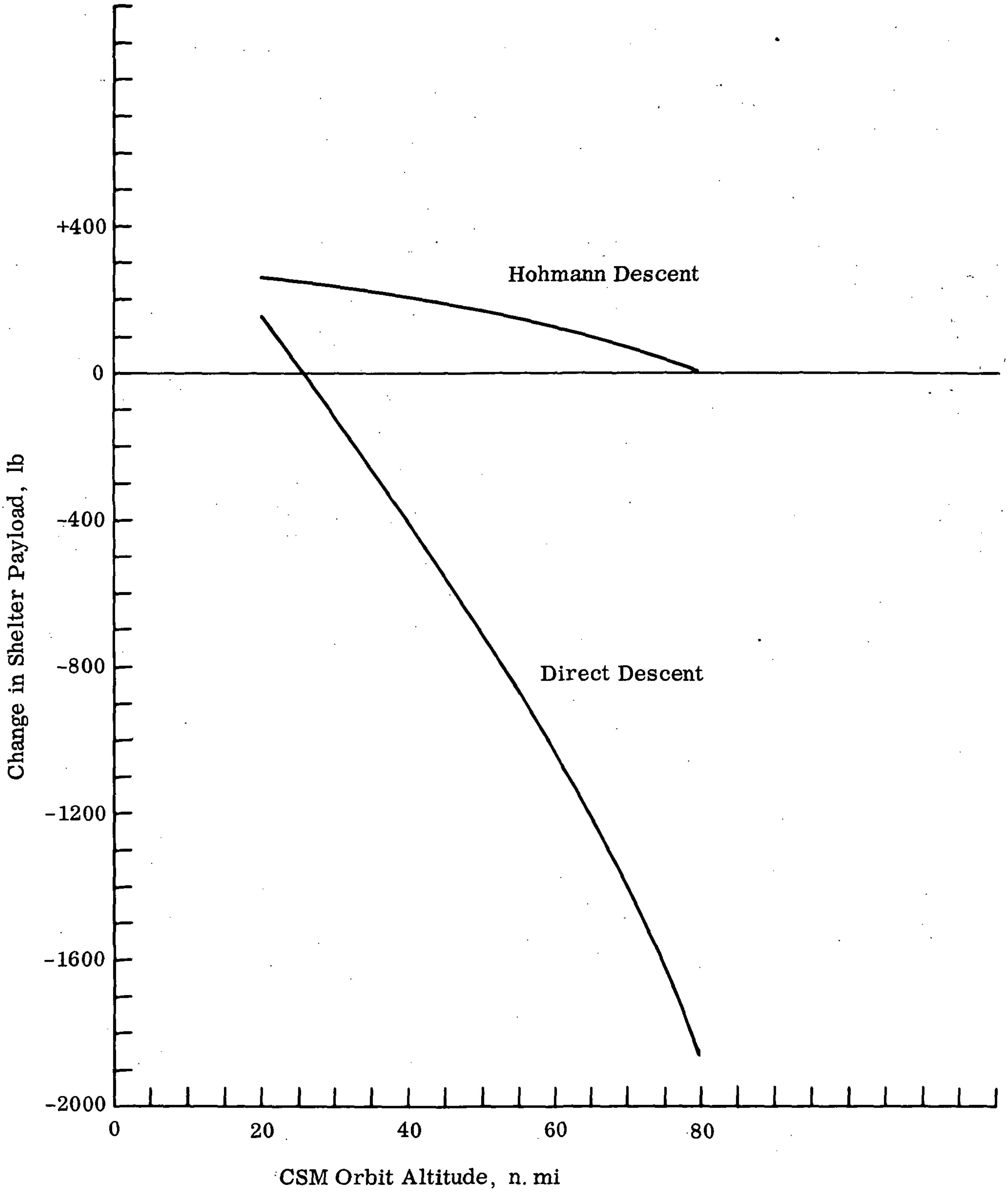

Fig. 4. 3-1 Truck Payload Capability - Hohmann/Direct Descent

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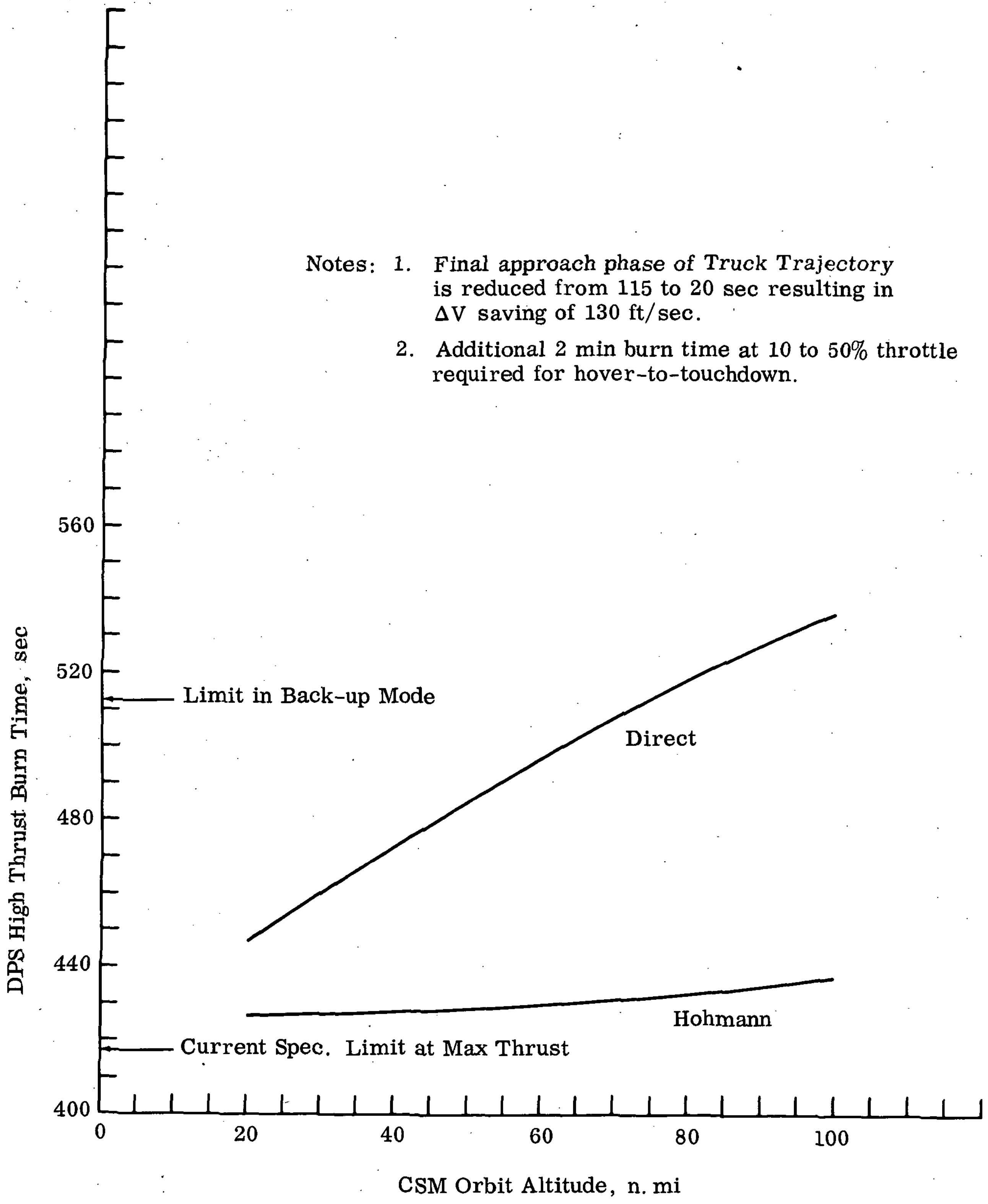

Notes: 1. Final approach phase of *Truck Trajectory* is reduced from 115 to 20 sec resulting in ΔV saving of 130 ft/sec.

2. Additional 2 min burn time at 10 to 50% throttle required for hover-to-touchdown.

Fig. 4.3-2 Descent Engine Burntime - Hohmann/Direct Descent

4.4 RELIABILITY AND MAINTAINABILITY

4.4.1 Assumptions and Background Data

A time line summary for a Truck design reference mission (Table 4.4-1), while not intended to represent any particular flight, has been selected to provide a basis for reliability estimation, configuration analysis, and mission success predictions. The mission times are divided into boost and non-boost periods. Applicable environmental stress (K) factors are shown for each period depending on operation or non-operation of the equipment during these periods. These factors are used to modify equipment inherent failure rates. In accordance with the mission time lines, K factors, subsystem equipment failure rates, math models, and operating usage times shown in this volume, the probability of mission success can be calculated on a subsystem basis.

Mission success is defined as the probability of not aborting the design reference mission because of a failure of the defined configuration. Although failures of the booster or CSM would cancel the mission, they could not be judged failures against the Truck.

Wherever possible, failure rate data were extracted from LEM Report No. LED-550-58, "Failure Rates Used for LEM Reliability Estimate." Data used from other sources are specifically denoted.

4.4.2 Reference Configuration - Reliability Estimates

Subsystem reliability math models, functional block diagrams (Fig. 4.4-1), and equipment utilization times (Table 4.4-2) were developed to determine system reliability estimates.

4.4.2.1 Subsystem Reliability Estimates

4.4.2.1.1 Navigation, Guidance and Control. The Guidance and Navigation Subsystem configuration for the Truck is the same as for the Shelter, except that the Rendezvous Radar and LEM Optical Rendezvous System are not used. Time is the same as for the Shelter, except that since there is no periodic transmittal of information after landing, the Digital Command Assembly and Program Coupler Assembly cease operation after post-landing checkout. The short operating time results in a 0.992568 probability of mission success.

4.4.2.1.2 Descent Propulsion Subsystem. The reliability analysis of the descent propulsion subsystem (DPS) involved investigation into the storage, regulation, and thrust capabilities of the main propulsion subsystem. The subsystem was evaluated by utilizing the existing LEM descent propulsion subsystem reliability analysis with some slight modifications (two vent valves and a pressure relief valve added on the Truck subsystem).

The mathematical reliability model for the DPS is:

$$R_{DPS} = R_1\ R_2\ R_3^5\ R_4^2\ R_5\ R_6\ R_7^3\ R_8^{60}\ R_9\ R_{10}\ (2 - R_{10})\ R_{11}^2 \left[(2-R_9R_{10})\ (2 - R_{10})\ R_{11}^2 \right]$$

$$R_{12}^2 \left[R_{13}^{\ 4} + 4R_{13}^{\ 3}\ (1 - R_{13}) + 2R_{13}^{\ 2}\ (1 - R_{13})^2 \right]\ \left[R_{14}^{\ 4} + 4R_{14}^{\ 3} \right.$$

$$(1 - R_{14}) + 2R_{14}^{2} (1 - R_{14})^{2}] \quad [R_{15}^{4} + 4R_{15}^{3} (1 - R_{15}) + 4R_{15}^{2} (1 - R_{15})^{2}]$$

$$[R_{16}^{4} + 4R_{16}^{3} (1 - R_{16}) + 4R_{16}^{2} (1 - R_{16})^{2}] \quad (R_{17} R_{18} + R_{19} - R_{17} R_{18} R_{19})^{5}$$

$$R_{20}^{5} R_{21}^{2} R_{22}^{2} R_{23}^{2} R_{24}^{4} R_{25}^{2} R_{26} R_{27} R_{28}^{4} (R_{29} + R_{30} - R_{29} R_{30})^{12}$$

When the combined reliability degrading factors: time (t), mechanical stress factor (K), and failure rate (λ) are introduced into the above mathematical model, according to the exponential relationship R = exp (-Kλ t), the product yields a descent propulsion subsystem reliability equal to 0.997986. This value is slightly lower than the LEM DPS reliability estimate and is caused by the modifications to the LEM DPS.

4.4.2.1.3 Reaction Control Subsystem (RCS). Reliability analysis of the RCS involved investigation into the attitude and fine translation capabilities of the vehicle, including helium, oxidizer and propellant storage, regulation and thrust capability. The mathematical reliability model for the RCS is:

$$R_{RCS} = R_1 \; R_2^{4} R_3 R_4^{5} R_5 \; (2 - R_5) R_6 [R_7 R_8 (2 - R_8) R_9^{2}] \quad [2 - R_7 R_8 (2 - R_8) R_9^{2}]$$

$$[R_{10}^{4} + 4R_{10}^{3}(1 - R_{10}) + 2R_{10}^{2}(1 - R_{10})^{2}] \quad [R_{11}^{4} + 4R_{11}^{3} (1 - R_{11})$$

$$+ 2R_{11}^{2}(1 - R_{11})^{2}] \quad [R_{12}^{4} + 4R_{12}^{3}(1 - R_{12}) + 4R_{12}^{2}(1 - R_{12})^{2}] \quad [R_{13}^{4}$$

$$+ 4R_{13}^{3}(1 - R_{13}) + 4R_{13}^{2}(1 - R_{13})^{2}] \quad R_{14}^{2}(R_{15} R_{16} + R_{17} - R_{15} R_{16} R_{17})^{2}$$

$$R_{18} R_{19} R_{20} \; [(R_{21} + R_{22} - R_{21} R_{22})^{2} \quad \{ 2 - (R_{21} + R_{22} - R_{21} R_{22})^{2} \}]$$

$$(R_{23} + R_{24} - R_{23} R_{24})^{15} R_{25}^{2} R_{26}^{2} R_{27}^{8} R_{28}^{8} R_{29}^{60} R_{30}^{16} R_{31}^{16} R_{32}^{2} R_{33}^{2}$$

When the combined factors are introduced for each reliability block established above, the product yields a reliability of the RCS equal to 0.966589.

The propellant tank bladders are the major contributing factor to the mission unreliability because of their high failure rate. No additional problem areas were uncovered.

The reliability of the Truck RCS is slightly lower than the value for the LEM mission.

4.4.2.1.4 Electrical Power Subsystem (EPS). The reference EPS configuration consists of two ascent-type batteries and associated ECA. The Truck electrical power profile time line and LEM ascent battery/ECA failure rates were used to assess the EPS configuration. A battery is considered operational (for reliability calculations) when it is activated and charged.

EPS time Line

Phase	Phase Time (hr)
Countdown, Launch, and Transposition	6.8
Translunar	111.6
Pre-separation Checkout	1.5
Descent to Touchdown	1.7
Total Mission Time:	121.6 hr

The math model is based on the success criteria that one battery and ECA are required for the mission duration. The redundant-battery EPS configuration yields a reliability of 0.999946.

4.4.2.1.5 Environmental Control Subsystem (ECS). The ECS maintains the thermal balance required for proper operation of the Truck electronic subsystems. The configuration consists of a circulation assembly, water boiler, glycol accumulator, water storage tank, and associated plumbing.

The following assumptions were made in development of the math model used for the reliability assessments.

- Water tank undergoes one operating cycle for the extent of the mission
- Heat transport system is considered to be in a pressurized (operative) state for the mission duration
- LED 550-58, dated 18 June 1965, and failure rate data supplied by Hamilton Standard are a valid basis for the reliability assessment.

The mission success probability based on the above assumptions is 0.999365.

4.4.2.1.6 Communications Subsystem. The reliability analysis of the communications subsystem investigated transmission and receiving capabilities, including status data.

The mathematical representation of the reliability for the mission is:

$$R = \left[1 - (1 - R_1)(1 - R_2)^2\right] R_3 R_4 (2 - R_4) \left[1 - (1 - R_5)(1 - R_6)^2\right]$$

$$R_7 R_8 (2 - R_8) R_9 (R_{10A} + R_{10B} - R_{10A} R_{10B}) (R_{11A} + R_{11B} - R_{11A} R_{11B})$$

When the combined factors are introduced for each of the reliability blocks established above, the product yields a reliability of 0.999868. The prime degrading component for this analysis was the signal processor assembly.

4.4.2.2 System Reliability Analysis

A summary of subsystem reliability estimates for the Truck, together with pertinent LEM data, is shown in Table 4.4-3. Approximation of structure, explosive, automatic controls and instrumentation subsystem reliabilities were obtained by utilizing LEM estimates with exponential degradation allowed for the extended duration.

In general,

$$R = e^{-K\lambda t} \text{ and } Q = 1.0 - R$$

For small values of $K\lambda t$,

$$Q \approx K\lambda t \text{ and } K\lambda \approx \frac{Q}{t}$$

Then

$$Q_2 \approx \frac{Q_1 \text{ x } t_2}{t_1}$$

$$Q_2 \approx \frac{Q_1}{115.567} \text{ x } 79.787 \approx 0.6904\ Q_1$$

where subscript 1 represents LEM and subscript 2 represents AES.

Subsystem	Q_1	Q_2	R_2
Automatic Controls & Instrumentation	0.000622	0.000429	0.999571
Structure	0.000022	0.000015	0.999985
Explosives	0.000076	0.000053	0.999947

4.4.3 Maintainability

The following points apply to Truck maintainability:

- Apollo LEM maintenance concepts are applicable to the Truck configuration
- Specific interchangeable assemblies, i.e., SCEA, PCMTEA, SPA, may be utilized after touchdown as a source for spares for the Shelter and Taxi
- In-flight maintenance is not feasible because the present configuration does not allow for EVA without depressurizing the CM.

TABLE 4.4-1

TRUCK DESIGN REFERENCE MISSION

Nom Phase	Phase Description	Boost Time K_O = 10.0 K_{NO} = 0.01	Non-Boost Time K_O = 1.0 K_{NO} = 0.001	Total Time
1	Total Preseparation (Incl. 10 hr of Pre-Earth Launch Checkout)	0.39	75.83	76.22
2	AES Checkout to Insertion (Total Checkout 1.85)	-	2.18	2.18
3	Insertion & Hohmann Transfer Orbit	0.01	0.968	0.978
4	Powered Descent from Pericynthion to Hover	0.14	-	0.14
5	Hover to Touchdown & Post-Ldg Checkout	0.019	0.25	0.269
		0.559	79.228	79.787

Table 4.4-2

REFERENCE TRUCK SYSTEM EQUIPMENT USAGE & FAILURE RATES

A. Guidance, Navigation & Control (R = 0.992568) (80-n.mi Trajectory)

Ident. No.	Name (& Qty if More Than 1)	Fail Rate/hr x 10^6	Equipment Usage Time, hr			
			Operate		Non-Operate	
			Boost	Non-Boost	Boost	Non-Boost
1	Inertial Measuring Unit	137	0.169	2.338	0.39	76.89
2	Power Servo Assy	126	↕	↕	↕	↕
3	Pulse Torquer Assy	62	↕	↕	↕	↕
4	Coupling Data Unit	543	↕	↕	↕	↕
5	LEM Guidance Computer	353	↕	↕	↕	↕
6	Cntrl Eletrncs Pwr Supply	20	↕	↕	↕	↕
7	Att. & Trans. Cntrl Assy	17.4	↕	↕	↕	↕
8	Program Coupler Assy	55.5	↕	↕	↕	↕
9	Digital Coder Assy	29.3	↕	↕	↕	↕
10	Landing Radar	144.5	↕	↕	↕	↕
11	LEM Optical Rendezvous System	292.0	↕	↕	↕	↕
12	Scanner	6.3	↕	2.338	↕	↕
13	Desc. Eng. Control Assy	21.0	↕	0.100	↕	↕
14	Desc. Eng. Latching Device	12.0	↕	0.100	↕	↕
15	Gimbal Drive Actuator	31.0	0.169	0.100	0.39	76.89

B. Descent Propulsion Subsystem (R = 0.997986)

1	He pressure vessel	.04	.559	79.228	0	0
2	Liquid Level Transducer	.05	.559	↕	0	0
3	Temperature Transducer (5)	.05	.559	↕	0	0
4	Pressure Transducer (2)	.05	.559	↕	0	0
5	Helium Initiate valve-squib	.06	.559	↕	0	0
6	Heat Exchanger	.60	.559	↕	0	0
7	Filter (3)	.31	.559	↕	0	0
8	Lines, joints, fittings (60)*	.05	.559	↕	0	0
9	Shut off valve	14.2	.559	↕	0	0
10	Pressure Regulator-fail open	13.67	.559	↕	0	0
11	Pressure Regulator-fail closed	13.67	.559	↕	0	0
12	Manifold (2)	.04	.559	79.228	0	0
13	Quad check valve-oxidizer-fail closed	8.7*	.159	0	0	0
14	Quad check valve-fuel-fail closed	8.7*	.159	0	0	0
15	Quad check valve-oxidizer-fail open	8.7*	.40	79.228	0	0
16	Quad check valve-fuel-fail open	8.7*	.40	↕	0	0
17	Pressure relief valve	5.7	.559	↕	0	0
18	Test Point 5 redundancies	12.5	.559	↕	0	0
19	Burst disc in series	.11	.559	↕	0	0
20	Burst disc (5)	.11	.559	↕	0	0

*Assumed vendor estimate

Table 4.4-2 (Cont)

B. Descent Propulsion Subsystem (R = 0.997986) (Cont)

Ident. No.	Name (& Qty if More Than 1)	Fail Rate/hr x 10^6	Equipment Usage Time, hr			
			Operate		Non-Operate	
			Boost	Non-Boost	Boost	Non-Boost
21	Oxidizer storage tank (2)	.04	.559	79.228	0	0
22	Fuel storage tank (2)	.04	.559	79.228	0	0
23	Vent valve (2)	12.5	.459	.1	0	79.228
24	Low level sensor (4)	.05	.559	79.228	0	0
25	Trim orifice (2)	.5	.559	79.228	0	0
26	Descent Engine Assembly-fire	226.005	.159	0	0	0
27	Descent Engine Assembly-no-fire	226.005	0	0	.40	79.228
28	Diffuser (4)	.05	.559	79.228	0	0
29	Fill valve 12 redundancies	3.66	.559	79.228	0	0
30	Cap in series	80.0	.559	79.228	0	0

C. Reaction Control Subsystem (R = 0.975700)

1	Helium Pressure Vessel	.04	.559	79.228	0	0
2	Pressure Transducer (4)	.05			↓	↓
3	Manifold	.04*			↓	↓
4	Temperature Transducer (5)	.05			↓	↓
5	Helium Initiate squib valve	.06			↓	↓
6	Helium filter	.31			↓	↓
7	Shut off valve - solenoid	14.2	.559	79.228	↓	↓
8	Pressure Regulator-fail open	13.67	.159	0	↓	↓
9	Pressure Regulator-fail closed	13.67	.159	0	↓	↓
10	Quad check valve-oxidizer-fail closed	8.7 *	.159	0	↓	↓
11	Quad check valve fuel-fail closed	8.7 *	.159	0	↓	↓
12	Quad check valve-oxidizer-fail open	8.7 *	.40	79.228	↓	↓
13	Quad check valve-fuel-fail open	8.7 *	.40	79.228	↓	↓
14	Burst Disc (2)	.11	.559		↓	↓
15	Pressure relief valve	5.7			↓	↓
16	Test point	12.5			↓	↓
17	Burst Disc	.11	.559	79.228	↓	↓
18	Oxidizer Tank (bladder) failure rate	8400.0	0		↓	↓
19	Fuel Tank (bladder) 10^6 cycles	8400.0	0		↓	↓
20	Main shut off valve	3.09	.559	79.228	↓	↓
21	Fill valve	3.66			↓	↓
22	Cap	80			↓	↓

*Assumed vendor estimate.

Table 4.4-2 (Cont)

C. Reaction Control Subsystem (R = 0.975700) (Cont)

Ident. No.	Name (& Qty if More Than 1)	Fail Rate/hr x 10^6	Equipment Usage Time, hr			
			Operate		Non-Operate	
			Boost	Non-Boost	Boost	Non-Boost
23	Fill Valve 15 redundancies	3.66	.559	79.228	0	0
24	Cap in series	80	.559	79.228	0	0
25	Thrust Chamber Assembly - fire (2)	1057.9	.159	0	0	0
26	Thrust Chamber Assembly - no-fire (2)	1057.9	0	0	.40	79.228
27	Isolation Valve (8)	3.09	.559	79.228	0	0
28	Propellant Inlet filter (8)	.31	0	0	.559	79.228
29	Lines, joints, fittings (60)*	.05	.559	79.228	0	0
30	Thrust Chamber Assembly Injector Valve-fire (16)	34.4	.159	0	0	0
31	Thrust Chamber Assembly Injector Valve-no-fire (16)	34.4	0	0	.39	79.228
32	Vent Valve (2)	3.66	.459	.1	0	79.228
33	Pressure Transducer (2)	.05	.559	79.228	0	0

D. Electrical Power Subsystem (R = 0.999946)

1	Ascent-Type Battery (2)	.40		121.6		
2	Ascent ECA (2)	20		121.6		

E. Environmental Control Subsystem (R = 0.999365)

1	Water Tank	296/C	1 cycle			
2	Fill Valve	3.66	.559	78.978		
3	Cap	80	.559	78.978		
4	Pressure Regulator	1.46				
5	Check Valve	.67				
6	Water Boiler	2.0				
7	Glycol Accumulator	1.34				
8	Glycol Filter	0.0				
9	Glycol Pump	16.1				
10	Bypass Relief Valve	1.12				
11	Check Valve	.67				

F. Communications Subsystem (R = 0.999868)

1	S-band steerable antenna	41.0	.169	0	.39	79.228
2	S-band omni-directional antenna	.025	↓	↓	↓	↓
3	S-band diplexer	1.7	↓	↓	↓	↓
4	S-band transmit-receive electronic replaceable assembly	52.9	↓	↓	↓	↓
5	FM modulator	.162*	↓	↓	↓	↓

*Assumed vendor estimate

Table 4.4-2 (Cont)

F. Communications Subsystem (R = 0.999868) (Cont)

Ident. No.	Name (& Qty if More Than 1)	Fail Rate/hr x 10^6	Equipment Usage Time, hr			
			Operate		Non-Operate	
			Boost	Non-Boost	Boost	Non-Boost
6	PM modulator	.757*	.169	0	.39	79.228
7	Signal Processor Assembly	64.549	↕	↕	↕	↕
8	VHF omni-directional antenna	.025	↕	↕	↕	↕
9	VHF Diplexer	1.7	↕	↕	↕	↕
10A	VHF Transmitter 'A'	12.067*	↕	↕	↕	↕
10B	VHF Transmitter 'B'	12.067*	↕	↕	↕	↕
11A	VHF Receiver 'A'	13.252*	↕	↕	↕	↕
11B	VHF Receiver 'B'	13.252*	.169	0	.39	79.228

*Assumed vendor estimate

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Table 4.4-3

Truck Reliability Summary

	LEM*			AES
Subsystem	Crew Safety	Apport	Estimate	Truck
Nav Guidance	0.999651	0.990700	0.988205	0.992568
Descent Propul	0.999899	0.999075	0.998764	0.997986
Ascent Propul		0.999961	0.998300	Not Reqd
RCS	0.997807	0.999804	0.919600	0.975700
EPS	0.999993	0.998600	0.963896	0.999946
ECS	0.999994	0.999446	0.994760	0.999365
Communications		0.999910	0.997680	0.999868
Instrumentation		0.999500	0.999378**	0.999571***
Auto Controls & Displays				
Structure	0.999999	0.999950	0.999978	0.999985***
Explosives	0.999954	0.999980	0.999924	0.999947***
Crew Provisions		0.999990	Not Avail	Not Reqd
System		0.987	0.866	.956

* Values Obtained From LPR-550-9: "Quarterly Reliability Status Report," 1 Aug 1965

** Does Not Include Sensors

*** Utilizes LEM Estimate With Exponential Degradation For Extended Duration

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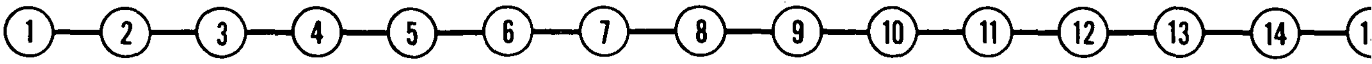
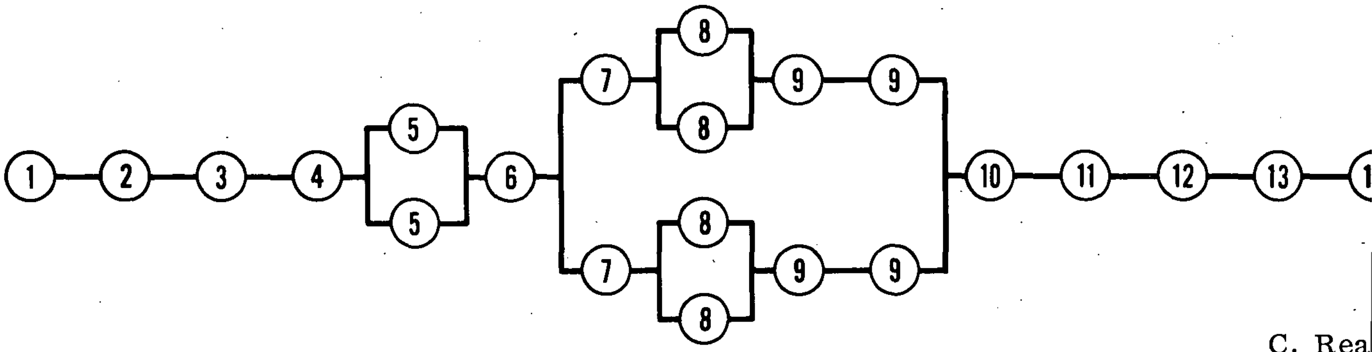
4-33



A. Guidance, Navigation & Control Subsystem



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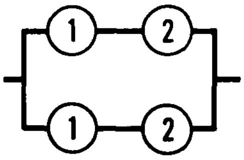
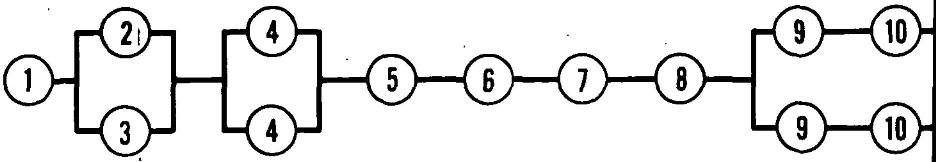


D. Electrical Power Supply Subsystem



E. Environmental Control Subsystem

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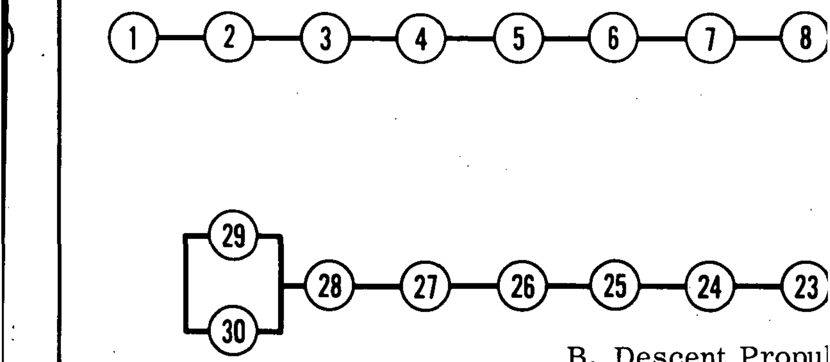
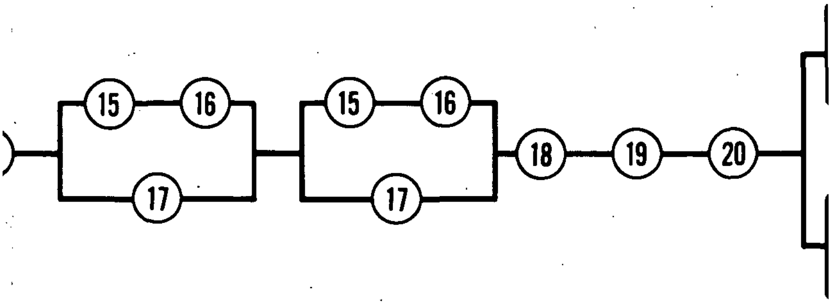
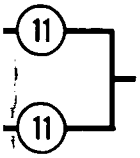
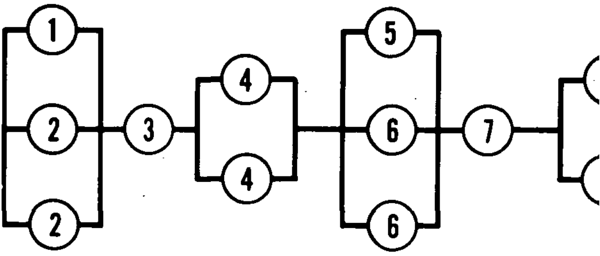


B. Descent Propul



tion Control Subsystem





F. Communications Su

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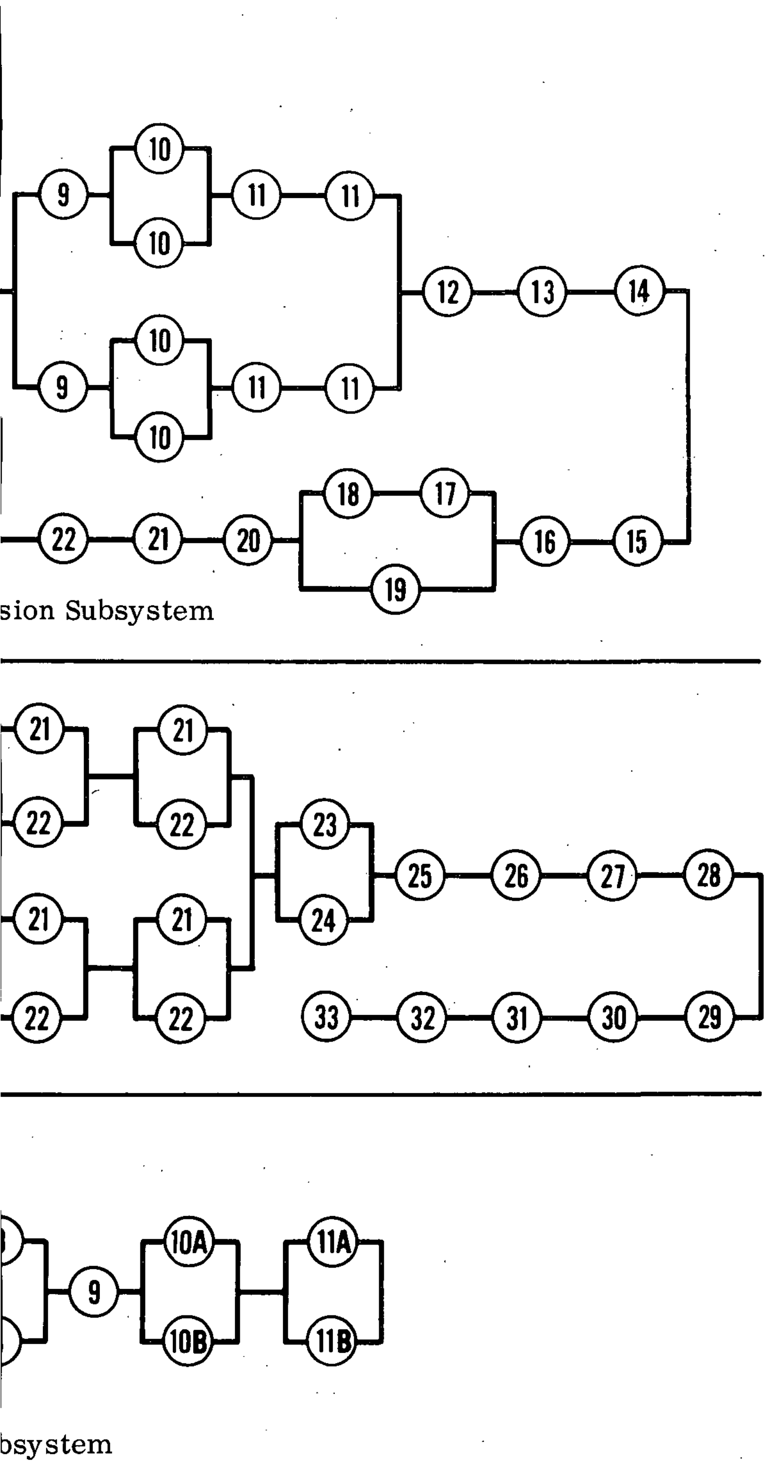


Fig. 4.4-1 Reliability Block Diagram

4.5 MASS PROPERTIES

4.5.1 Ground Rules

The major ground rules affecting the mass properties analysis are contained in Section 1 of this volume.

4.5.2 Assumptions and Background Data

The Truck weights are based on the August 1965 LEM weight statement. The payload capability of the Truck is predicated on full descent propellant tanks and the current 32,750-lb LEM design separation weight.

Subsystem equipment was located to keep the Truck cg on the engine thrust line (not including payload). No attempt was made to define a payload for the Truck.

The Truck would be able to land any payload that does not exceed the maximum design ascent stage mass properties. The approximate bounds for a Truck payload are:

- Weight: 10,000 lb
- X_{cg}: Up to 45 in. above separation plane
- Y_{cg} & Z_{cg}: Up to 1 in. off thrust center line
- Inertia I_{xx}: Up to 6500 slug-ft^2
- Inertia I_{yy}: Up to 3300 slug-ft^2
- Inertia I_{zz}: Up to 5650 slug-ft^2

Any payload exceeding these limits must be critically evaluated to insure compatibility with the Truck landing gear, RCS, and propulsion subsystem, and vehicle dynamic stability.

For the mass properties study, the RCS was assumed to be the same as for the Shelter (eight thrusters and 140 lb of RCS propellant). Payloads will have to be evaluated to insure that the amount of propellant is compatible with the vehicle mass properties. Addtional propellant can be added by reducing payload weight.

4.5.3 Description of Tables

The truck mass properties summaries by mission phase and by subsystem are presented in Tables 4.5-1 and 4.5-2, respectively. Table 4.5-3 is a detailed weight statement listing the basic descent stage weight and identifying added and deleted equipment. The total weight of the Truck is 22,738 lb at separation, which provides a payload capability of 10,012 lb.

Table 4.5-1

TRUCK MASS PROPERTIES SUMMARY BY MISSION PHASE

Mass Property		Dry	Burn-Out*	Separation
Weight, lb		4,677	5,224	22,738
cg, in. from ref datum	x	156	154	158
	y	-2	-2	0
	z	3	3	1
Moments of Inertia, (cg) slug-ft^2	I_{x-x}	5,130	5,459	17,032
	I_{y-y}	3,495	3,763	11,166
	I_{z-z}	3,251	3,458	8,429

* Burn-out & Lunar Landing assumed to be same.

Notes:
- cg Given in inches from Ref. Datum.
- x-cg In LEM stations (Ascent/Descent separation plane is LEM Sta. 200.0
- y & z cg Measured from vertical center line.
- Moments of Inertia in slug-ft^2 about vehicle cg.

Table 4.5-2 TRUCK MASS PROPERTIES SUMMARY BY SUBSYSTEM

Code	Subsystem	Wt, lb	cg, in.*			Moments of Inertia, slug-ft^2		
			x	y	z	I_{xx}(roll)	I_{yy}(pitch)	I_{zz}(yaw)
1.0	Structure - Desc	1,543	156	1	- 3	1,514	977	984
2.0	Stab & Cont	42	166	-13	-20	22	7	15
3.0	Nav & Guid	342	178	-28	23	335	329	56
5.0	Environ Cont	41	166	31	-20	9	5	7
6.0	Landing Gear	531	121	0	4	2,043	1,128	1,071
7.0	Instrumentation	175	166	27	28	25	14	14
8.0	Elect Power	566	160	-18	19	130	92	104
9.0	Propulsion	1,150	153	3	-6	530	356	348
10.0	Reaction Control	152	177	-18	2	147	66	83
11.0	Communications	110	214	22	21	85	104	130
12.0	Cont & Displ	25	175	0	0	0	0	0
	TOTAL DRY WT	4,677	156	-2	3	5,131	3,495	3,251
	<u>TRAPPED & RESIDUAL</u>							
5.0	Environ Control	20	162	0	0	1	1	0
9.0	Propulsion	505	132	1	-2	300	196	124
10.0	Reaction Control	22	174	-47	34	10	1	9
	TOTAL WT AT BURN OUT	5,224	154	-2	3	5,459	3,763	3,458
	<u>ORBITING EXPENDABLES</u>							
9.0	Propulsion	17,357	160	0	0	11,380	7,307	4,787
10.0	Reaction Control	140	173	-46	34	67	6	60
	TOTAL WT AT SEP	22,738	158	0	1	17,032	11,166	8,429

* From Ref. Datum.

Table 4.5-3 TRUCK DETAILED WEIGHT STATEMENT

AES TRUCK DRY REFERENCE CONFIGURAT

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
1.0002	DST STRUCT	1499	156	2	0
1.101	SEPAR SYS	-16	199	18	26
1.1111	BATTRY SPT	-25	164	57	36
J.1114	EGRES PLTF	-10	198	0	91
1.1511	H2O TK SPT	-13	169	-36	-36
1.0	RCS THS SP	5	188	-72	72
1.0	RCS THS SP	5	188	72	72
1.0	RCS THS SP	5	188	-72	-72
1.0	RCS THS SP	5	188	72	-72
1.0	RCS TK MTS	8	193	-46	0
1.0	EQUIP SPTS	50	164	38	-38
1.0	EQUIP SPTS	30	164	-38	-38
1.0	STRUCTURE	1543	156	1	-3
2.2	ATCA	27	170	-38	-38
2.5	DECA	15	158	32	12
2.0	STAB+CONTROL	42	166	-13	-20
3.10	PROG COUP	78	180	-38	60
3.10	DIGIT COD	15	180	-38	60
3.110	CDU CNVTRS	13	180	-46	-46
3.11	IMU PLTFRM	42	190	0	100
3.12	AUTO TRCKR	50	190	0	100
3.13	LGC COMPTR	58	181	-30	-46
3.14	PSA SERVOS	15	180	-46	-46
3.16	LGC-PSA CB	10	180	-46	-46
3.17	NAV BASE	6	180	-46	-46
3.18	PTA TORQUE	12	180	-46	-46
3.19	SCEA	6	195	30	30
3.31	LR ANTENNA	23	115	-53	-53
3.32	LR ELECTRN	14	170	-40	-40
3.0	NAV+GUIDANCE	342	178	-28	23
5.112	H2O EVAP S	7	162	46	-30
5.2	AUTO DUMP	2	162	46	-30
5.2	VVS + PLMB	5	162	0	0
5.21	COOL RECIR	8	162	46	-30
5.221	ACCUMULATR	3	162	46	-30
5.411	H2O TANK	6	190	61	-35
5.61	COLD PLATS	10	162	0	0
5.0	ENVIRNTL CTL	41	166	31	-20
6.0	LNDNG GEAR	531	121	0	4
6.0	LNDNG GEAR	531	121	0	4
7.11	SIGNL CNDT	86	165	38	38
7.12	PCMTE	39	165	38	42
7.4	SENSORS	50	169	0	0
7.0	INSTRMENTATN	175	166	27	28
8.111	ASNT BTTRY	131	150	-38	38
8.111	ASNT BTTRY	131	150	-38	38
8.121	BATT CNTRL	10	150	-38	38
8.121	BATT CNTRL	10	150	-38	38
8.13	PYRO BATTS	7	180	61	37
8.3	DIST SYS	77	170	0	0
8.4	WIRNG PROV	200	170	0	0
8.0	ELEC PWR SUP	566	160	-18	19
9.22	PROP TANKS	239	154	0	0
9.24	OXID TANKS	269	154	0	0
9.26	PLUMBING	57	126	0-	6
9.32	HE TANKS	100	148	49-	46
9.36	PLUMBING	49	178-	17-	35
9.36	VENT VALVE	15	180-	17-	35
9.42	ENGINE DES	400	154	0	2
9.46	MISC	21	152	0	0
9.0	PROPULSION	1150	153	3-	6
10.21	FUEL TK LH	9	173	-46	34
10.22	OXIDIZ TK	11	173	-46	-34
10.23	PLUMBING	36	173	-46	0
10.24	SENSORS	10	173	45	0
10.31	HE TK LH	11	188	-61	34
10.33	PLUMBING	18	175	0	0
10.4	THRUSTERS	57	180	0	0
10.0	RCS	152	177	-18	2
11.11	VHF TRSCVR	13	175	-40	-40
11.12	SIG PROC	9	185	38	44
11.13	VHF ANTNNA	5	312	0	0
11.21	SB TRNSPND	20	185	38	44
11.22	SB PWR AMP	15	185	38	55
11.23	DCA	15	180	-38	60
11.24	INFLT ANT	2	268	0	0
11.26	SB STR ANT	21	312	96	0
11.0	ANT SW MTX	5	175	-40	-40
11.0	MISC	5	175	0	0
11.0	COMMUNICATN	110	214	22	21
12.12	AUTO CTLS	25	175	0	0
12.0	CTLS+DSPLYS	25	175	0	0
	AES TRUCK DRY WT	4677	156	-2	3

AES TRUCK BURNOUT

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
	AES TRUCK DRY WT	4677	156	-2	3
5.7	GLYCOL	20	162	0	0
5.0	TRP+RES ECS	20	162	0	0
9.12	PROP TRAPD	455	129	0-	1
9.34	HELIUM	50	156	8-	8
9.0	TRP+RES PROP	505	132	1	-2
10.11	PROP TRPPD	20	173	-46	34
10.32	HELIUM	2	188	-61	34
	T+R RCS	22	174	-47	34
	AES TRUCK B/O	5224	154	- 2	3

AES TRUCK SEPARATION

CODE	TITLE	WEIGHT POUNDS	C.G. X	Y	Z
	AES TRUCK B/O	5224	154	- 2	3
5.7	H2O	17	190	61	-35
5.0	EXPNDBL ECS	17	190	61	-35
9.112	PROPELLANT	362	188	0	0
9.112	PROPELLANT	15057	162	0	0
9.112	PROPELLANT	1862	135	0	0
9.112	PROPELLANT	76	150	0	0
9.0	EXPNDBL PROP	17357	160	0	0
10.0	EXPND RCS	140	173	-46	34
	TRUCK SEPAR	22738	158	0	1

5. SUBSYSTEMS ENGINEERING

5.1 ELECTRICAL POWER

5.1.1 Ground Rules

- No interchange of electrical power between the Truck and the payload.

5.1.2 Assumptions and Background Data

- Translunar primary power for the Truck is assumed to be supplied by the CSM
- Being unmanned, the Truck must have sufficient automatic controls to perform essential functions which would be manually performed in the LEM.
- Relocation of busses, controls and protections and conversion equipment to the descent stage will not affect their performance.
- Voltage at power source terminals: 28 to 32.5 volts

5.1.2.1 Power and Energy Profile Data

The power profile (Fig. 5.1-1) shows that the total mission energy requirements are 14.04 kw-hr, of which the CSM will supply 9.53 kw-hr for the translunar phase. This leaves 4.51 kw-hr which must be supplied by the Truck. The Truck energy and power levels are essentially the same as the Taxi and Shelter until lunar landing is completed.

Table 5.1-1 shows the detailed power, energy and duty cycles assumed for the equipment used. As with the LEM, 7.5% has been added to the total loads for distribution losses, and an additional 20% growth has been added to both the power and energy requirements to allow for unforeseen changes.

5.1.2.2 Mission Success

The Phase A Truck Report of 15 Oct. 1965 states that the reliability of one LEM ascent battery is sufficient for achieving mission success. However, a review of additional configurations to establish the trade-offs of weight, cost, and complexity against mission success showed that there can be a significant improvement in reliability and mission success by using redundant batteries.

5.1.3 Reference Configuration

5.1.3.1 Configuration Description

The Reference configuration is based up on two 9-kw-hr ascent batteries, each capable of supplying the energy requirements of the Truck, with the translunar energy requirements supplied by the CSM. The EPS schematic is shown in Fig. 5.1-2.

The Truck EPS is designed for minimum complexity commensurate with reliability. Because it is unmanned, LEM EPS controls must be replaced or modified to satisfy the automatic, remotely controlled, or pre-programmed logic requirements. A relay junction box (RJB) to be designed will satisfy the logic and switching requirements.

5.1.3.1.1 Feeder Configuration. Because the entire EPS is to be compactly mounted in the descent stage, the feeders will be of short length, eliminating the need for redundant feeders. The RJB will provide logic, switching, and acceptance of commands to connect GSE ac and dc power, CSM dc power and Truck battery power to the Truck busses, as required. The RJB will also contain the dead-face requirements for de-energizing GSE and CSM feeders.

5.1.3.1.2 Bus Configuration. There is one dc bus and one ac bus. The short feeders leading to the buses will help maintain the bus voltages at nominal levels slightly higher than the other vehicles.

5.1.3.1.3 Protection and Control Equipment. For each battery there is a modified LEM Ascent Stage ECA which provides reverse current and overload protection, current monitoring, and prevents a failed battery from degrading the system. This unit also provides "on-off" control of its associated battery.

5.1.3.1.4 Primary Power Source. The primary power source for the Truck is two redundant 9-kw-hr LEM ascent batteries installed in the Truck descent stage. The characteristics of this battery are shown in Table 5.1-2. Power levels for the Truck descent and LEM ascent missions are similar, thus battery performance for the two vehicles will be closely related.

5.1.3.1.5 Inverter. One inverter is provided. Since the Truck inverter time line is much shorter than that of the LEM, and its power requirements are estimated to be much less than LEM requirements, it is felt that a single LEM inverter will provide the required reliability.

5.1.3.2 Performance

The performance of the EPS will be comparable to the LEM and other AES vehicles as far as voltage characteristics and limits are concerned. A summary of other characteristics follows:

	Total Weight, lb	Rating
2 Ascent Batteries (LEM)	260	18 kw-hr
2 Ascent Battery ECA's (Modified)	20	--
1 Single-Phase, 400-cps, 115-v Inverter (LEM)	15	350 VA
CSM - FCA, Translunar Power	--	9.53 kw-hr

5.1.3.3 Location and Integration of EPS Components

The Truck power supply, control, and distribution section is located in quadrant I of the descent stage. The batteries are installed on cold rails for active cooling in the same manner as in the LEM and the other AES vehicles. Heat generation levels will be of similar magnitude, but lower total energy will be generated than in the LEM ascent mission. The installation requirements of other EPS components are essentially the same as the comparable equipments on the other vehicles. The major difference, other than those already described, is the installation of a descent stage bus. In concept, an isolated and protected area will be selected as close to the power sources as possible. Circuit protective devices will be installed where they are needed to preclude the generation of progressive or catastrophic failures. Control logic will be included in the distribution section and/or the relay junction box that will allow the automatic control of required functions.

5.1.4 Alternate Configuration

For the alternate configurations no bus or inverter changes were made; the changes involve the primary power battery source and its controls.

The Phase A configuration and other alternate configurations are presented in Table 5.1-3, with the major parameters considered.

5.1.5 Configuration Choices

If the predicted reliability of 0.99271 of the Phase A configuration meets the EPS apportionment for mission success, then a light-weight, low-cost, configuration is available. A very significant increase in reliability (0.99995) can be obtained with only a small increase in weight (20 lb) as shown in alternate configuration number 3. However, this configuration requires the development of a 5-kw-hr battery at an estimated cost of $250,000.

The reference configuration has a predicted reliability of 0.99995 at a 140-lb increase above the Phase A configuration but no battery vendor development is required.

TRUCK-ELECT

C

Equipment	Equipt Power Levels	Countdown	Launch & Earth Ascent	Earth Orbit	Insertion & Initial Coast	Transposition
Time min		60	12	270	25	40
Time hr		1.0	0.2	4.5	0.417	0.66
GN&C						
Ldg Radar Htr	50/10				80%/8.0	10.
Ldg Radar	122.5/108					
IMU (Standby)	45.5	45.5	45.5	45.5	45.5	45.
IMU (Operate)	300					
LGC	110					
LEM Opt Rendez Sys	51					
LEM Opt Rendez Sys	15AC					
Rendez Radar Htr	50/25				80%/20.0	25.
Rendez Radar	221.5/162					
Rendez Radar	14AC					
Prog Coupler Assy	15					
Subtotal		45.5	45.5	45.5	73.5	80.
PROPULSION						
Desc Eng Reg Sol Valve	28					
Desc Eng Gaging	16					
Throttle Act Amp	270/85					
Mix Ratio Cont Act	21/3.1					
Shutoff Valve	15/12.5 (4 Units Operating)					
Subtotal						
S&C						
ATCA	129/79					
DECA	28/18					
DECA	2.7/1.1 AC					
GDA(2)	48/32 AC					
Subtotal						
RCS						
Cluster Htr (4)	8					
Thrust Chmbr Assy (16)	56					
Prop Quant Gaging	32.1					
Subtotal						
ECS						
Clycol Pump	28					
Subtotal						
COMMUNICATIONS						
S-Band Ant Htr	6			6.0	6.0	6.0
S-Band Xcvr	36.0					
S-Band Pwr Amp	62.0					
Sig. Proc Assy	15.5					
S-Band Steer Ant	13.9/1.4					
S-Band Steer Ant	3.4/3.2 AC					
VHF (Recv)	1					
VHF (Xmit)	30					
Dig Comd Assy	15					
Subtotal				6.0	6.0	6.0
INSTRUMENTATION						
PCMTEA	12.9	12.9				
Sig Cond Unit	18.5	18.5				
Sensors	4.4	4.4				
Subtotal		35.8				
EPS						
Battery ECAs	5 ea	5.0	5.0	5.0	5.0	5.0
Inv Losses (65% eff)						
Subtotal		5.0	5.0	5.0	5.0	5.0
TOTAL POWER						
Subtotal		86.3	50.5	56.5	84.5	91.5
Distrib Losses (7.5%)		6.5	3.8	4.2	6.3	6.9
Curr Status Avg Pwr		92.8	54.3	60.7	90.8	98.4
Growth Allow (20%)		18.6	10.9	12.1	18.2	19.7
Design Avg Pwr		111.4	65.2	72.8	109.0	118.1
DESIGN ENERGY, kw-hr		111.4	13.1	327.8	43.6	78.7

TOTAL ENERY INCL. COUNTDOWN = 14.04 kw-hr

Mom: Momentary

Neg: Negligible

Table 5.1-1

CAL POWER LOAD ANALYSIS DATA SHEET
ntdown through Touchdown

Continue Translunar Trip	Insert into Lunar Orbit	Coast in Orbit	Checkout	Separate	Orient	Insert into Orbit	Coast to Pericynthion	Initial Pwrd Descent	Final Pwrd Descent	Hover to TD
6540	6	150	90	1.3	28.7	0.5	60	6	2	3
109	0.1	2.5	1.5	0.0217	0.478	0.0083	1.0	0.1	0.033	0.05
10.0	10.0	10.0	14.4							
			6%/6.5		17%/18.5		7%/7.6	108.0	108.0	108.0
45.5	45.5	45.5								
			300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0
			110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0
			51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0
			15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
4.2	25.0	25.0	19.4							
			6%/9.7		17%/27.9		53%/85.9	162.0	162.0	162.0
			6%/0.8		17%/2.4		53%/7.4	14.0	14.0	14.0
			15.0		15.0		15.0	15.0	15.0	15.0
59.7	80.5	80.5	541.8	491.0	539.8	491.0	591.9	775.0	775.0	775.0
						Mom/1.9	Mom/Neg	Mom/0.2		
							7%/.1.1	16.0	16.0	16.0
						85.0		85.0	85.0	85.0
						3.1		3.1	3.1	3.1
						60.0		53.9	50.5	50.0
						150.0	1.1	158.2	154.6	154.1
			68.6	76.0	91.7	76.0	91.0	104.0	104.0	104.0
			10%/1.8			18.0		19.3	19.0	19.0
			10%/0.1			1.1		2.4	2.4	2.4
			10%/6.4			64.0		64.0	64.0	64.0
			76.9	76.0	91.7	159.1	91.0	189.7	189.4	189.4
			32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
			0.3	36.1	1.7	7.5	1.7	9.7	9.3	35.5
			20%/6.4	32.1	32.1	32.1	32.1	32.1	32.1	32.1
			38.7	100.2	65.8	71.6	65.8	73.8	73.4	99.6
			28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
			28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
			36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
			62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0
			15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
			1.7	1.7	2.7	3.9	1.7	2.7	7.7	13.9
			3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.4
			1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
			20%/6.0	30.0	10%/3.0	30.0	15%/4.5	40%/12.0	50%/15.0	50%/15.0
			15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
6.0	6.0	6.0	146.4	170.4	144.4	172.6	144.9	153.4	161.4	167.8
			12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9
			18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5
			4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
			35.8	35.8	35.8	35.8	35.8	35.8	35.8	35.8
			10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
			13.3	9.8	9.8	44.9	9.8	45.7	45.7	45.8
			23.3	19.8	19.8	54.9	19.8	55.7	55.7	55.8
65.7	86.5	86.5	890.9	921.2	925.3	1163.0	978.3	1469.6	1473.3	1505.5
4.9	6.5	6.5	66.9	69.1	69.4	87.3	73.4	110.2	110.4	112.9
70.6	93.0	93.0	957.8	990.3	994.7	1250.3	1051.7	1579.8	1583.7	1618.4
14.1	18.6	18.6	191.6	198.1	198.9	250.1	210.3	315.9	316.7	323.7
84.7	111.6	111.6	1149.4	1188.4	1193.6	1500.4	1262.0	1895.7	1900.4	1942.1
9240.0	11.2	278.7	1723.0	25.8	571.5	12.5	1262.0	189.6	62.6	97.1

2

Table 5.1-2

TRUCK BATTERY CHARACTERISTICS

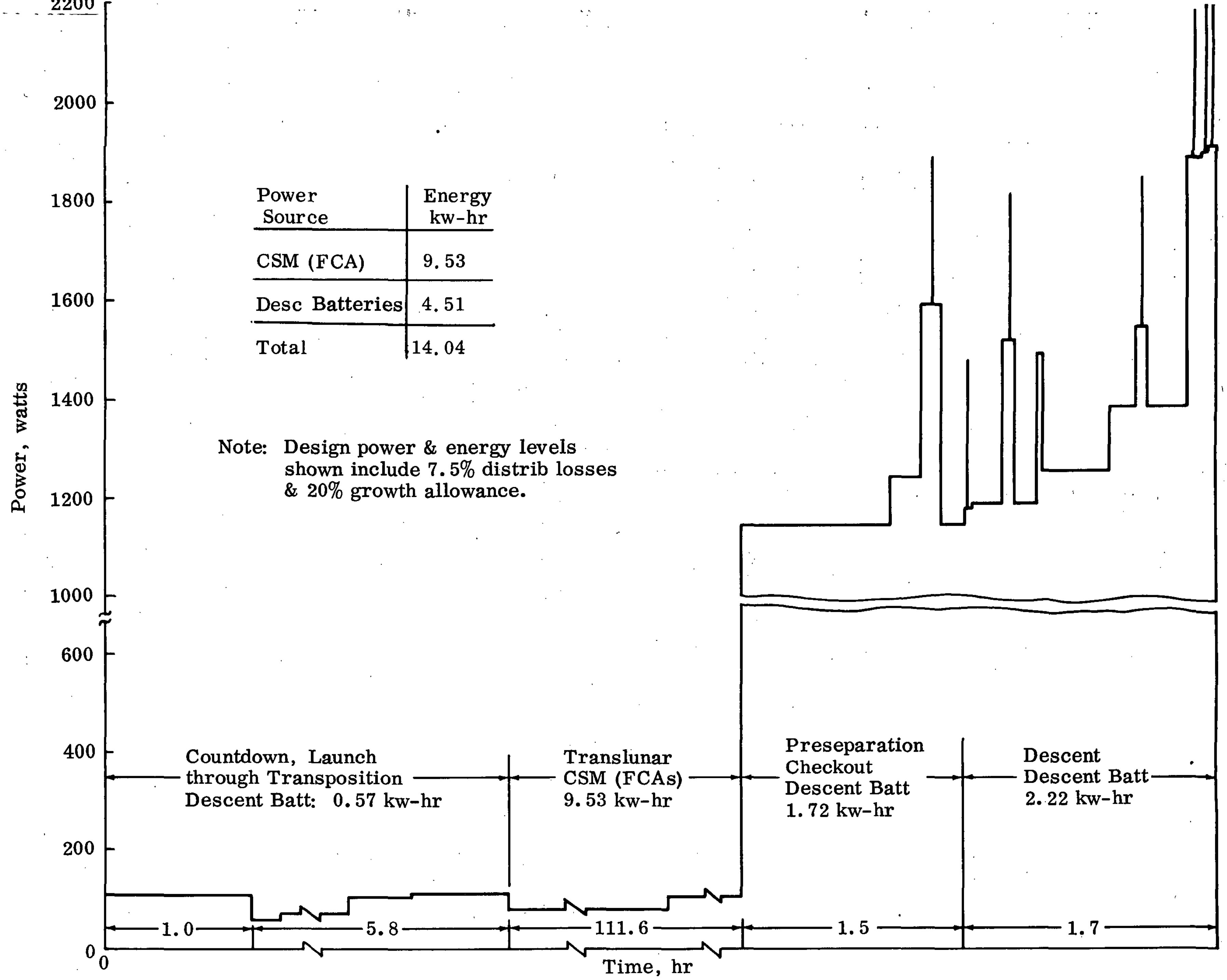
No. Cells	20
Weight, lb	130.5
Volume, cu in.	1545
Dimensions in. (h x w x l)	8.0 x 5.125 x 37.0
Capacity amp-hr	340/300*
Energy, kw-hr	10.2/9.0*
Watt-hr/lb	78/69*
Watt-hr/cu in.	6.6/5.8*
Mission watt-hr/lb	62 (LEM) 34.5 (Truck)
Mission watt-hr/cu in.	5.2 (LEM) 2.9 (Truck)
Wt of Terminals & Other Hdwe, lb	Zero
Canister Weight, lb	10.5
Canister Material	Mg
Cycling Capability	3
Cell Weight, lb	6.0
Silver Weight/Cell, gm	952
Zinc Weight/cell, gm	746
Cell Dimensions, in. (w x th x h)	
with Terminal	4.9 x 1.82 x 7.5
without Terminal	4.9 x 1.82 x7.0
No. Cells, Positive/Negative	12/13
Total Effective Cell Area, sq in.	620
Separator System	Polyamide, Cellulose, Rayon
Electrolyte Qty, cc; wt, gm; Conc, %	320/432/35
Voltage at 10 amp, Initial/Plateau/Final	31.4/30.9/29.5
Voltage at 40 amp, Initial/Plateau/Final	30.2/30.1/27.4
Capacity after 30 days Charged Stand at $32^{\circ}/80^{\circ}/100^{\circ}F$	1.1C/1.1C/1.025C
Heat Generated, Btu	7,200/3,800**
Specific Heat	0.19
Short Circuit Current into 0.01 Ω Load, amp	750
Mounting Structure Weight, lb	5

* After Predischarge
** Normal LEM Mission/Abort (1 Battery)

TABLE 5.1-3

TRUCK CONFIGURATION SUMMARY

Config	Major Components		Weight, lb		Energy, kw-hr			Reliability	Devel Cost, $1000's	● Advantages o Disadvantages
	Qty	Nomencl	Component	Config	Avail	Reqd	Spare			
Ref Config	2 2	9 kw-hr ASC Batt ECA	260 20	280	18	4.67	13.33	0.99995	-	● High reliability with LEM Batts ● Low cost o High weight
Alt. 1 (Ph.A)	1 1	9 kw-hr ASC Batt ECA	130 10	140	9	4.67	4.33	0.99271	-	● Use of LEM Batt ● Low cost o Low reliability
Alt. 2	1 1	5 kw-hr Batt (New) ECA	70 10	80	5	4.67	0.33	0.99271	250	● Lowest weight o Devel cost for new battery o Low reliability
Alt. 3	2 2	5 kw-hr Batt (New) ECA	140 20	160	10	4.67	5.33	0.99995	250	● High reliability at low weight o Devel cost for new battery



Power Source	Energy kw-hr
CSM (FCA)	9.53
Desc Batteries	4.51
Total	14.04

Note: Design power & energy levels shown include 7.5% distrib losses & 20% growth allowance.

Fig. 5.1-1 Truck Electrical Power Design Profile

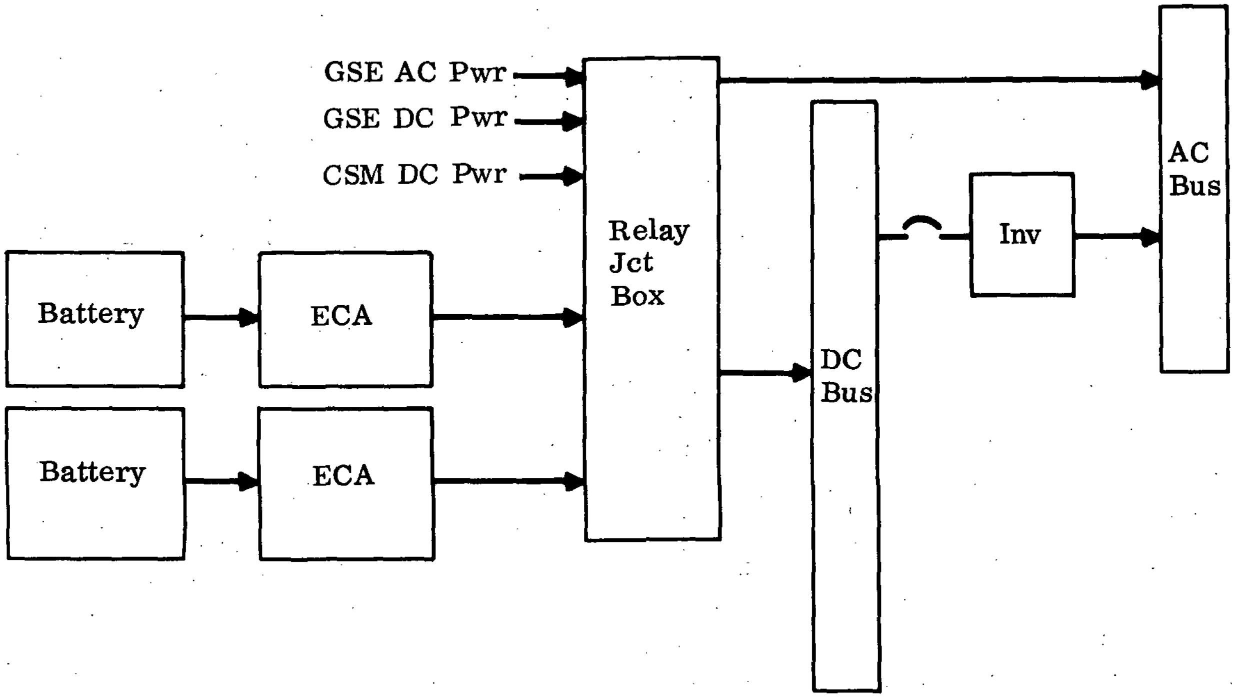


Fig. 5.1-2 Truck Electrical Distribution Schematic Reference Configuration

5.2 ENVIRONMENTAL CONTROL

5.2.1 Ground Rules

The following ground rules have guided the establishment of the Environmental Control Subsystem (ECS) design objectives and the subsequent subsystem configuration development for the Truck:

- Truck will make an unmanned automatic landing
- Payload will be independent of Truck
- Maximum use of basic LEM hardware.

5.2.2 Assumptions

In defining the ECS for the Truck the following assumptions have been made:

- Use of a single glycol pump will not meet reliability requirements
- Rate of waste heat generation from Truck equipment will be lower than that for the basic LEM.

5.2.3 Recommended Configuration

Active and semi-active environmental control subsystems have been considered for the Truck. The active system is recommended. It consists of a coolant recirculation assembly, a water evaporator, a coolant accumulator, a water storage tank, a coolant differential pressure sensor, and an automatic pump control. Glycol coolant is circulated through the electronic equipment cold plates and the heated glycol passes through the water boiler where heat is rejected through the evaporation of water. The environmental control subsystem and electronic equipment are activated approximately 90 min prior to CSM-Truck separation, and are shut down after lunar touchdown. The energy dissipated during this period is less than 5 kw-hr which requires approximately 20 lb of water for heat rejection.

The active ECS for the Truck is shown in Fig. 5.2-1. The active system is assembled entirely from LEM ECS components. The major components of the active system are:

- Water Storage Tank - a LEM ascent stage pre-pressurized water storage tank with a storage capacity of 40 lb of water carries the 20 lb of water needed for the mission
- Glycol Accumulator
- Water Boiler - a LEM redundant coolant loop water evaporator has the cooling capacity required; however, any growth in the cooling load will require use of the LEM main water evaporator
- Coolant Recirculation Assembly - two of the coolant pumps used in the LEM primary coolant loop are functionally retained. Automatic coolant pump switching (in case of failure of one pump) will be accomplished by the pump differential pressure sensor and pump switching controller
- Cold Plates - with the addition of cold plates for the Star Tracker, DCA, and PCA, cold plates are provided for the following Truck equipment:
    - LEM Guidance Computer
    - Coupling Data Unit

- Power Servo Assembly
- Automatic Tracker Assembly (Star Tracker used in LEM Optical Rendezvous System)
- Propellant Quantity Gaging System
- Mission Programmer
- Signal Conditioning Electronic Assembly
- Pulse Code Modulation and Timing Electronics Assembly
- Inverter
- Battery
- Electronic Control Assembly
- VHF Transmitter
- Attitude Translation Control Assembly
- S-band Antenna Electronics
- S-band Transmitter
- S-band Power Amplifier.

The ECS power requirement is 29 w. Total subsystem weight is 72 lb, including 17 lb of glycol and 20 lb of water for evaporative cooling.

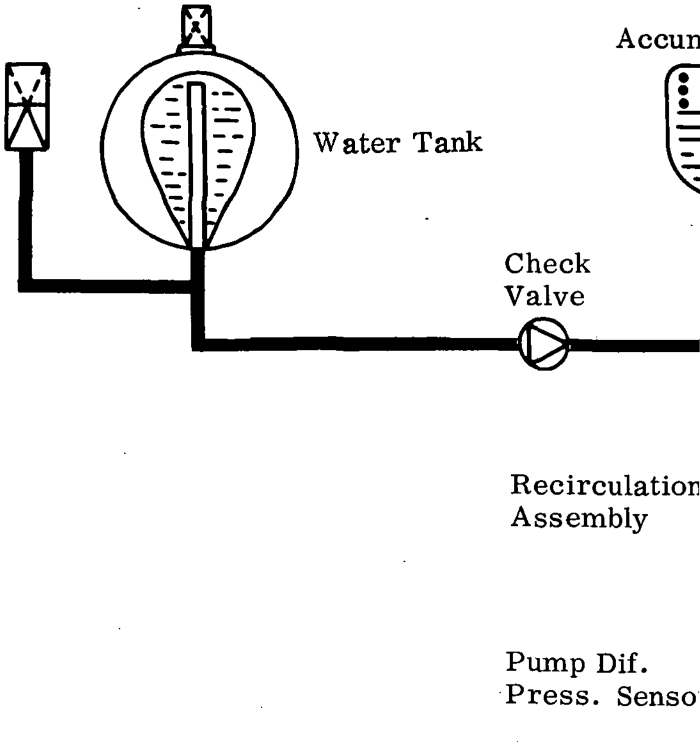
5.2.4 Alternate Configuration

A semi-active ECS would consist of a glycol coolant loop similar to that used with the active system, except that the means for actively dissipating heat, the water evaporator, and the water storage tank, are deleted. Heat is transferred and rejected to the Truck structure by having the coolant loop make thermal contact with selected portions of the structure. The semi-active system is assembled from basic LEM ECS components except for those that would dissipate heat to the Truck structure. (The current LEM heat transport section is thermally isolated from the LEM structure.)

5.2.5 Discussion of Configuration Choice

The active cooling system is recommended for the Truck mission for the following reasons:

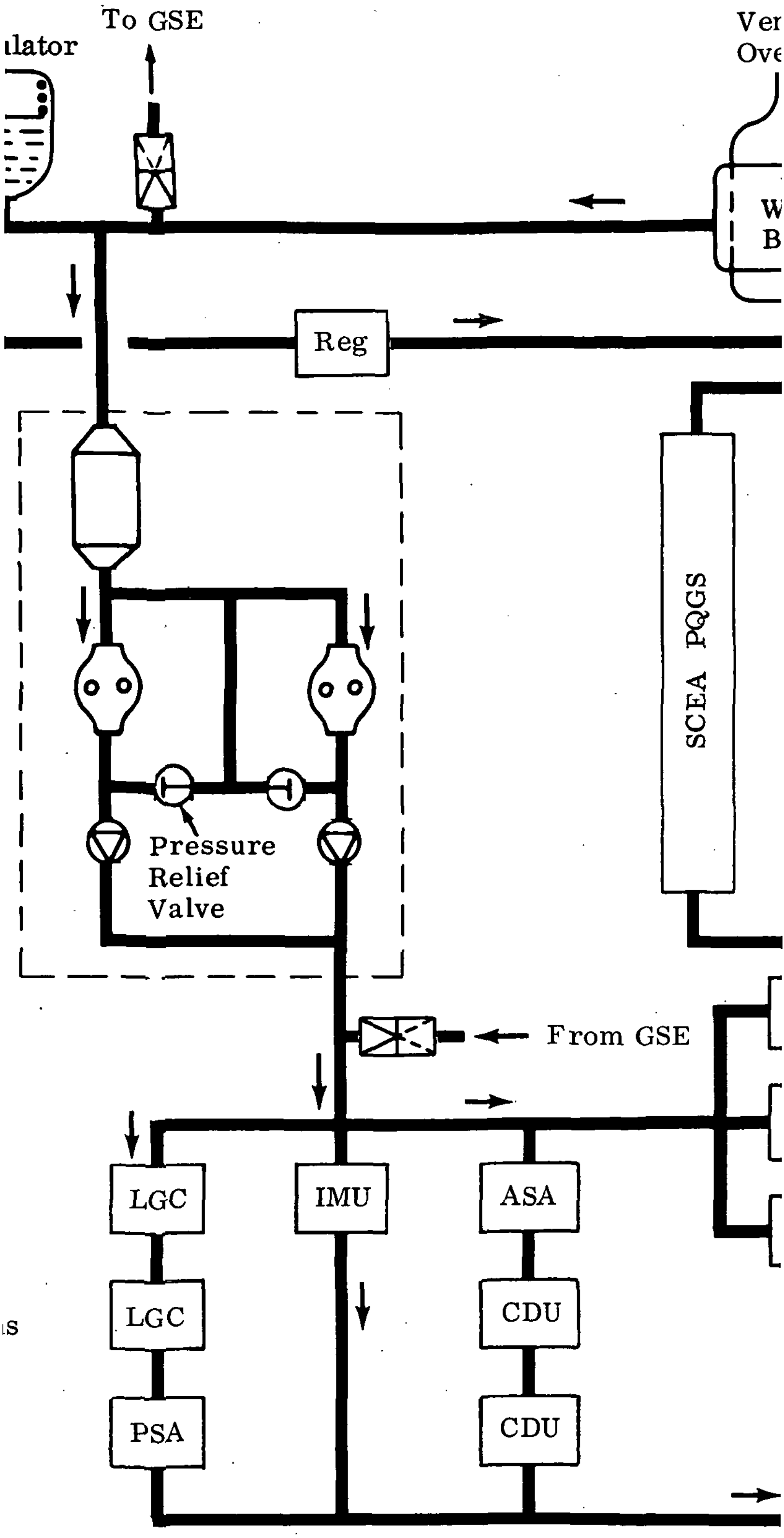
- It represents a minimum change configuration
- It provides flexibility, since the cooling capability of the active system allows for greater growth
- It represents the more conservative system and requires less development.



Abbreviations Used on Heat Transport Section

LGC	LEM Guidance Computer
CDU	Coupling and Display Unit
PSA	Power Servo Assy
IMU	Inertial Measuring Unit
ASA	Abort Sensor Assy
SP	Signal Processor
S-BX	S-Band Transponder
S-BP	S-Band Power Amplifier
VHF	Very High Frequency Communicatio
INV	Inverter
ATCA	Attitude & Translation Control Assy
BAT	Battery
ECA	Electronic Control Assy
PCM	Pulse Code Modulation
SCEA	Signal Conditioning Electronic Assy
PQGS	Propellant Quantity Gaging Sys
DCA	Digital Coder Assy
PCA	Program Coupler Assy

5-14-1


ılator
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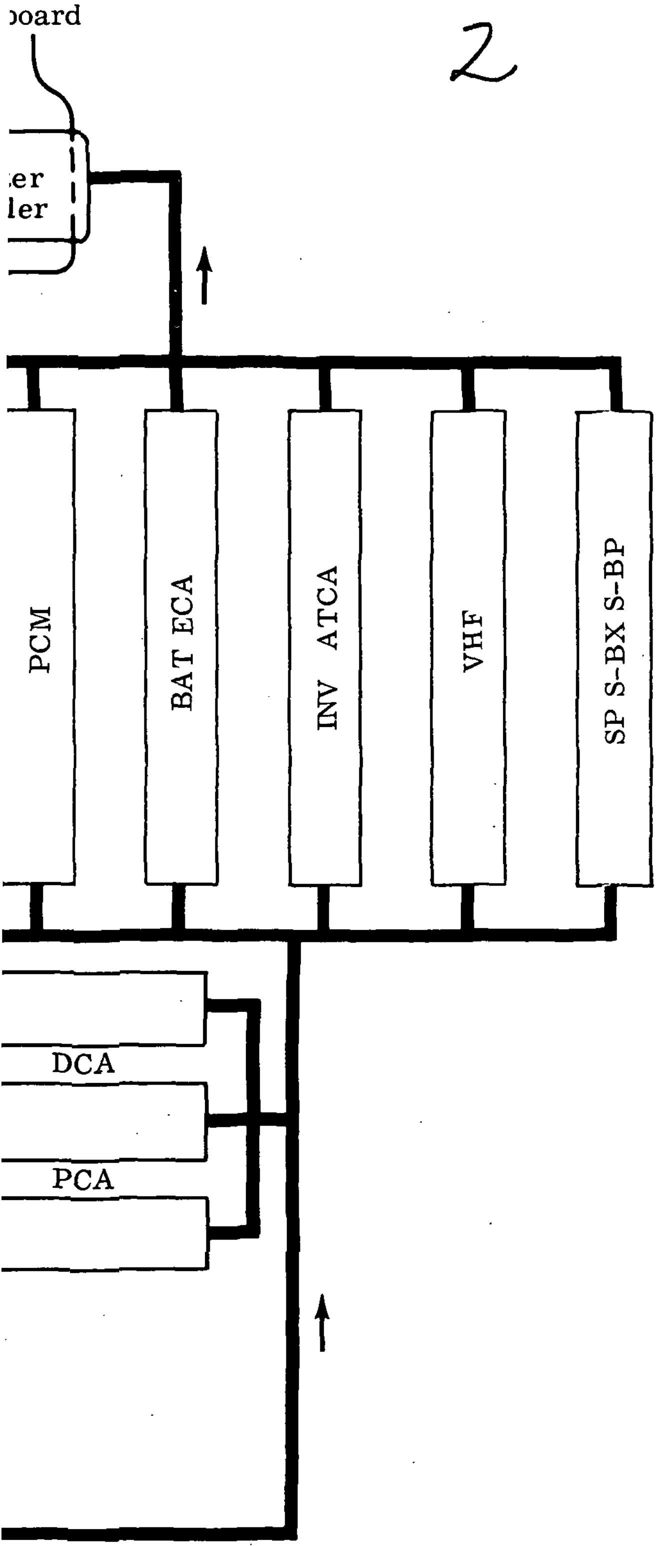


Fig. 5.2-1 Truck ECS

5.3 GUIDANCE, NAVIGATION AND CONTROL

5.3.1 Ground Rules

- Design for an 80-n.mi Hohmann tansfer trajectory; study effects of direct descent trajectory
- Lunar surface missions will be as described for the Shelter by NASA/MSFC

5.3.2 Assumptions

- Primary Navigation Guidance and Control Section (PGNCS), GFE, will be capable of performing the functions required for the Truck
- Unmanned landing is accomplished by a pre-programmed descent trajectory to a pre-selected landing site
- Orbit initialization and IMU alignment is accomplished remotely prior to separation, initiated by the astronaut or by MSFN
- IMU update in lunar orbit, prior to pericynthion, is accomplished by using the Automatic Star Tracker (LEM Optical Rendezvous System, LORS) in conjunction with the LGC
- Post-landing checkout and shutdown will be controlled by the pre-programmed LGC and monitored by Earth via data downlink
- S-band steerable antenna will be locked on to Earth for transmission during the descent coast phase
- LORS as developed for the LEM will be provided to AES for the Truck as GFE
- No requirement exists for any subsystem operation after confirmed Truck lunar landing and status check.

5.3.3 Reference Configuration

The Reference configuration (Fig. 5.3-1) is that of the PGNCS with modifications, the LEM I Program Coupler Assembly (PCA), selected portions of the Control Electronics Section, and the addition of the X-Y scanner. The Abort Guidance System (AGS) is not required because the Truck mission is unmanned and therefore has no abort requirement. The LEM Alignment Optical Telescope (AOT) has been removed and replaced by the LEM Optical Rendezvous System (LORS), which will be used to update the IMU during descent. In the Reference configuration (unaided landing) the Rendezvous Radar is also removed. Reference Truck GN&CS changes from the present LEM are functionally described in the following paragraphs.

5.3.3.1 X-Y Scanner

The primary steerable antenna operation assumes that prior to Truck separation the antenna may be set to lock on Earth when line-of-sight (LOS) is achieved (predetermined antenna position). At LOS, and after phase loop lock-on, automatic tracking will be initiated. Assuming Truck maneuvers during descent will not exceed the angular tracking capabilities of the steerable antenna in velocity and acceleration (20 and 60 deg/sec), the antenna at touchdown will be in the automatic track mode with Earth.

To insure the communication link during the unmanned portion of descent, an X-Y scanner will provide a search mode to the S-band antenna. The scanner will drive the S-band steerable antenna whenever earth acquisition is interrupted. When acquisition is lost, an error threshold signal will energize a relay in the X-Y search pattern generator, initiating a search pattern to control the X and Y axes antenna servo drive. The type of search scan and scan rate will be a function of the vehicle dynamics, probability of detection, and ease of implementation. When the track signal is re-acquired, the signals to a comparator logic circuitry will fall below the threshold level, thereby permitting automatic earth tracking mode to re-initiate.

5.3.3.2 Program Coupler

The PCA used on the unmanned LEM I vehicle will be used to perform the switching functions normally performed by the astronaut. The PCA accepts commands from either the LGC or the uplink.

The PCA contains two relay matrices, a 16 by 16 matrix containing 127 relays, driven from the LGC through relay drivers, and a 16 by 6 matrix containing 48 relays, driven by relay drivers contained in the Digital Coder Assembly. All these relays are latching relays with independent set and reset coils.

The preprogrammed LGC performs a post-landing checkout and shutdown sequence through the 16 by 16 relay matrix in the PCA. The up/down link will differ from the LEM LTA-1 in that the S-band will be used instead of UHF/VHF.

The DCA will decode the received S-band signal and energize the appropriate relays through its relay drivers.

5.3.3.3 LGC Software and Hardware Changes

The LGC will require a pre-programmed discrete interface for initiating IMU fine alignment prior to Truck/CSM separation and prior to Hohmann transfer at pericynthion. This function is inserted manually by the astronaut in the present LEM. Two methods of generating this discrete are via CSM uplink or pre-programmed LGC command.

The eight-jet RCS "B" system of LEM is the Recommended configuration for the Shelter. The LGC has the capability of operating with the "B" system. The Reference Truck also uses eight RCS jets, but the two upward firing nozzles are canted to avoid plume impingement on the payload. It is suggested that these canted nozzles be used only when separating the Truck from the CSM, and that the descent attitude be controlled by unbalanced use of the four downward firing jets - a procedure similar to the ascent phase of the present LEM mission. If further study indicates a need for the upward firing jets during Truck descent, the effect of their cant angle on LGC software would require assessment.

It should be clearly noted that in nearly all cases when LGC Truck software changes from LEM, it results in a hardware change. This is because of the very high percentage of fixed rope memory in the LGC which results in low flexibility (36,864 fixed vs 2048 variable).

5.3.3.4 PGNCS Orbit Initialization

After system warmup prior to separation of the Truck and CSM, the following data must be entered remotely into the LGC: Landing site coordinates, attitude information, and orbital parameters. These are entered manually by the astronaut in the

Taxi and Shelter. For the Truck, three methods of orbital initialization appear feasible and are as shown in Fig. 5.3-1 and discussed below:

- VHF data link from CSM to Truck - for continuous Truck subsystem monitoring, a *Truck-to-CSM data link exists in the present configuration.* When the Truck is not in line-of-sight (LOS) with Earth, the status data must be recorded. Data is sent by VHF data link from Truck to CSM for transmission to Earth via S-band when LOS occurs. The data link from the Truck to CSM is similar to the Apollo LEM VHF transmitter data link. PGNCS orbit initialization in lunar orbit can be accomplished by the addition of a CSM-to-Truck data link. The data links are discussed in detail in Paragraph 5.5.
- A second method of initializing the PGNCS is through a hard wire link between the CSM and Truck. The DSKY located in the CSM allows the astronaut to remotely send the required data to the Truck LGC via the DSKY key punch. Verification of the system performance prior to separation can also be checked via the DSKY display panel.
- A third method of PGNCS initialization is by the use of MSFN. During the first lunar orbit, when in LOS of Earth, MSFN would initialize the LORS for IMU alignment.

5.3.3.5 Auto Tracking Assembly

For an unmanned lunar landing, the Truck requires the addition of an automatic alignment technique for the IMU. The present LEM configuration aligns the IMU to a star reference via a manually-controlled telescope. The Truck guidance and control system performs the same function with an automatic star tracker. This requires new equipment in the Truck flight control system which is described below. The auto star tracker LORS is mounted on the navigation mounting base, replacing the AOT. The present LEM guidance computer has the capacity for the required star catalogue and program. The auto tracker assembly is used to provide initial IMU alignment prior to Hohmann transfer, and for IMU updating prior to the power descent.

The auto tracker assembly consist of:

- Optical Star Tracker
- Tracker Electronic Unit
- Coupling Data Units

As shown in Fig. 5.3.2, position and coarse attitude data from the CM are used as initial inputs to the IMU. Based on these inputs and within the limits of the tracker gimbals, the modified LEM computer selects a star from its catalogue. Command elevation and azimuth signals are sent to the CDU after the required matrix transformation of the star coordinates from stored inertial reference to vehicle body axes. The CDU converts the computer digital outputs to analog form, and also compares the tracker readout angles with the computer command angles so that the true command signal sent to the electronics unit is the difference between these two.

The tracker electronics unit shapes, modulates, and amplifies the above signals for the respecitve azimuth and elevation gimbal servo motors. When the respective gimbal angles equal the computer command angles, no further signal is received by the servo loops, and the selected star should be well within the ±2 deg field of view of the sensor. A star acquisition signal initiates the fine alignment mode where the star signal is modulated and used to drive the gimbal servo loops to null. In this mode, the computer and the CDU outputs are not used. The sensor-modulated light signal is sent directly to the electronics unit to X and Y channels where they are detected and modified to the required elevation and azimuth drive signals.

A null condition occurs when the star is tracked to within 0.15 millirads of the sensor center. At null, the tracker gimbal angles are sent to the CDU's for conversion to digital inputs to the computer. The computer performs the inverse of the original matrix transformation, and with information from at least two stars, updated platform angles are determined.

The differences between present platform angles and the tracker determined angles are then used as signals to the platform gyro torquers to realign the platform.

The optical star tracker consists of a star sensor mounted in azimuth and elevation gimbals, rigidly attached to the IMU in the LEM AOT location (Fig. 5.3-3).

The LEM guidance computer is used for the required computer functions. The computer is required to store a star catalog of 25 to 34 stars, comprised of stars of 2 to 3 magnitude within the gimbal limits of the tracker from separation until touchdown. These must be stored as sets, since a minimum of two stars is required for three-axis reference. During a typical mission, only two or three sets of stars are used for tracking. Therefore, the computer includes the logic to select a particular set, depending upon location and attitude information from either the CM or the IMU.

The command angles must be in terms of the vehicle body axes, since the tracker gimbals are mounted directly to the vehicle. Since the star angles are stored in terms of the IMU or Stable Member (SM) reference, a coordinate transformation is required before the command signals can be used. Therefore, the computer's function in the command mode is to solve for the azimuth and elevation angles using the prestored inertial components of the selected star and the IMU gimbal angles.

IMU attitude updating follows the tracker fine align mode. Upon receipt of a null signal from the sensor, the computer then functions in a reverse mode to update the IMU, using tracker information. This information is in the form of fine azimuth and elevation angles for the selected star. Thus the process is reversed, and the IMU reference components are solved for in terms of the elevation and azimuth angles, using the appropriate coordinate transformation.

The newly determined inertial coordinates of the star are now compared with the initial values, and the required gimbal angle rotations are determined. The computer converts the angles to digital signals which are sent to the platform gyro torques. With this fine alignment of the IMU is completed.

5.3.4 Alternate Configurations

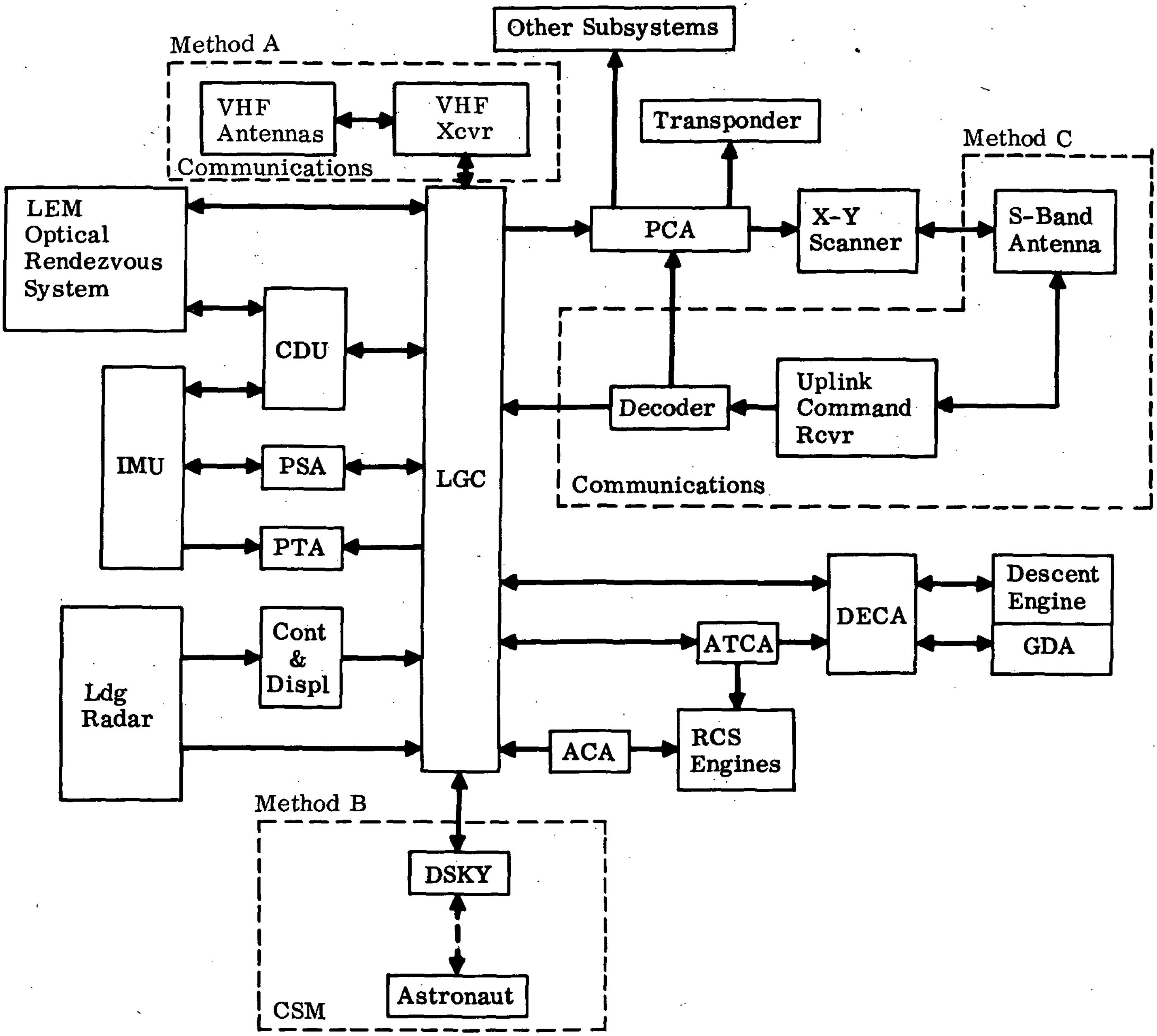
- A 16-jet RCS, similar to that used on the LEM, could be substituted for the recommended eight-jet RCS. The GN&C changes needed to control the vehicle are software changes. The GN&C computer (LGC) will have 16-jet select logic developed by MIT for LEM. It may be desirable to have jet failure discretes sent to the LGC for the unmanned Truck mission. The need and extent of change in the LGC software and interfacing will depend on the MIT LEM logic definition.
- Other possible alternates use eight jets, with selected jets rotated 90 deg.
- For Truck missions where it is possible and desirable to aid the landing by an emplaced beacon, a rendezvous radar would be required in the Truck. (Refer to Paragraph 5.5 for a discussion of beacon-aided landing techniques.)

5.3.5 Discussion of Configuration Choices

The 80-n.mi descent trajectory is similar to the present LEM trajectory. The required trajectory software and sensor interface changes in the PGNCS are held to a minimum, compared with the modifications that would be required in the AGS. It is doubtful that the AGS would have the memory capacity to perform the necessary functions.

If implementation of the present LEM includes an LORS, much of the software and interface requirements will have been completed on the LEM project.

With the direct descent trajectory, the shorter time between separation and touchdown would eliminate the need for a second IMU alignment. However, the orbital initialization and IMU alignment must still be performed remotely.



Abbreviations

RCS: Reaction Control Subsystem	GDA: Gimbal Drive Actuator
IMU: Intertial Measuring Unit	DECA: Descent Engine Control Assy
CDU: Coupling Data Unit	ACA: Attitude Control Assy
PSA: Power Servo Assy	DSKY: Display & Keyboard
PTA: Pulse Torque Assy	PCA: Program Coupler Assy
LGC: LEM Guidance Computer	ATCA: Attitude Translation Control Assy

Fig. 5.3-1 Reference Truck Guidance, Navigation and Control Subsystem

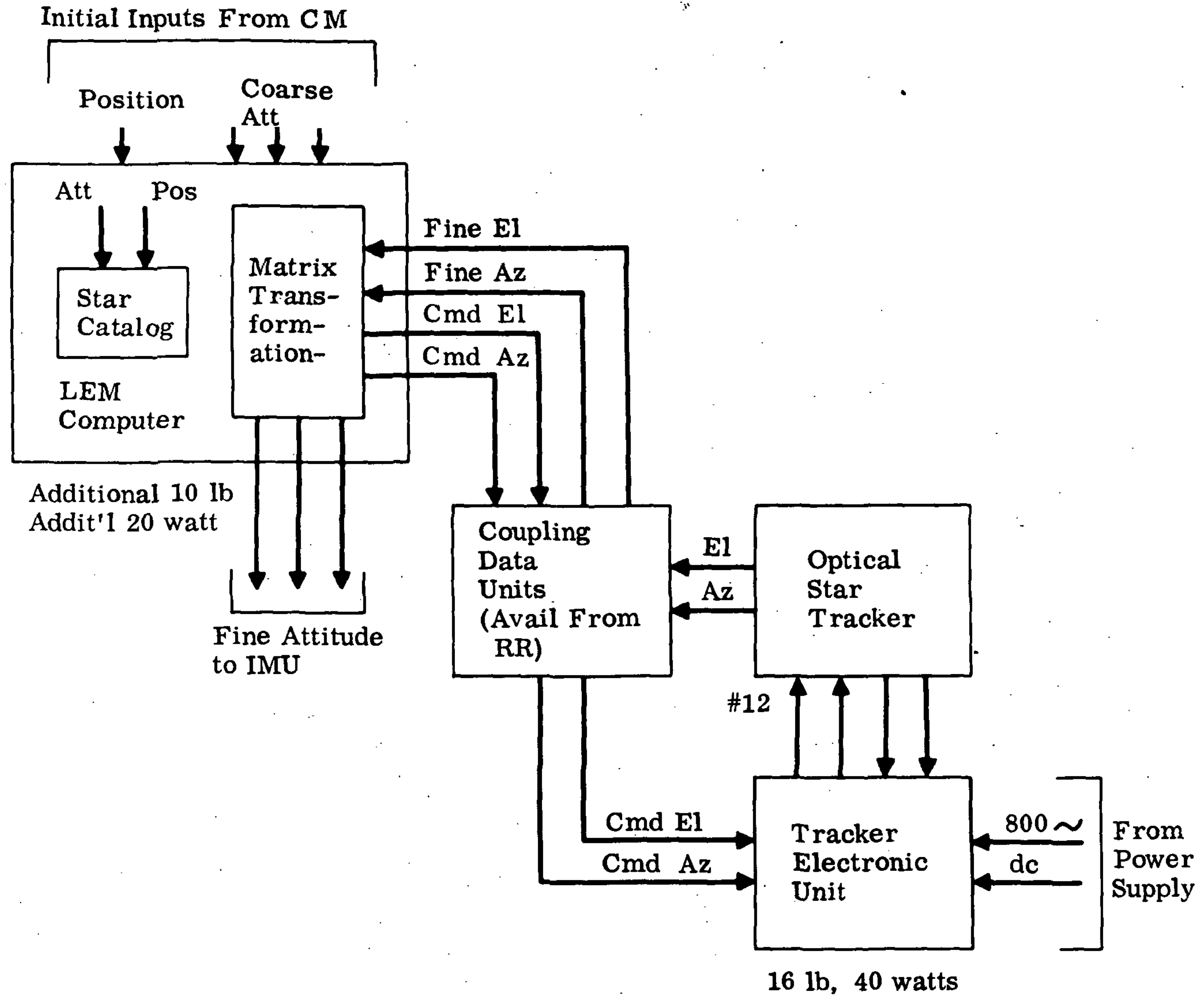


Fig. 5.3-2 Auto Tracker Assembly

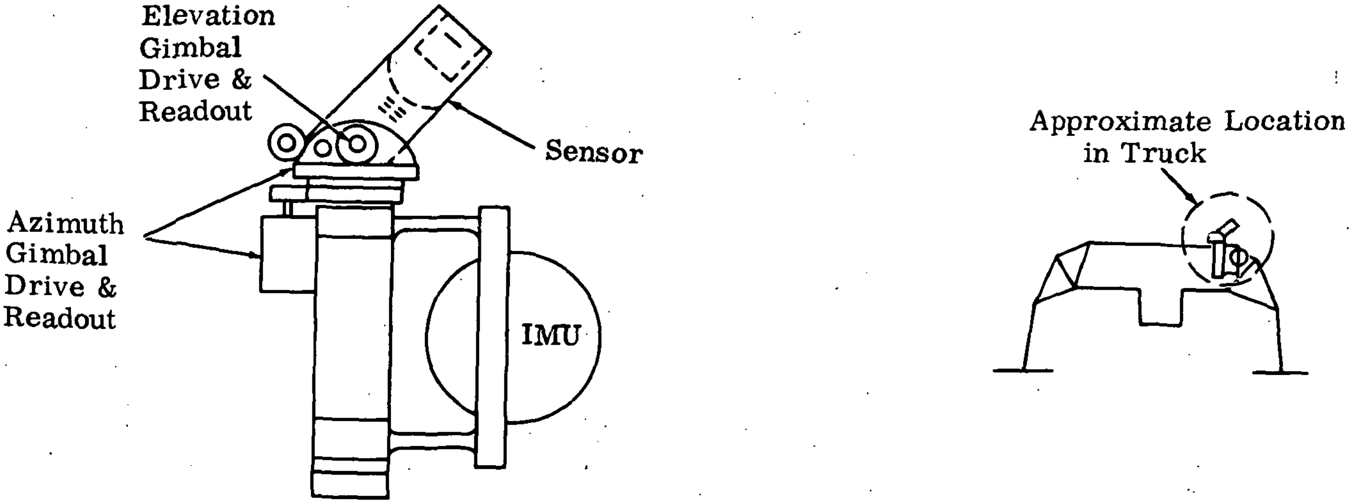


Fig. 5.3-3 Optical Star Tracker Mounting and Location

5.4 REACTION CONTROL AND PROPULSION

5.4.1 Ground Rules

There were no ground rules unique to the Reaction Control or Propulsion Subsystems.

5.4.2 Assumptions and Background Data

5.4.2.1 Assumptions

- RCS propellant requirements for the Truck descent are roughly the same as for the present LEM, and may be somewhat less if the direct trajectory without hover phase is selected.
- Maximum RCS propellant requirements are estimated to be 140 lb, usable. New trajectory data are not expected to result in significant changes in propellant loading.
- Descent phase of the mission is such that the requirements imposed on the descent propulsion subsystem are within its capability as defined by LEM.

5.4.2.2 Background Data

- Descent helium pressurant will warm up to the level of the relief valve pressure setting within 24 hr after landing. Concern over the resultant uncontrolled venting led to study of alternate methods of venting as discussed in Paragraphs 5.4.3.1, 5.4.3.2, and 5.4.6.

5.4.3 Reference Configuration

5.4.3.1 Reaction Control Subsystem (RCS)

A modified LEM RCS is used to provide attitude control for the Truck between separation from the CSM and touchdown. The modifications to the LEM configuration were prompted by functional and mission reliability requirements. Several arrangements of thrusters and a modification to the propellant supply were considered during this study.

The Truck will utilize only a single oxidizer and a single fuel tank. The propellant quantities available from this tankage are adequate for a lunar landing, based on the nominal LEM descent profile. The use of redundant tankage as in the basic LEM will not enhance mission success, since the decision and action necessary to profit from the redundancy requires the presence of a man.

Relocation of the RCS to the descent stage allows an increase in thruster radii, and thereby increases the maximum moment from 1100 ft-lb to approximately 1250 ft-lb. The relocation also allows for reconfiguration of the feed and pressurization lines with the elimination of one set of propellant manifolds and the ascent interconnect valves (Fig. 5.4-1 and 5.4-2).

The isolation valves are also removed. They are normally used to prevent a loss of propellant when a malfunction occurs in a thruster or thruster control valve, but malfunction detection and isolation valve control requires action by the astronaut. An automatic sensing and control system could be developed for the Truck, but further study is required to determine the desirability of this approach in terms of mission success and system development.

After landing, damage to the Truck payload or injury to an astronaut could result from an exploded RCS helium and/or propellant tank caused by micrometeoroid penetration of the tanks or overpressurization of the propellant tanks because of a simultaneous malfunction of a regulator and a relief valve. As a precaution against this hazard, the stress level of the tanks will be reduced to preclude explosive failure in the event of penetration. A squib-operated valve will be placed in each helium pressurizing line between the quad check valves and the propellant tank. Actuation of the valve will release helium to the lunar vacuum. When the system has drained down to the vapor pressure of the propellant, boiling will take place inside the bladder, releasing vapor and recycling the bladder outward until it reaches the tank wall where, being physically restrained, the boiling will stop. Permeation of propellant through the bladder is expected to release only an unnoticeable quantity of vapors into the lunar atmosphere. A tank pressure of 25 psia, corresponding to a propellant temperature of 90°F is the maximum anticipated. If a problem in recycling the bladder is found, it will be a simple modification to incorporate a pressure regulating valve in the helium dump line, set for a maximum of 40 psia. Consequently, the propellant will never boil and the bladder will not be recycled.

Other arrangements were studied in Phase A which involved dumping the remaining propellant, as well as the helium onto the surface of the moon. However, the problems of what to do with the frozen propellant "snow" (assuming an astronaut might approach the Truck through a field of frozen oxidizer or fuel), and how to keep the dump lines from freezing while dumping propellants into a vacuum, led to a re-evaluation of the procedure. The proposed solution is simpler and cheaper (two squib valves vs four), and requires no electrical power for heaters or concern about proper sequencing of events.

In contrast to the LEM, the Reference Truck uses only eight RCS thrusters (Fig. 5.4-1 and 5.4-2). The four downward-firing thrusters are retained, and are fired in pairs to provide pitch and roll control by unbalanced couples. This procedure is essentially the same as used during the ascent phase of the LEM mission. One forward and one side-firing thruster provide unbalanced couples for yaw control. The two upward thrusters are used only to separate the Truck from the CSM. These thrusters are canted outward to minimize plume impingement on the payload volume; no "cut-outs" in this volume are required.

This configuration represents the minimum weight concept which provides the required ΔV and rotational control for the automatic, unmanned landing. Horizontal translation is not required in the landing maneuvers presently planned for the Truck.

The mission success reliability of the RCS has been re-evaluated considering the complete eight-jet subsystem, and compared with the descent phase of the LEM. For this comparison, a single failure is assumed to result in a mission failure in either case. The crew safety abort provisions of the LEM were not considered. The resultant reliability is 0.9757 for the Truck and approximately 0.96 for the LEM descent phase, indicating that the LEM and Truck systems are approximately equal in this respect.

Operation of the pitch and roll thrusters in unbalanced pairs imparts a cumulative vertical translational ΔV of approximately 0.6 fps to the vehicle; this added ΔV is not critical.

5.4.3.2 Descent Propulsion

The Truck descent propulsion will be the same as that in the LEM except for three added vent valves which will be used to depressurize the helium and propellant tanks following lunar landing (Fig. 5.4-3). Two low-pressure relief valves will be used in series with the propellant tank vent valves to limit the quantity of propellant vapors vented to the lunar atmosphere.

The use of vent valves to depressurize the descent helium and propellant tanks is dictated by safety considerations. The use of three vent valves is necessitated by the low temperatures of the supercritical helium. Venting the supercritical helium through the propellant tank vent valves would freeze the propellant vapors and might eventually clog the vent line. The sequence of operations will be the venting of the supercritical helium tanks, followed by venting one set of propellant tanks and then the other. Since the Truck is unmanned, the venting must be accomplished automatically or by command link.

The primary safety concern is a catastrophic failure of the helium or propellant tanks. Tanks may fail in at least two ways. An increase in tank pressure combined with a failed-closed relief valve is one. It is estimated that the tank pressure will increase to the level of the relief valve pressure setting within 24 hr as a result of the rise in temperature of the cold pressurizing helium gas. The second means of catastrophic failure is micrometeoroid penetration of a tank with an internal pressure greater than 40 psi. Based on the tank geometries and material, 40 psi was established as a conservative estimate of the pressure level at which no crack propagation will occur if the tank is punctured.

A second safety concern is the possible contamination of the astronaut's garments with propellants as a result of uncontrolled (random) venting when the astronaut is on the lunar surface and in close proximity to the vehicle. During the lunar day, the oxidizer vapors will react with the garment material, possibly causing injury, and fuel vapors clinging to the material may subsequently contaminate the breathing oxygen when the astronaut re-enters the vehicle. The conditions associated with the lunar night are discussed below.

These considerations dictate the use of a low-pressure relief valve in series with each of the propellant tank vent valves. Originally, the tank pressure was to have been reduced to lunar atmosphere (vacuum), the reduction in pressure causing propellant boiling and a corresponding reduction in temperature, eventually freezing the propellant bulk. Heat flow from the vehicle structure would then have slowly vaporized the frozen propellant, with the vapors flowing overboard through the vent valves, thus presenting the same contamination problem discussed above. Therefore, a low-pressure relief valve has now been added to limit the quantity of propellant vapors which are vented to the atmosphere. The relief valves will be set at 40 psia (maximum), the estimated "safe" pressure level for the tanks. The nominal relief valve reseat pressure will be 30 psia.

The phenomenon of liquid/vapor forming "snow" when vented into a vacuum (Ref. 5-1) has led to the final design consideration for the vent system. This phenomenon also presents a contamination problem similar to that discussed above. The lunar night's low temperature prevents the "snow" from vaporizing and dispersing. Thus, the lunar surface can become covered with a layer of propellant "snow" which can be tracked into the vehicle on the astronaut's shoes. It is therefore desirable to confine the vented propellant to an area which the astronaut will not traverse, such as the area directly below the descent stage. Further studies are required to be certain that the vented propellants will not disperse beyond the perimeter of the descent stage. The possibility of venting the propellants into their respective tank bays is also being explored. The available volume in the bays is sufficient to hold the vented propellant. Problems of sealing adjacent oxidizer and fuel tank bays and compatibility of materials within the bays have not yet been explored.

5.4.4 Alternate Configuration

5.4.4.1 Sixteen-Thruster RCS

A 16-thruster RCS may be used, utilizing single pressurization and propellant feed sections (Fig. 5.4-4). The four upward-firing thrusters would be canted outward as in the reference eight-jet system. Two modes of operation are possible:

- As described for the reference mission, except balanced couples may be used for yaw control.
- If the cant angle is small, and preliminary studies show that 20 to 25 deg will adequately clear the payload, the RCS may be operated with balanced couples in the same manner as LEM. There will be some performance degradation due to the cross-coupling effects of the canted thrusters. Further studies will be required to define the maximum cant angle.

Several advantages can be cited for retention of all 16 thrusters. First, the calculated mission success reliability of the 16-jet system is slightly greater than the eight-jet system (0.9817 vs 0.9757). This calculation considers that:

- In case of a failure of one of the jets during checkout in lunar orbit, the failed jet can be switched off. The LGC jet select logic would then automatically choose another jet to achieve the desired control. With an eight-jet system, a single jet failure will probably result in failure of the mission.

- If any one of the 16 jets fails "closed" during lunar descent, vehicle control can be maintained through the automatic jet logic selection of an alternate pair of jets. A failed closed jet in the eight-jet system could result in mission failure.

- Torque produced by a failed "open" jet during the final phase of lunar descent can be off-set by the firing of a jet in the opposite direction. Although the propellant consumption for this mode of failure is much larger than normal, adequate propellant reserves could be provided to accommodate this type of failure for as long as 3 min, if RCS tanks (one set) are completely filled. (An estimated 140 lb of RCS propellant is needed for a normal lunar descent; full tanks would hold 276 lb). A failed open jet in the eight-jet system will result in loss of vehicle control and mission failure.

Second, retention of all 16 jets results in minimum hardware and software changes to the LEM. An eight-jet RCS would probably require some software changes to the LGC jet select logic, to provide the means of operating the thrusters in pairs for pitch and roll maneuvers. This problem is still under investigation by GN&C.

5.4.4.2 Extendible RCS

If the thrusters were mounted on a boom which could be mechanically extended, the upward firing thruster plume would no longer impinge on the payload. Actuation could be provided by the same helium pressurant used on the RCS propellants, thereby eliminating additional actuation energy sources and any problem in sequencing. Thus, if the thrusters are capable of firing, they will also be properly deployed. The actuation pressure can be taken from the helium line between the helium initiating squibs. This pressure will increase to the full 3050 psi in the helium bottle, thereby providing an excellent, self-contained, energy source.

An additional gaseous helium bottle may be necessary. A deployable boom would require flexibility in the propellant feed lines (which are rigid in the basic LEM). This might be accomplished either by flexible hose or by rotating joints. The former is preferred. This is probably the weakest aspect of the deployable thruster concept. In addition, this configuration has added weight, cost, and complexity when compared with the canted thrusters.

5.4.4.3 Methods of Venting Propellant Tanks

Alternate methods of preventing the previously-discussed contamination problems were investigated.

- Possibility of decomposing the propellant into non-toxic, low freezing-point gases was explored. Other than burning with a fuel, no means of decomposing oxidizer was found. The use of Shell Catalyst No. 405 to decompose the fuel was investigated. The manufacturer provided the information that the 50-50 fuel combination has been satisfactorily decomposed using the catalyst. To date, no attempt to analyze the decomposition products has been made.
- Possible use of a fused quartz helium diffusion cell to separate the helium and propellant vapors was briefly investigated. The fused quartz, being permeable to helium, would allow it to vent overboard while retaining the propellant vapors. Possible problems regarding the size and weight of the diffusion cells were indicated. Further investigations into the size, weight, flow capacity, and material compatibility of the diffusion cell are required.

5.4.5 Discussion of Configuration Choices

The eight-jet Truck RCS, as shown in Fig. 5.4-1, is used in the Reference configuration because it is able to satisfactorily accomplish its mission requirements while saving cost and weight: approximately 67 lb over the 16-thruster arrangement shown in Fig. 5.4-4. Useful storage volume is also made available. The mission success reliability for the subsystem is 0.9757 as compared to approximately 0.96 for the LEM descent phase. Slightly higher reliability (0.9817) could be attained, if required, by use of 16 jets. The various RCS considered during the study are summarized in the Table 5.4-1. All arrangements have mission success reliability equal to or greater than the LEM descent phase.

TABLE 5.4-1

RCS THRUSTER ARRANGEMENTS

Thruster Arrangement	Advantages	Disadvantages
8 Jet - Top Canted	Plume Clears Payload Light Weight	No Redundancy
8 Jet - Uncanted	Like Shelter	Payload Impingement Requires Cut-Outs No Redundancy
16 Jet - Top Canted	Plume Clears Payload Some Redundancy using LEM Controls	Heavy Requires Additional Sensors to Utilize All Redundancy
16 Jet - Uncanted - Deployable	Plume Clears Payload Some Redundancy using LEM Controls Larger Moment Arm	Heavier Less Reliable Requires More Development Requires Additional Sensors to Utilize All Redundancy

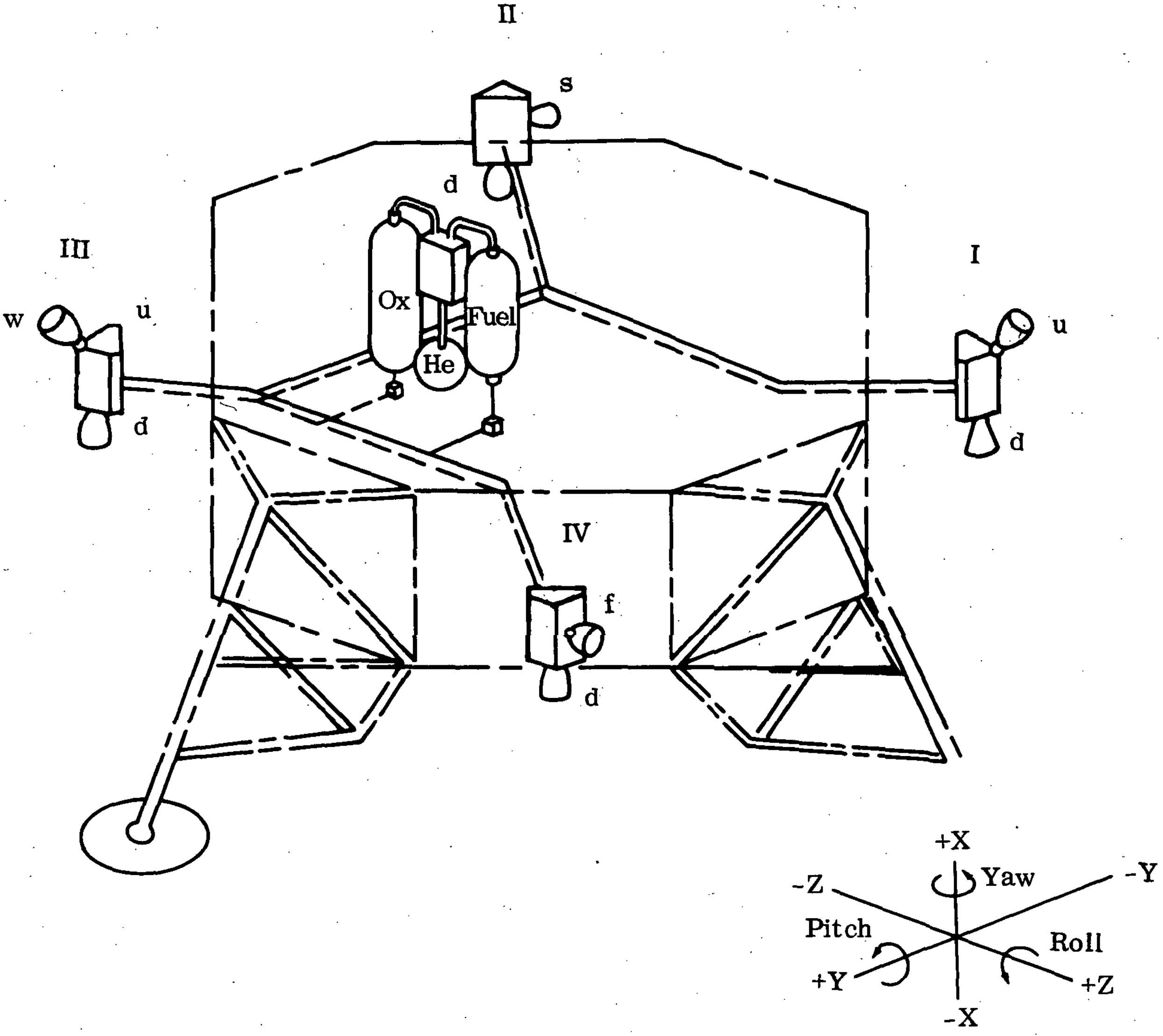


Fig. 5.4-1 General Arrangement, Reference Truck RCS

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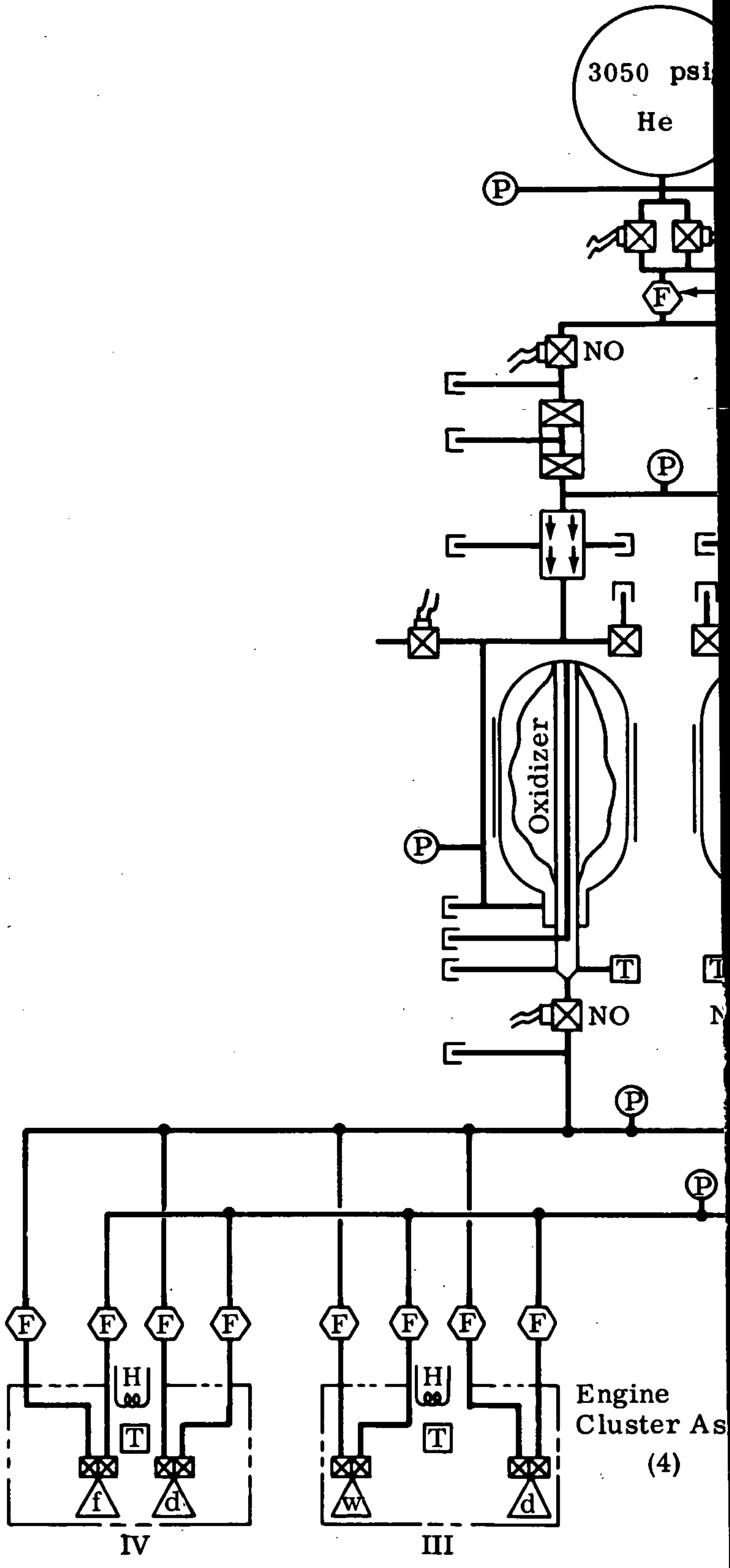
3050 psi
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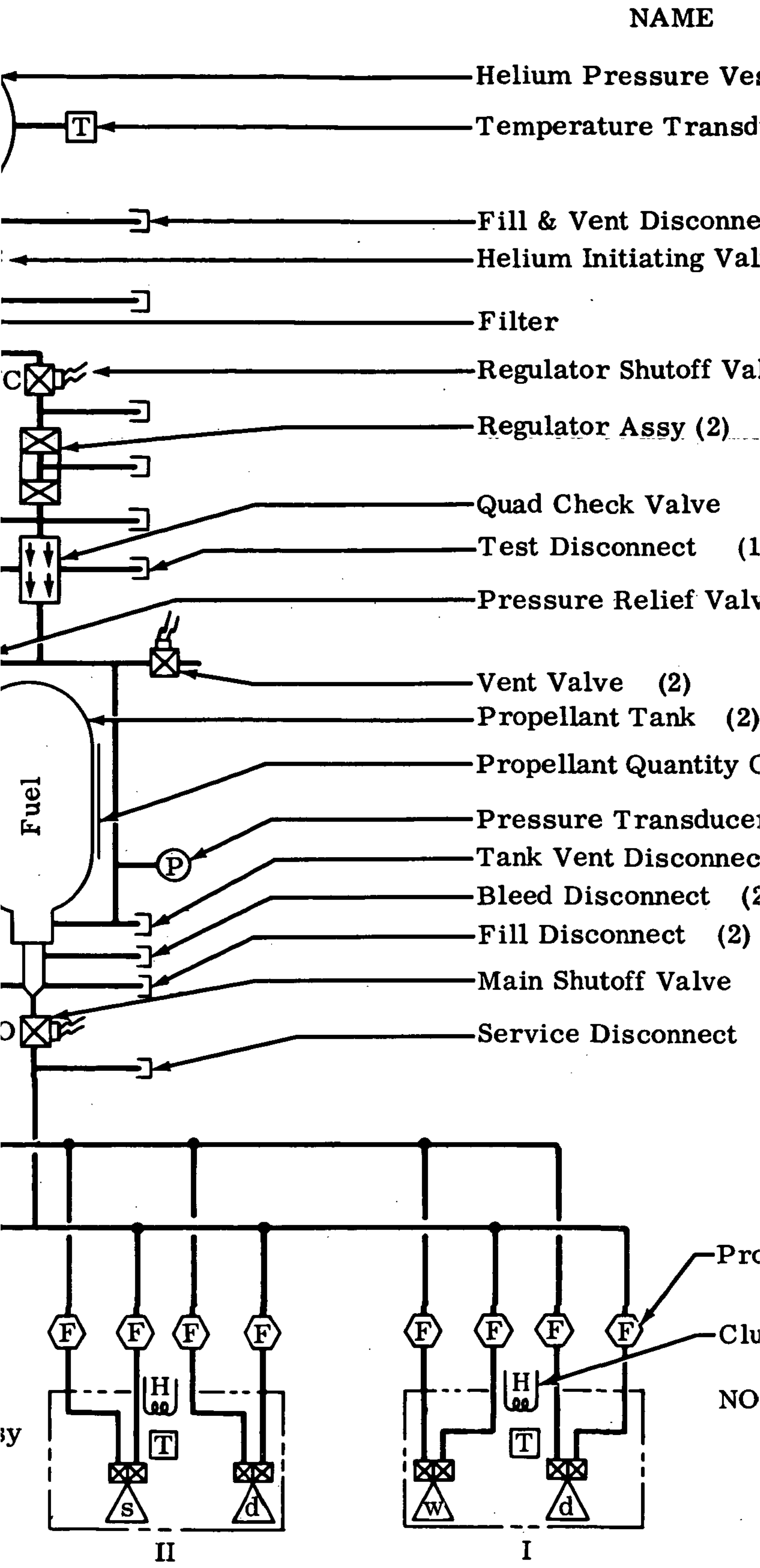
NAME
Helium Pressure Ve
T
Temperature Transd
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Filter
C
Regulator Shutoff Va
Regulator Assy (2)
Quad Check Valve
Test Disconnect (1
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Vent Valve (2)
Propellant Tank (2)
Fuel
Propellant Quantity (
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ellant Inlet Filter (16)

ter Assy Heater (4)

E: Valve positions (NO-open, NC-closed)
shown are for a normally operating
system only.

Fig. 5.4-2 Truck - Reaction Control System

Legend

1 Pressure Relief Valve (3)
2 Fill Disconnect (3)
3 Pressure Transducer (2)
4 He Initiating Valve
5 Liquid Level Transducer
6 Vent Disconnect (3)
7 He Pressure Vessel
8 Heat Exchanger
9 Filter
10 Regulator Shutoff Valve (2)
11 Regulator Assy (2)
12 Test Disconnect (9)
13 Quad Check Valve (2)
14 Vent Valve (3)
15 Diffuser (4)
16 Propellant Tank (4)
17 Temp Transducer (5)
18 Low Level Sensor (4)
19 Trim Orifice (2)
20 Propellant Inlet Filter (2)
21 Descent Engine Assy
22 Low Pressure Relief Valve (2)
23 Isolation Valve (4)

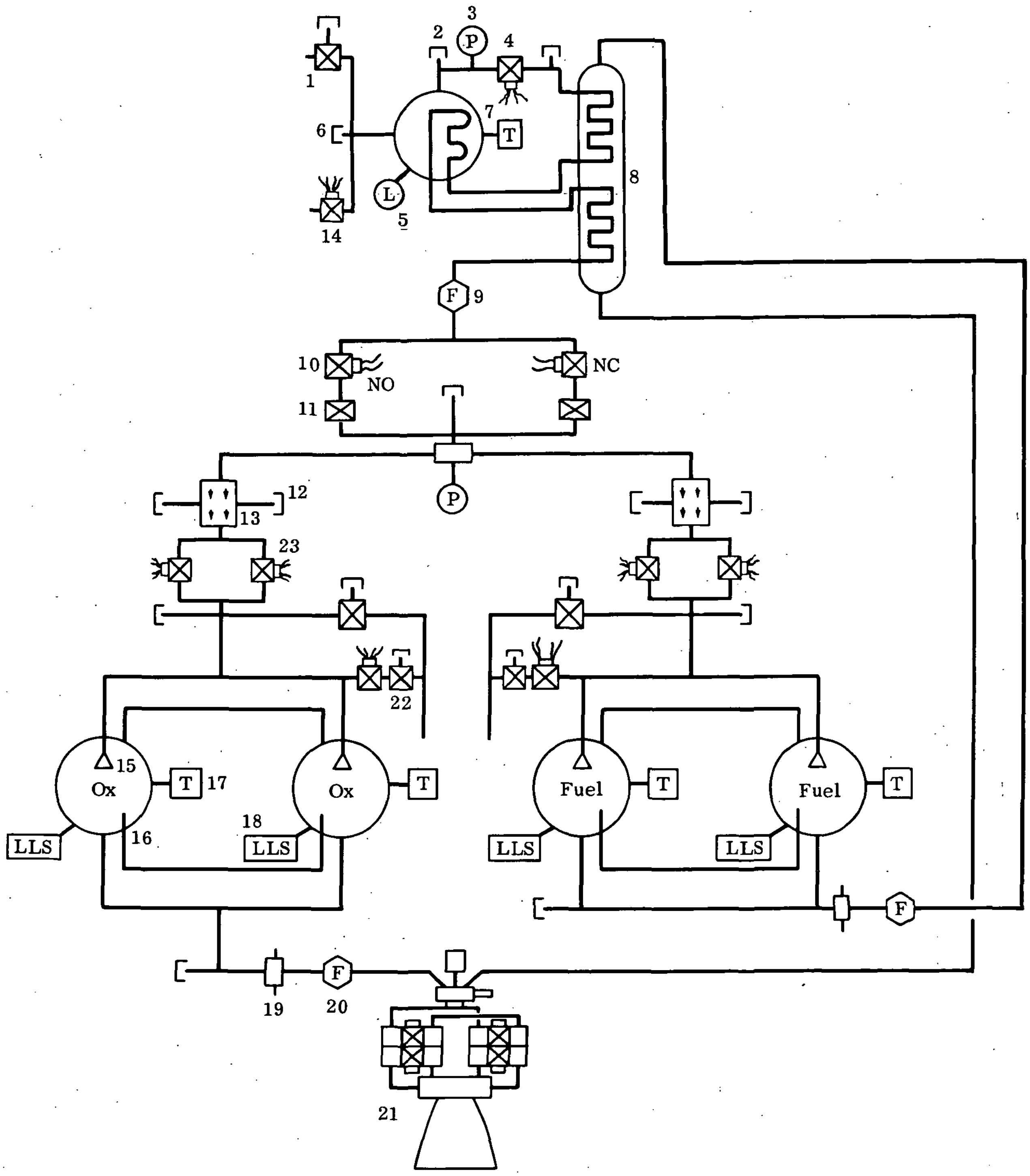
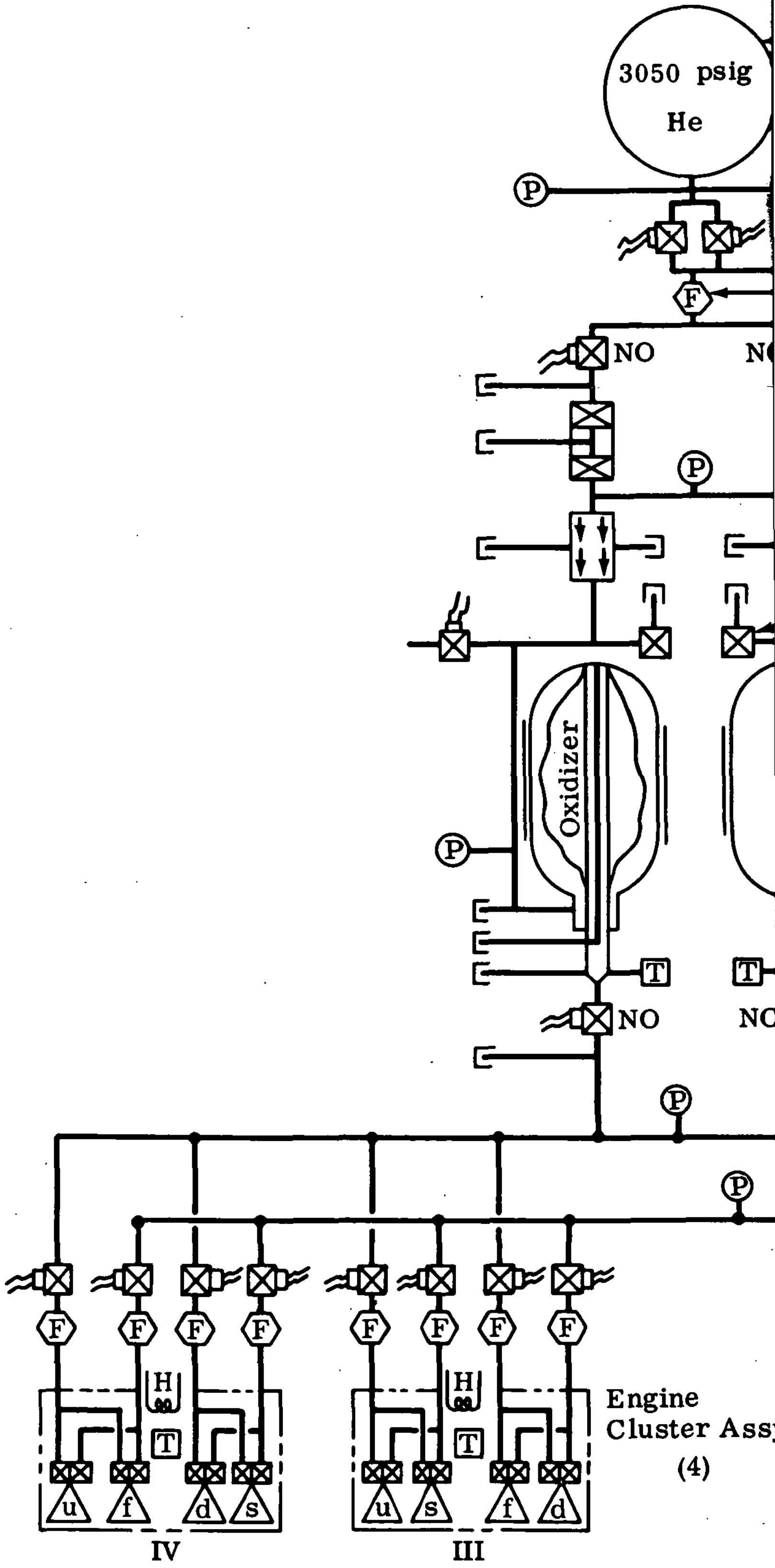


Fig. 5.4-3 Truck - Descent Propulsion System


3050 psig
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F
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N
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Cluster Ass
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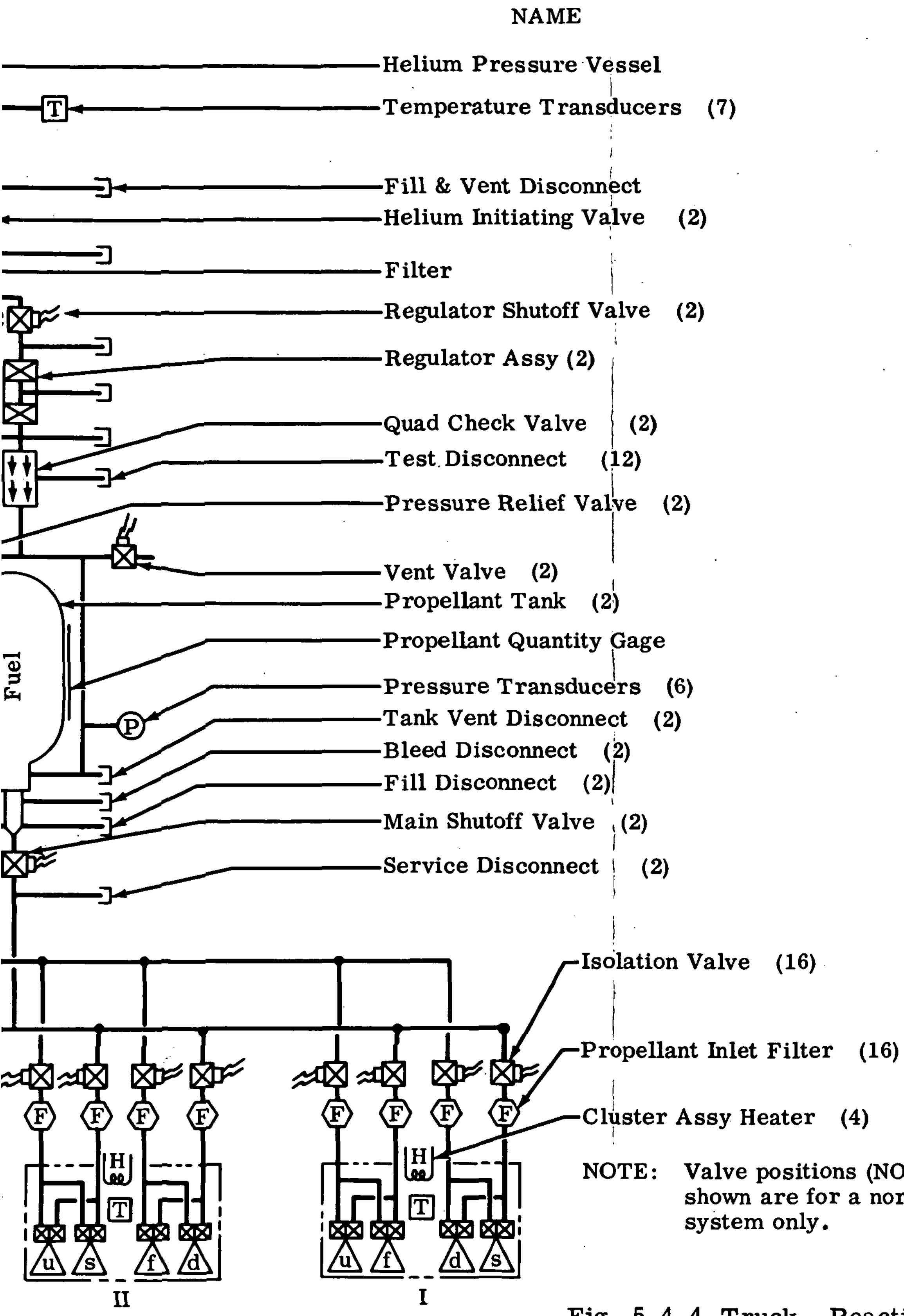


NOTE: Valve positions (NO-open, NC-closed) shown are for a normally operating system only.

Fig. 5.4-4 Truck - Reaction Control System Alternate Configuration

5.5 RF ENGINEERING (Communications, Radar, Antennas, Electromagnetic Compatibility)

5.5.1 Ground Rules

- Performance capability of the Truck is independent of the payload
- Truck/Shelter subsystem equipment commonality should be maintained where possible

5.5.2 Assumptions and Background Data

5.5.2.1 Assumptions

- Continuous status monitoring with real-time transmission is required from separation to touchdown for failure analysis
- No requirement for communications exists after post-landing status data is obtained
- Crew safety design is not a requirement for the Truck
- There are no requirements for TV transmission from the Truck to Earth
- Only CSM status data will be monitored by MSFN during the translunar flight (no Truck status data)
- Truck descent trajectory is similar to that of the Shelter

5.5.2.2 Background Data - Electromagnetic Compatibility (EMC)

- MIL-E-6051C specifies the basic requirement for EMC
- LEM Specification LSP-530-001 will be the primary EMI control specification for the Truck, and LEM Specification LSP-400-5 will govern GSE.

5.5.3 Reference Configuration

The Reference configuration uses subsystems and equipment from the Shelter and the Apollo LEM, except where the Truck mission or configuration produce unique requirements.

5.5.3.1 Communications

5.5.3.1.1 General. Since the astronaut cannot enter the Truck as he can the Shelter, pre-separation checkout and activation of equipment must be performed remotely, by umbilical or RF link from the CSM or up-link from Earth. The latter method is used for the Reference configuration (the Shelter command up-link has the required capability).

The Communication Subsystem provides:

- Continuous Truck status data transmission from lunar orbit checkout to post-landing status assessment
- Capability for sequential automatic pre-separation checkout of the Communications Subsystem
- Capability of status data transmission to CM (VHF link) and Earth (S-band link).

It is assumed that the Truck/CSM separation occurs on the far side of the moon. Truck status data will then be transmitted to the CSM via the VHF link at 1600 bits per second. When Earth line-of-sight is achieved, the CSM VHF status data link could be continued or the data could be sent directly to Earth via S-band at 51.2 kilobits per sec as with the Shelter. The latter is preferred, since lunar horizon VHF transmissions to the CSM could be marginal, and a higher bit rate appears to be required during the powered descent phase. For the S-band link, automatic Earth acquisition capability of the steerable antenna must be provided as it is in the Shelter.

The down-data link is part of the normal telemetry data link used for status data. It also is used as the verification link for confirmation of the received commands.

The up-data link provides start, stop, advance, and select functions to particular sub-sequences or alternate programs on board the Truck, as well as real-time commands. Modifications to the Shelter-type communications equipment are limited to terminating unused lines and supplying control voltages wherever necessary, to simulate quantities normally supplied by the missing controls and displays or other deleted interfacing subsystems. The Reference Truck configuration otherwise retains the Apollo LEM Communications and Antenna Subsystems with modifications and addition of new equipment as summarized in Table 5.5-1. The Communication Subsystem configuration is shown in Fig. 5.5-1.

5.5.3.1.2 Command Receiver. An S-band command receiver is added to the existing Apollo subsystem. It is on continuously from Earth launch until touchdown. It will accommodate three commands:

- Transceiver "turn-on A" - selects primary S-band transceiver
- Transceiver "turn-on B" - selects back-up S-band transceiver
- Transceiver "turn off" (A or B).

The main commands (other than the above "turn-on/turn-off" functions) are processed by the receiver portion of the S-band transceiver and the decoder; i.e., the data link proper. The additional primary/backup select commands, referred to above, are included as supplementary functions to avoid design modifications to the S-band transceiver.

5.5.3.1.3 Command Decoder. This unit processes the information contained in the received data subcarrier (70 kc) conveyed to it for demodulation, validation, decoding and routing of the received commands to the system commands interface. Outputs to the LGC and PCA, in addition to other discrete circuits, will be provided.

5.5.3.1.4 Antenna Switching Matrix. This matrix interfaces the PCA. Antenna selection on the recommended Shelter configuration will be made through the Earth command up-link.

The up-link command system is used to modify the mode or configuration of the receiving chain which includes selection of S-band antenna (i.e. Omni 1, Omni 2, or steerable).

5.5.3.1.5 S-Band Transceiver. The S-band transceiver is modified to accommodate the data link sub-carrier (70 kc). Additional interfaces are added for the command receiver to switch the transceiver on or off, and to select the primary or backup mode of operation.

5.5.3.2 Antennas

5.5.3.2.1 General. The Apollo LEM antennas to be used on the Reference Truck are:

- S-band steerable (high gain)
- S-band in-flight omni
- VHF in-flight omni
- Landing radar.

It is desirable that the antenna performance be independent of the payload and identical to the LEM performance characteristics. However, antenna location problems will occur because of the variable vehicle configurations caused by payloads. An attempt was made to retain the present LEM antenna locations in the docking structure. One docking scheme (Fig. 5.5-2) bridges the payload, and the antenna locations are approximately identical to those on Apollo LEM. A second alternative (Fig. 5.5-2) utilizes a central cylindrical structure for CSM docking. Because antennas mounted directly to this structure would be blocked by the CSM or Truck, the docking structure is extended to locate the antennas as shown. The locations are similar to those of LEM.

A third alternative configuration exists, in which shelter-type payloads would allow the proposed antennas to be located directly on the payload.

The S-band steerable antenna "look" capabilities during the Truck's powered descent must be studied, including the effects of:

- Vehicle configuration including payload
- Complete descent trajectory
- Lunar landing site
- Vehicle attitude history during descent.

5.5.3.2.2 S-Band Steerable Antenna. There are modifications to the antenna drive electronics to accomplish automatic re-acquisition of Earth.

5.5.3.2.3 S-Band In-Flight Omni Antennas. These antennas will be parallel-coupled to provide optimized omni-directional coverage without the switching from one antenna to the other presently required for operational selection.

5.5.4 Alternate Configuration

5.5.4.1 CSM Truck Control

A study was made of configurations in which the CSM assumes the control and monitoring functions. Of the two frequencies considered, UHF (450 mc) and VHF (260 mc), the UHF link is more favorable because of equipment availability.

For the UHF link, the Truck configuration is shown in Fig. 5.5-3 and summarized in Table 5.5-2. The necessary equipment changes to the CSM communication system to support this configuration are illustrated in Fig. 5.5-4 and summarized in Table 5.5-3. The design concept involves the remote control of the Truck from the CM by using available unmanned Apollo R&D LEM I equipment. The LEM Mission Programmer (LMP) is placed on the Truck; the LMP receives 450-mc Truck control data from the CM encoder/transmitter. The 450-mc Truck receiver is on from launch, or is programmed on at the appropriate time. An unmodified LEM S-band transceiver is used, which enables the Truck to send status data to MSFN after LOS is established.

The astronauts in the CM have the capability of initiating checkout and Truck/CSM separation sequences stored in the LMP. Display equipment is needed aboard the CSM to ascertain proper equipment response and operational sequences. The CSM can monitor the 1.6 kbps status data from the Truck by means of this display and/or record it for later transmission to Earth. The Truck capability of transmitting status data, via S-band, directly to MSFN is still available for LOS. Limitations exist for the amount of data displayed in the CSM. Further mission definition is required to determine accurately the subsystem complexities inherent in this approach.

5.5.4.2 Beacon Aided Landing

When a Shelter and/or Taxi land prior to the Truck, it is possible to aid the Truck landing by use of a passive or active beacon, located either on the Shelter/Taxi or deployed at some favorable nearby site. By this means, the CEP would be reduced and the possibility of landing on unfavorable terrain minimized. The beacon-aided approach would provide accurate slant range, range rate, and angle data with respect to the selected site and insure a landing within 200 ft of the beacon.

When only the unmanned Shelter has been previously landed, the Truck landing would be similar to that of the Taxi, in that the CSM Rendezvous Radar beacon transponder antenna and associated electronics (located in the Shelter to aid the Taxi) would be used. Where both the Shelter and Taxi have been landed, the Shelter could be used as above or the astronauts could deploy an inflatable or manually erected beacon at a suitable site.

5.5.4.2.1 Passive Beacon. A passive beacon could be a corner reflector (square or trihedral), a Luneberg Lens, or a spherical reflector. The square corner reflector is the optimum passive beacon for the unmanned Truck landing. It has adequate coverage, as well as the largest echo area for a given outside dimension. The corner reflector is simple, easily deployed, and several can be clustered if additional coverage is desired.

5.5.4.2.2 Active Beacon. The Apollo Rendezvous Radar Transponder System selected for the Taxi-landing would work equally well with the Truck if the Rendezvous Radar were installed on the Truck.

With an active beacon, such as the CSM Transponder, the antenna coverage is the significant parameter. At angles close to the horizon (0 to 15 deg), the CSM Transponder antenna radiation level varies between -1 and -15 db. The Truck landing trajectory is, at present, incident to a landing site within these angles close to the horizon. Consequently the -15 db pattern null degrades the Rendezvous Radar Transponder performance from 400 to 70 n.mi maximum range. (If necessary, this could be improved by minor modification to the aperture, radome, and/or ground plane of the Transponder.) The active beacon could also be deployed by Taxi astronauts, possibly on a mast erected at the desired landing site.

5.5.5 System Considerations

The Truck trajectory characteristics are assumed similar to those of the Shelter (Fig. 5.5-5). It is assumed the Rendezvous Radar Antenna Truck location is such that during the descent the antenna-beacon LOS is always available (no vehicle blockage).

An approximate Rendezvous Radar performance capability using a passive reflector can be determined from the radar range equation assuming a reflector dimension of 10λ with inherent 2-db construction loss. The range at which detection occurs is found to be 5 n.mi. If beacon interception is desired at 20 n.mi, a minimum 40λ dimension reflector would be needed. The reflector angular coverage is approximately ±30 deg in both principal planes. This coverage is adequate, provided the vehicle trajectory descent flight path (directed towards the reflector) falls within this cone.

For the case where the Shelter active beacon is used, the Truck's guidance system would require a coordinate bias to insure a safe landing in the Shelter vicinity. A coordinate bias of 700 ft magnitude would insure a safe landing, assuming a 200 ft beacon aided landing accuracy. The bias would be programmed and determined either by Earth or by astronaut survey.

The high signal-to-noise ratio obtained using an active beacon would provide greater tracking accuracy at the expense of Shelter power consumption and transponder reliability (relative to a passive beacon). In addition, the active transponder is susceptible to possible damage or misorientation of antenna coverage during the Shelter landing.

Calculations were performed to determine the quantitative enhancement of the return signal from a passive beacon as compared to that from the Lunar surface. Assuming the nominal vehicle trajectory, a 40λ passive reflector, and the maximum and minimum lunar reflectances developed in Ref. 5-2, the resultant enhancement is shown in Fig. 5.5-6. A minimum of 10 db enhancement is available at 20 n.mi and it increases inversely with range. A second source of enhancement is the scattering of incident signals by the irregularities of the lunar surface.

The advantages and disadvantages of active and passive reflectors are tabulated below:

ACTIVE BEACON

Advantages	Disadvantages
Installed in Shelter and deployed for Taxi mission, consequently readily available for Truck mission	Less relative reliability considering power requirements and storage periods
Higher signal to noise ratio; therefore, good tracking accuracies	Requires modification (biasing) to guidance program to ensure safe landing
Taxi mission not required as prerequisite for Truck mission	Subject to misorientation or damage during Shelter landing
Limited radar search mode is available within constraints of side lobe lock on	Development required for improved horizon coverage

PASSIVE BEACON

Advantages	Disadvantages
Proper beacon orientation assured; therefore, good angular coverage	Taxi mission must be successful to ensure deployment
Guidance system biasing not required	Beacon development may be required
Greater relative reliability	Less signal-to-noise ratio available
Limited search mode possible	Additional weight for Taxi mission

Before the final selection of a systems design can be made, the following points require further consideration:

- Complete Shelter/Truck commonality adds more weight and flexibility than necessary.
- A systems design satisfying only the Truck mission requirements would necessitate new and/or modified equipment
- Control and monitoring: MSFN only, CSM only, or CSM and MSFN
- Determination of the extent of electromagnetic compatibility problems and electrical isolation circuitry required for use of CSM/Truck umbilical line. This requires complete definition of the CSM/Truck system and electrical interfaces.

TABLE 5.5-1

REFERENCE TRUCK COMMUNICATIONS EQUIPMENT SUMMARY

Units or ERA	Status	Required Action and Comments
S-Band Transceiver ERA	modified	Needs additional output for 70-kc uplink subcarrier accommodation
		Modify S-band Transceiver switching control circuit to enable the new command receiver to select the primary "A" or redundant backup "B" S-band Transceiver.
S-Band Steerable Antenna Electronics Ass'y ERA	modified	Modify drive electronics to enable the S-band steerable antenna to acquire the Earth signal by automatic means.
Command Receiver	new	Need additional S-band Receiver for redundancy switching, of the S-band "A" and "B" Transceivers and on-off switching of transceiver.
Command Decoder ERA	new	The "heart" of the new Data link - needed for sub-bit detection, decoding, validation and routing the system commands.
Antenna Switching Matrix	new	Switching Complex, needed to implement the automatic antenna system selection (more intricate design, needed if S-band omni 1 and 2 are time shared between command receiver and S-band Transceiver).

TABLE 5.5-2

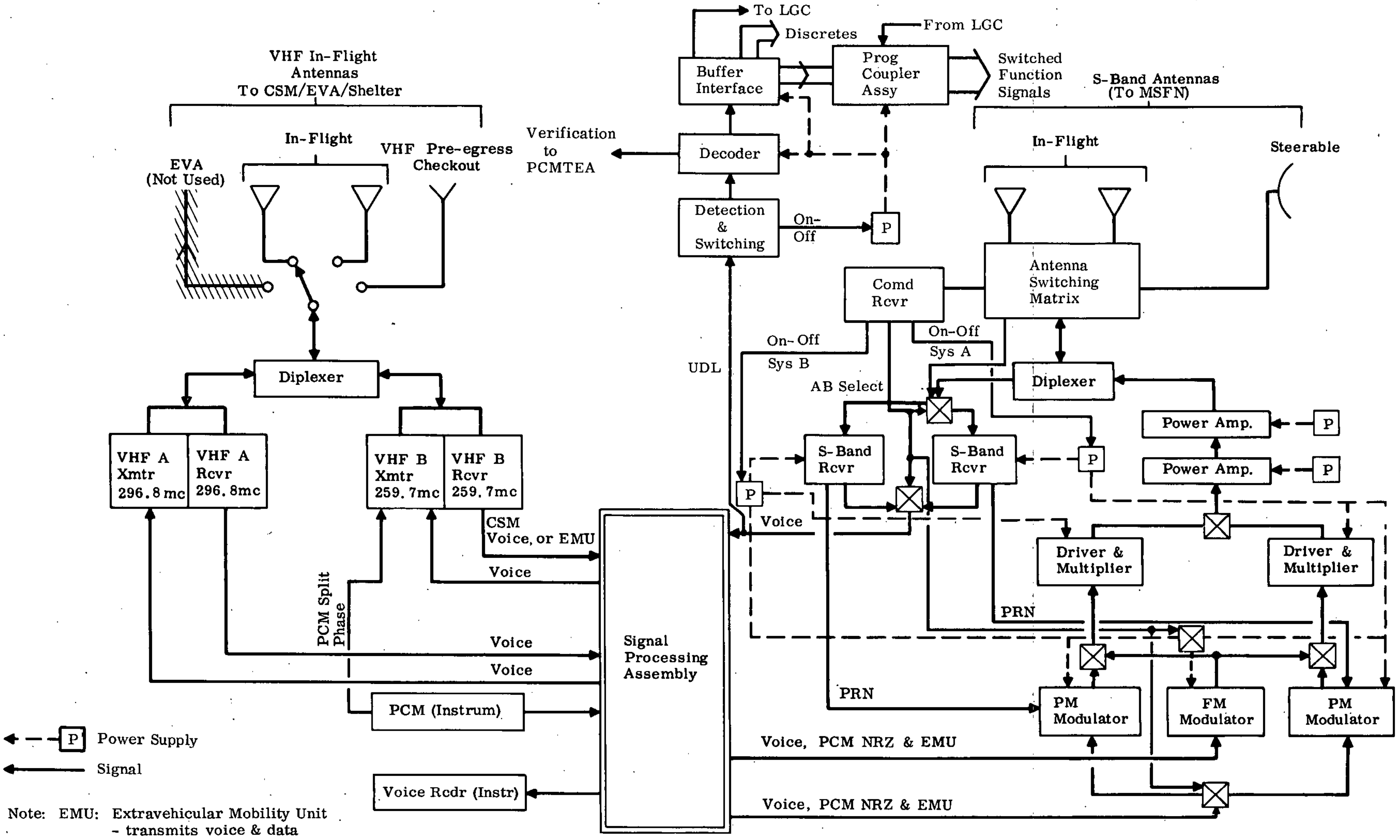
ALTERNATE TRUCK COMMUNICATION EQUIPMENT SUMMARY

Equipment	Status	Comments
Truck Signal Processing Assembly (TSPA)	New	Truck mission requires a minimum of communication-mode switching. New TSPA will provide fixed terminations (control voltages, etc.) to the S-band transceiver, VHF transceiver and ass'ys which normally interface with the SPA. An interface with the PCA will also be provided to allow control of comm. system by the control link. The TSPA will contain the PCM/NRZ data and 512-kc reference input and subcarrier bi-phase modulation circuitry for generation of 1.029 mc subcarrier. Voice, emergency voice, emergency key, TV, voice Bio and VHF voice Bio relay capability is to be deleted.
LEM Mission Programmer	Added	The LEM 1 mission programmer (less program reader ass'y) is added to the basic LEM vehicle
RF Switch with PCA Interface	New	A PCA interface is required to allow CSM control of transceiver antenna's
VHF Transceiver Ass'y 'B'	Modified	VHF receiver portion of the transceiver ass'y is to be deactivated or removed
VHF Infight Antennas	Modified	The VHF antennas are to be coupled to provide spherical coverage without switching

TABLE 5.5-3

ALTERNATE CSM COMMUNICATIONS EQUIPMENT SUMMARY

Equipment	Status	Comments
Command Keyboard	New	This keyboard interfaces with the encoder and allows astronaut selection of commands to be issued to the Truck
Encoder And Modulating Equipment	New	The commands obtained from the keyboard are formatted and encoded by this ass'y. The message format and modulation must be compatible with the LEM mission programmer on the Truck
Command Transmitter	New	Supplies the RF signal. The frequency and modulation must be compatible with the LEM mission programmer on the Truck
Decommutation Equipment	New	This assembly accepts the 1.6 kbps PCM from the Truck (normally received by an existing receiver on the CSM and taped) and removes pertinent data words from the data train. The output from this assembly drives the Truck Data display board.
Truck-Data Display Board	New	Presents pertinent data visually to the astronauts aboard the CSM
CSM Decoder	Possible Modification	If command relay to Truck via CSM is desired, modification may be required to provide this capability



Note: EMU: Extravehicular Mobility Unit
- transmits voice & data

Fig. 5.5-1 Reference Truck Communication Subsystem

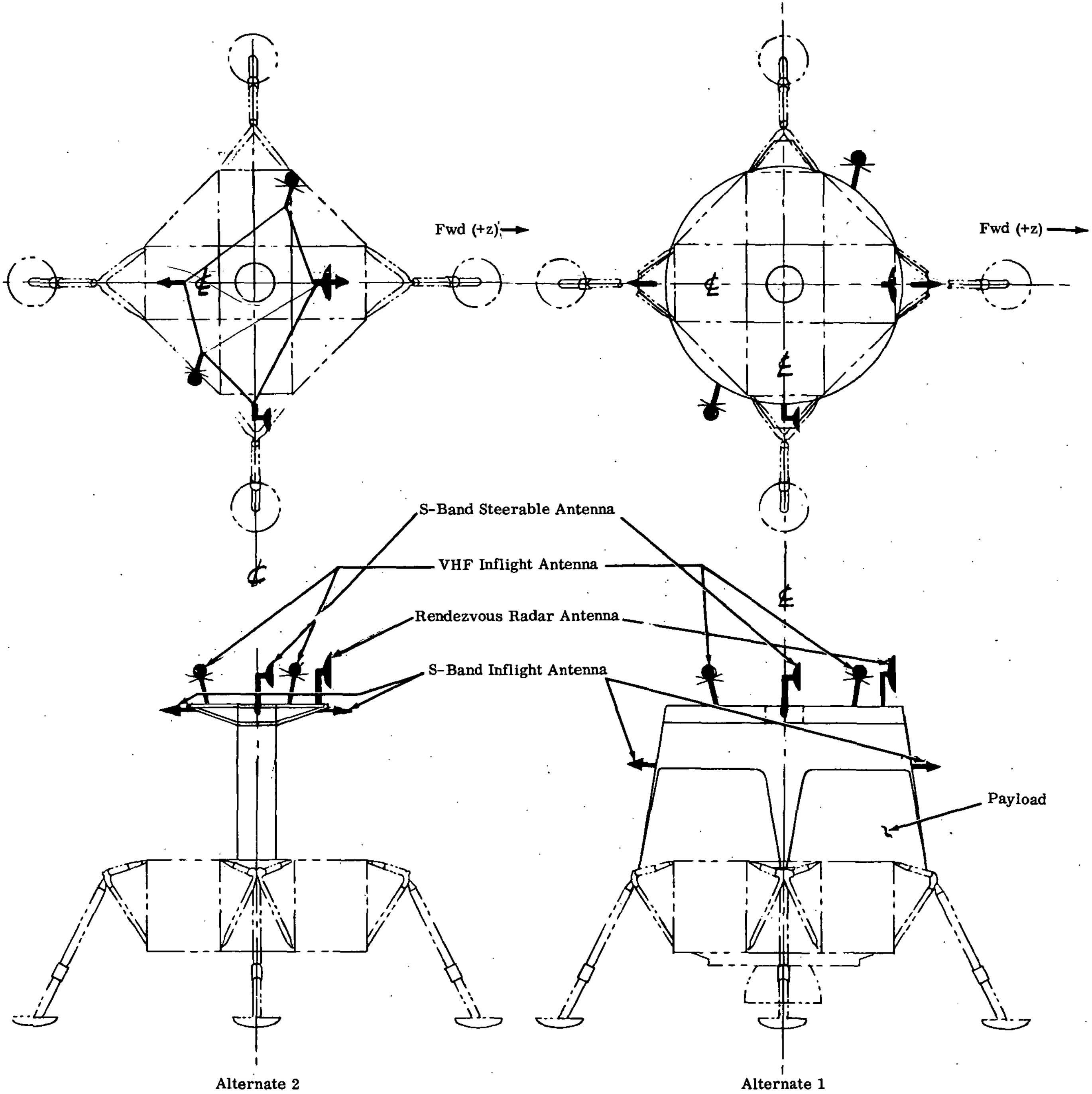
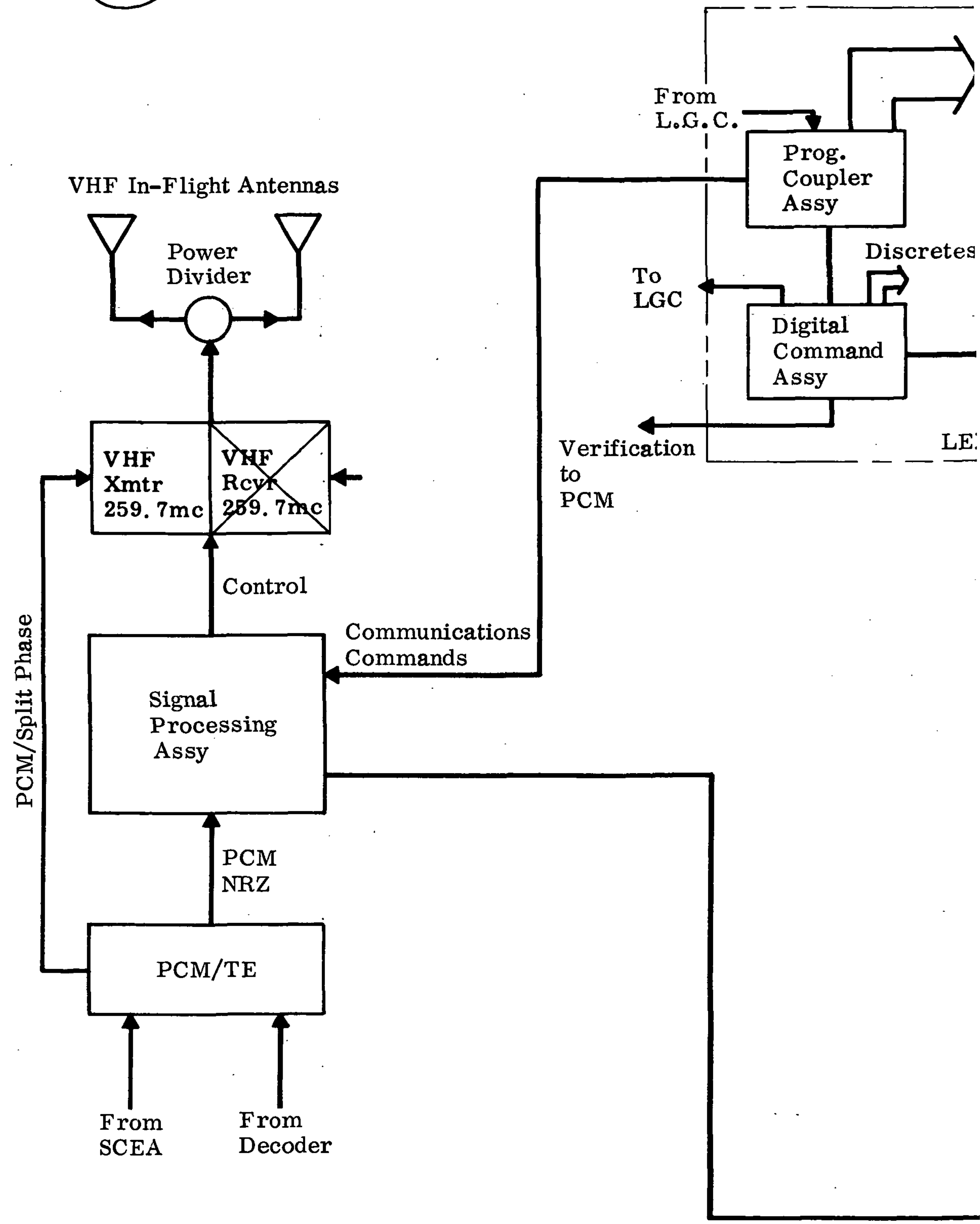
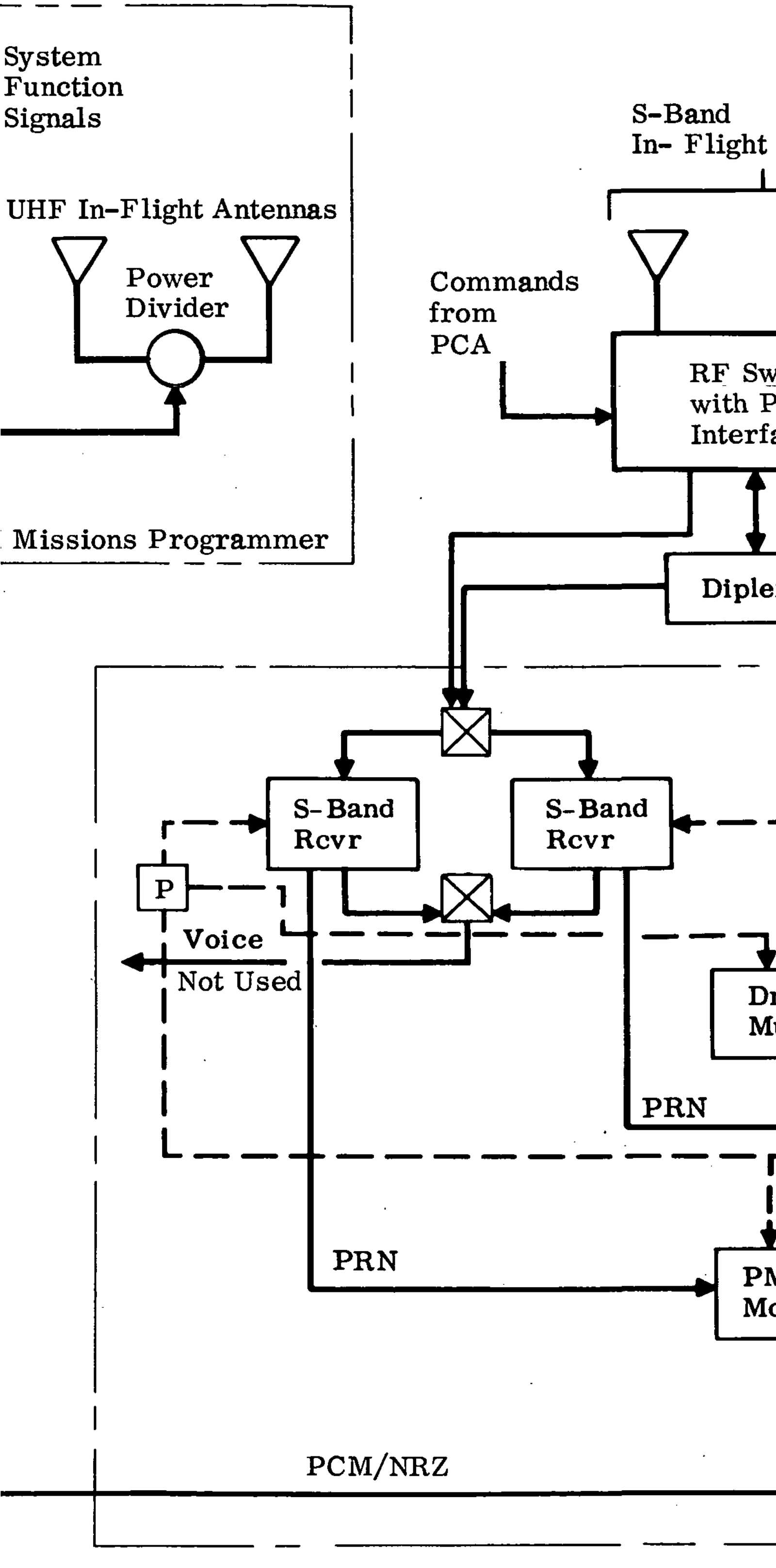
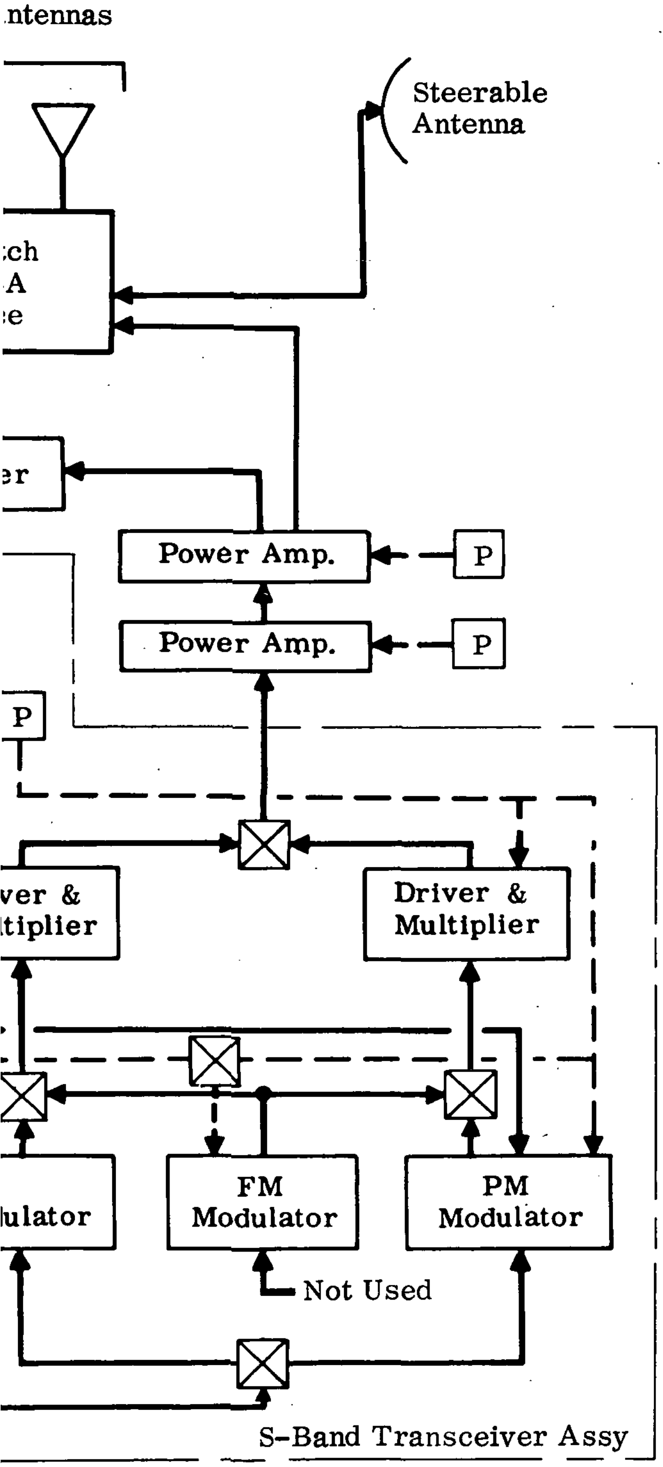


Fig. 5.5-2 Alternate Docking Structures - Antenna Locations


VHF In-Flight Antennas
Power Divider
VHF Xmtr 259. 7mc
VHF Rcvr 259. 7mc
Control
PCM/Split Phase
Communications Commands
Signal Processing Assy
PCM NRZ
PCM/TE
From SCEA
From Decoder
From L.G.C.
Prog. Coupler Assy
Discretes
To LGC
Digital Command Assy
Verification to PCM
LE


System
Function
Signals
UHF In-Flight Antennas
Power
Divider
Missions Programmer
S-Band
In- Flight
Commands
from
PCA
RF Sw
with P
Interfa
Diple
S-Band
Rcvr
S-Band
Rcvr
P
Voice
Not Used
Dr
Mu
PRN
PRN
PM
Mo
PCM/NRZ



ig. 5.5-3 Alternate Truck Communications System - Control Data Link from CSM

3

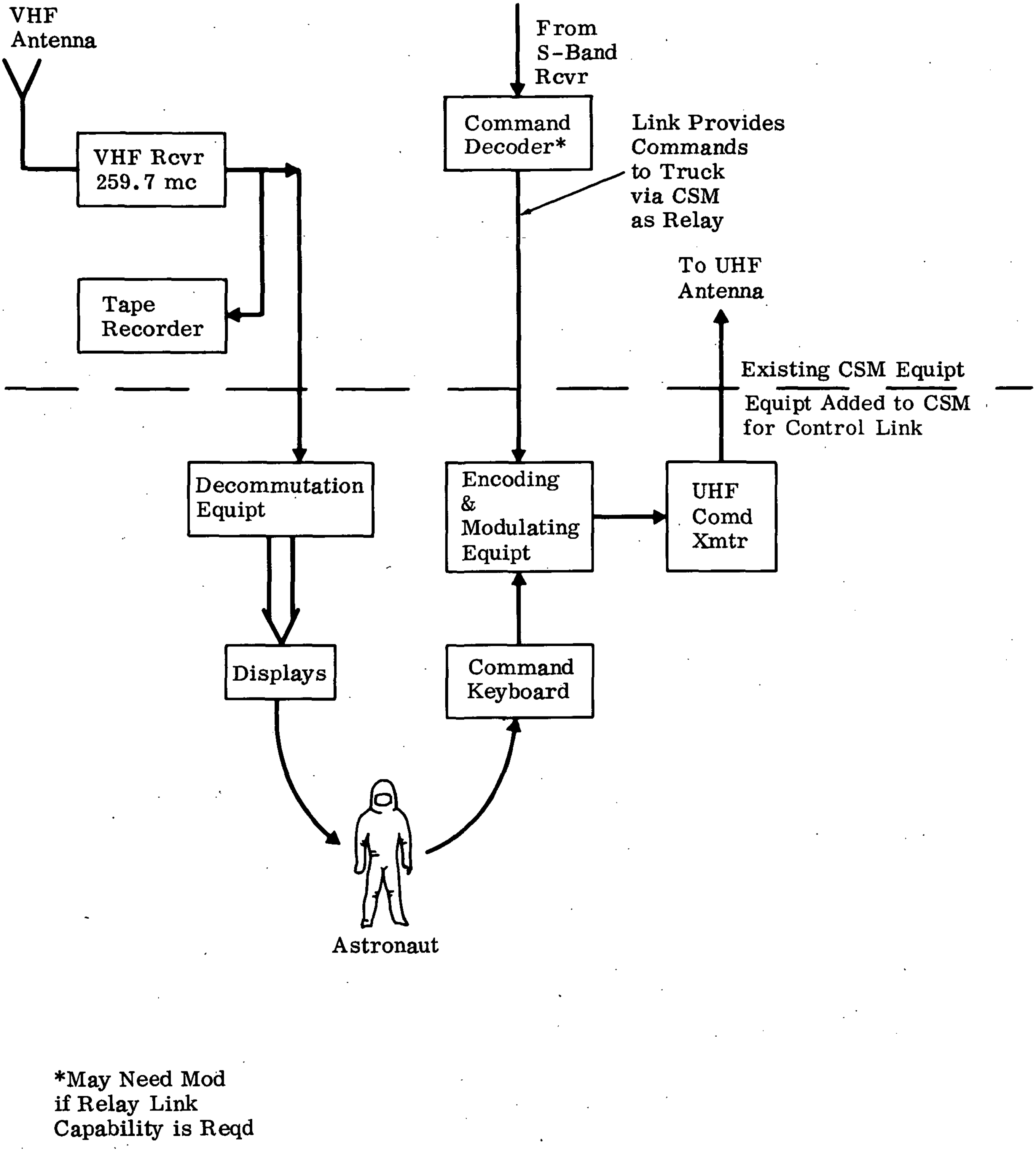


Fig. 5.5-4 Alternate Truck Control Data Link from CSM

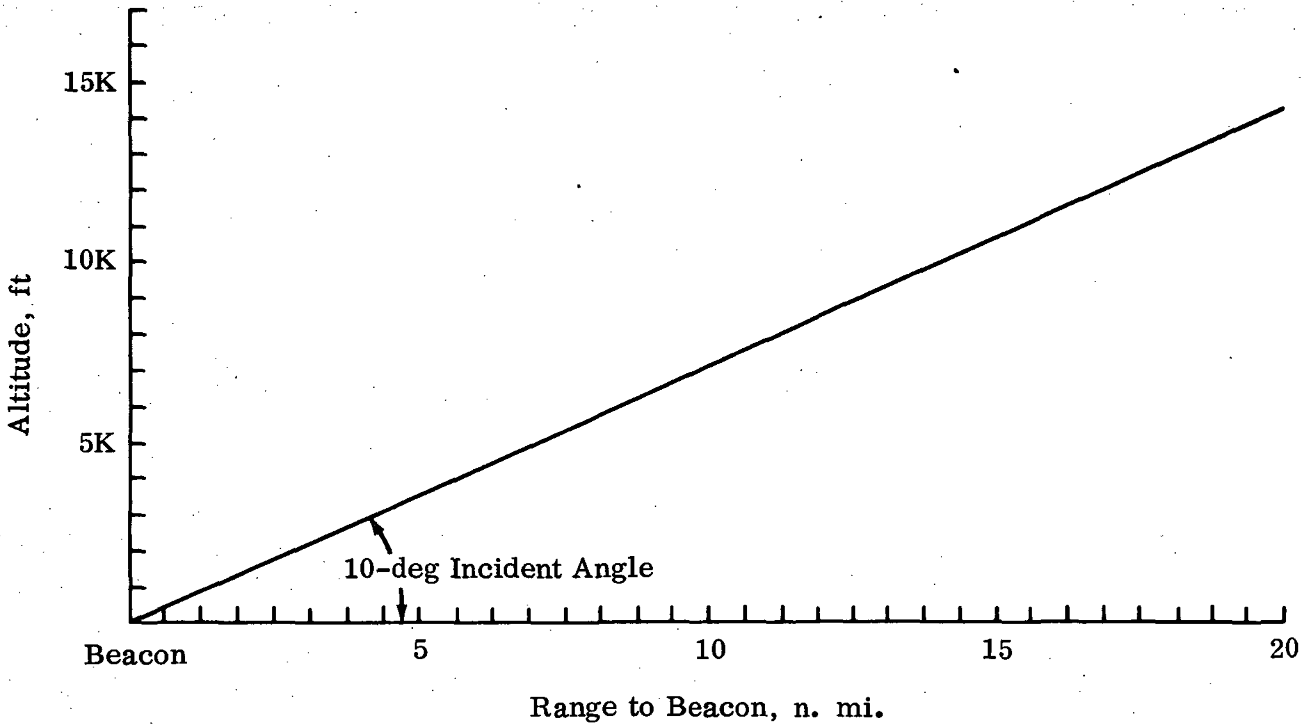


Fig. 5.5-5 Assumed Trajectory

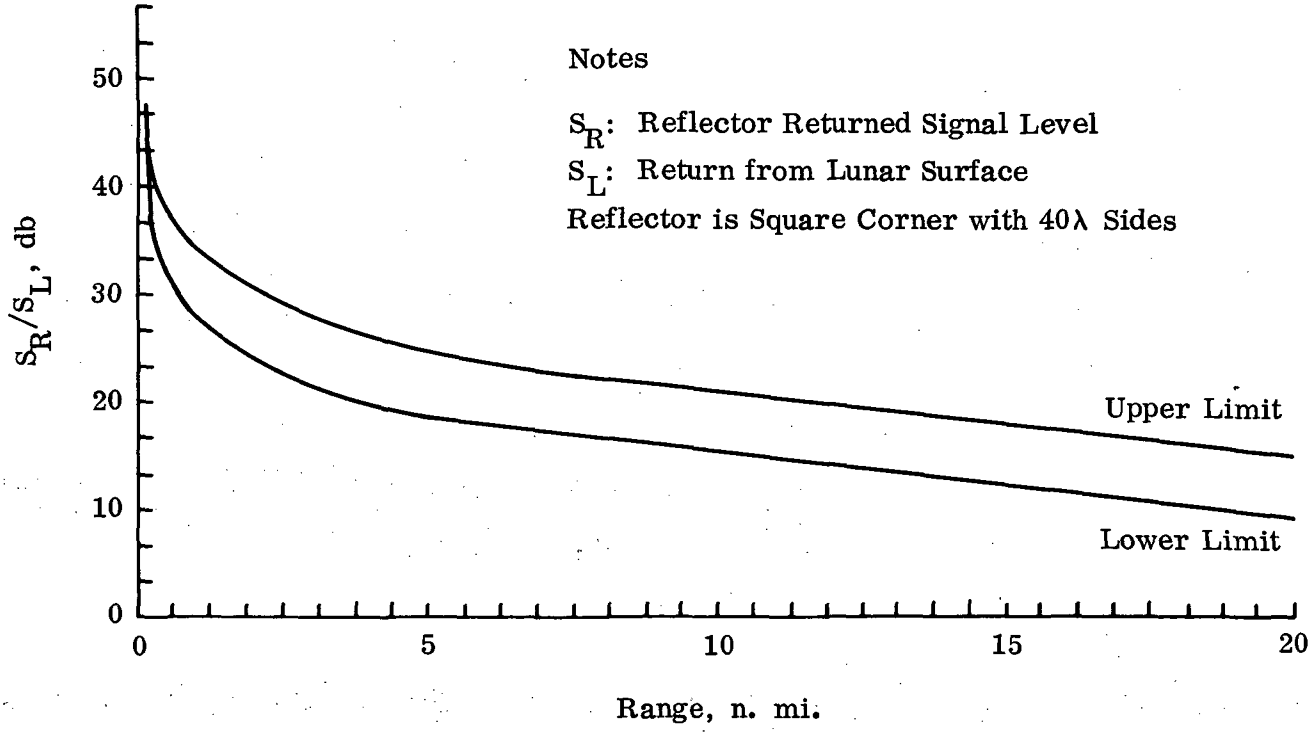


Fig. 5.5-6 Signal Enhancement

5.6 INSTRUMENTATION

5.6.1 Ground Rules

- LEM communications equipment is assumed for all flights
- All operational data will be presented to the ground during line-of-sight mission phases only
- No on-board recording capability for operational data

5.6.2 Assumptions and Background Data

The following assumptions were used in standardizing an approach for the operational data acquisition section of the Truck:

- Existing LEM PCM will be utilized for operational data.
- Changes in operational measurements will not exceed the present LEM measurements.
- No hardline data interface between the Truck and CSM(assumption for subsystem design only).

The primary function of the Operational Instrumentation Section is to acquire and present spacecraft housekeeping data to the astronauts and ground monitoring personnel. In reviewing the measurement requirements of the Reference Truck, it was concluded that the existing LEM instrumentation would fulfill this task.

5.6.3 Reference Configuration

The Reference Operational Instrumentation Section for the Truck (Fig. 5.6-1) is mainly comprised of existing LEM assemblies or components. The existing LEM assemblies have certain built-in flexibility which allows for some minor configuration changes. The Truck measurements list (Table 5.6-5) was reviewed and analyzed to assure that the changed support requirements would still be adequately covered using the existing LEM system. A power and weight summary of the Recommended configuration appears in Table 5.6-4.

5.6.3.1 Transducers

The sensors of the standard vehicle convert the physical and electrical phenomena of interest into a usable form for presentation to the astronauts or ground station personnel. These measurements from the various subsystems provide the majority of the input sources to the operational acquisition system. LEM transducers exhibit the following characteristics:

- Light weight (small volume)
- Low power consumption
- Deliver a high-level output
- High accuracy.

For any measurement unique to the Truck which requires transducers not previously used on LEM, the transducers will be selected using LEM characteristic as listed above and will meet AES qualification standards. Preference shall be given to transducers which have been developed for other space missions and have a high-level output, therefore requiring no additional signal conditioning. A summary of the parameters to be measured on the Truck appears in Table 5.6.2. Allocated transducer wright and power consumption is listed on the enclosed measurements list (Table 5.6-5).

5.6.3.2 Signal Conditioning Equipment

The electronics assembly (SCEA), as presently designed for LEM, conditions the signals from transducers and numerous signal monitoring points throughout the spacecraft and properly routes them to the Operational PCMTEA. The SCEA assembly fulfills these basic functions:

- Acts as a junction and routing assembly for all analog measurements and signals being monitored
- Supports the signal confitioning sub-assemblies which condition the measurement input signals.

The SCEA is composed of a single chassis assembly. The assembly can accommodate up to 24 separate subassembly modules. Once the measurements are determined for a given AES mission, an analysis will be performed on each measurement to assign a signal conditioning circuit to that measurement. The total number of signal conditioning subassemblies for the mission will then be packaged into the assembly (SCEA). The Truck measurements list (Table 5.6-5) reflects deletion of some existing LEM measurements and the addition of new measurements required for the AES. This listing indicates that the changing requirements for measurements can still be accommodated within the existing SCEA using adaption techniques presently employed by LEM. No modification to the assembly or its subassemblies, as now used by LEM, is anticipated, based on the measurements summarized in Table 5.6-3. The unit, however, will require re-wiring of the input-output routing and a new configuration of subassemblies is required. The following constraints are applicable to the rework required:

- Sub-assembly circuits are bench calibrated and adjusted for each measurement
- Input signals are grouped in subassemblies by types of conditioning required, not by subsystems, therefore the elimination of a vehicle subsystem does not necessarily allow the deletion of any modules.

5.6.3.3 Pulse Code Modulation and Timing Electronics Assembly

The PCMTEA in the reference configuration consists of an unmodified LEM assembly. The data acquisition capability of this unit includes the multiplexing, encoding, and timing of high-level analog, parallel digital, and serial digital data. The number of channels, sampling rates, and word lengths for each of the three data forms are presented in Table 5.6-1. The unit operates at a normal data rate of 51,200 bps, and a reduced data rate (commanded remotely) of 1600 bps. The PCMTEA will operate as it does in the present LEM, including accepting a timing reference for the LEM Guidance Computer and providing various timing signals to interfacing subsystems. The NRZ(C) data output is routed to the Communications Subsystem for real-time transmission.

5.6.3.4 Uplink Commanded System

During the entire Truck mission the electrical power to the Instrumentation Subsystem will be controlled by the communication up-link (Fig. 5.6-2).

5.3.6.5 Operational Measurements

The Truck measurement requirements shown in Table 5.6-5 were initiated by the various subsystems, reviewed by the Operations section (to assure proper and complete checkout support), compared against the mission objectives (to assure adequate coverage), and used as the basis for sizing the Operational Instrumentation Acquisition System. A summary of these measurements is found in Table 5.6-2, which reflects the various types of Instrumentation required and the quantities requested for each of the vehicles subsystems. These measurements support the spacecraft's performance and management, and furnish sufficient information to:

- Enable normal spacecraft operations to be performed
- Provide status of expendable items
- Provide status of operational events.

5.6.4 Alternate Configuration

There were no alternate configurations studied because of the ability of the existing LEM system to satisfactorily perform all the desired tasks.

Table 5.6-1
PCMTEA INPUT DATA CAPABILITY

Data Format: 51,200 bits/sec Output Rate				
Data Form	No. Channels	samples/sec	bits/word	words/sec
Analog - High Level	5	200	8	1000
Analog - High Level	17	100	8	1700
Analog - High Level	6	50	8	300
Analog - High Level	35	10	8	350
Analog - High Level	137	1	8	137
Digital Parallel	1	200	16	400
Digital Parallel	3	100	8	300
Digital Parallel	4	50	8	200
Digital Parallel	1	10	8	10
Digital Parallel	37	1	8	37
Digital Serial	1	50	40	250
Digital Serial	1	50	24	150
TOTAL	248			4834
Partial Format: 1,600 bits/sec Output Rate				
Analog - High Level	59	1	8	59
Digital Parallel	15	1	8	15
Note: The low bit rate format of the LEM PCMTEA is presently undergoing design changes. The input capability presented here is incomplete and will be expanded when the design is finalized.				

* Normalized to 8 bit words

Parameter Subsystem	Acceleration	Phase	Current	Vibration	Power	Frequency	Force	Position	Biomedical
Structures									
Thermodynamics									
Electrical Power			1			1			
Environ Control									
Nav & Guid		1	2					1	
Radars					4	4		1	
S & C - CES									
S & C - AGS									
Instrumentation									
Propulsion - Ascent									
Propulsion - Descent								2	
Reaction Control									
Communications		1	2		4			2	2
Pyrotechnics									
Totals		2	5		8	5		6	2

Note: All battery configuration used for this sizing

Table 5.6-2

TRUCK OPERATIONAL MEASUREMENT SUMMARY

Radiation	Velocity	Mass	Res./Cont.	Pressure	Quantity	Rate	Strain	Temperature	Combination	Voltage	Time	Discrete	Acoustic	Ph-Acidity	Undefined	Stimuli	Total S/S Measurements	TM Total	C & W & DISP	Prelaunch C/O
								3	1			8					12	4		1
								1		4		3					10	9		9
				2	1			2		7		5					17	8		14
	3							5		65		14					91	41		76
	3									26		7			11		56	3		40
										42		18			4		64	38		57
										1	2				8		11	10		11
				7				5	4			14					32	19		22
				6	2			7	1	8		5					29	19		27
				1						9		3			11		35	5		24
	6			16	3			23	6	162	2	77			34		357	152		281

Table 5.6-3

TRUCK SCEA SUMMARY

	SCEA Subassembly Type LSP-360-													
	502-2	502-3	503-1	503-3	504-1	504-2	504-3	504-4	504-5	505-1	506-2	507-1	509-1	TOTAL
Total Measurement Circuits	14	N/A	1	N/A	2	11	N/A	N/A	37	1	14	8	2	90
Circuits/ Subassy	4	N/A	3	N/A	4	10	N/A	N/A	12	3	4	4	4	N/A
Quantity of Subassys Reqd	4	N/A	1	N/A	1	2	N/A	N/A	4	1	4	2	1	20
No. Spare Circuits	2	N/A	2	N/A	2	9	N/A	N/A	11	2	2	-	2	32
ERA No. 1	4	N/A	1	N/A	1	2	N/A	N/A	4	1	4	2	1	20
ERA No. 2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 5.6-4

INSTRUMENTATION SUBSYSTEM WEIGHT & POWER SUMMARY

	Transducers	SCEA	PCMTEA	TOTAL
Power, watts	4.4	18.5	12.9	35.8
Weight, lb	7.6	38.3	37.0	82.9

```
                                   PAGE NUMBER    1
                                   NOVEMBER 8,1965

X X X X X X X X X X X
X      LEM-AES      X
X     REFERENCE     X
X       TRUCK       X
X PHASE B    FORM A X
X X X X X X X X X X X
```

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

```
                                              LEM-AES VEHICLE LIST
                                                      TRUCK
             CONTRACT NUMBER NAS9-4983                                                         PAGE NUMBER   2
             REFERENCE TRUCK                                                                   NOVEMBER 8,1965
                                                                                             C T                        C
                                          INTEREST       FREQ A S S S B G O M MH C F A X   XDCR   FREQ A OSY            REFERENCES  H
    ID            MEASUREMENT              RANGES         OR  C C / I I R P C S/ / / / X  RANGES   OR  C NIP XDCR XDCR     OR      N
   CODE        NAME AND LOCATION      LOW NORM HIGH UNIT RATE C R S G T D S C SL W L D X LOW HIGH RATE C DGE -PWR  WT.     NOTES    G

   EL0021-B

   E-MODULE CODE
             A-ADAPTER          H-LEM SHELTER         P-LUNAR ORBIT LAB.
             B-BOOSTER          J-STIMULI             S-SERVICE EQUIPMENT
             C-COMMAND MODULE   L-LAUNCH ESCAPE SYS.T-LEM TAXI
             E-EARTH ORBIT LAB  ,M-LEM TRUCK          Y-GROUND TEST ARTICLE
             G-LEM              N-GSE EQUIPMENT

    L-FUNCTIONAL SUBSYSTEM CODE
             A-STRUCTURES       I-STAB/CONTROL-AGS   R-REACTION CONTROL
             B-THERMODYNAMICS   L-INSTRUMENTATION    T-COMMUNICATIONS
             C-ELECTRICAL POWER M-MECHANICAL DESIGN Y-PYROTECHNICS
             F-ENVIRON CONTROL  N-RADARS             X-EXPERIMENTS
             G-NAV.AND GUIDANCE P-PROPULSION A/S
             H-STAB/CONTROL-CES Q-PROPULSION D/S

     0021-IDENTIFICATION NUMBER (BY SUBSYSTEM)

            B-MEASUREMENT CLASSIFICATION CODE
             A-ACCELERATION     J-BIOMEDICAL         S-STRAIN
             B-PHASE            K-RADIATION          T-TEMPERATURE
             C-CURRENT          L-VELOCITY           U-COMBINATION MEAS.
             D-VIBRATION        M-MASS               V-VOLTAGE
```

```
                                                LEM-AES VEHICLE LIST
                                                       TRUCK
          CONTRACT NUMBER NAS9-4983                                                        PAGE NUMBER   3
          REFERENCE TRUCK                                                                  NOVEMBER 8,1965
                                                                                      C T                            C
                                            INTEREST       FREQ A S S S B G O M MH C F A X    XDCR    FREQ A OSY                   REFERENCES  H
   ID               MEASUREMENT              RANGES         OR  C C / I I R P C S/ / / / X   RANGES    OR  C NIP XDCR XDCR         OR       N
  CODE           NAME AND LOCATION     LOW NORM HIGH UNIT RATE C R S G T D S C SL W L D X LOW HIGH  RATE C DGE -PWR  WT.          NOTES     G

          E-POWER            N-RESIST/CONTINUITY W-TIME

          F-FREQUENCY        P-PRESSURE          X-DISCRETE EVENT

          G-FORCE/MECH.IMPED. Q-QUANTITY         Y-ACOUSTICAL

          H-POSITION         R-RATE              Z-PH-ACIDITY


     MEASUREMENT

   NAME AND LOCATION

          DESCRIBES THE MEASUREMENT TO BE OBTAINED AND ITS LOCATION,STATED

            BRIEFLY.


      INTEREST

       RANGES

   LOW NORM HIGH UNIT

          MINIMUM,NORMAL AND MAXIMUM MEASURAND RANGE EXPECTED AND ITS

            ASSOCIATED UNITS.


   FREQ

    OR

   RATE

          REALISTIC RECOVERABLE RESPONSE RATE REQUIRED (IN CPS)


   ACC

          REALISTIC RECOVERABLE END-TO-END SYSTEM ACCURACY IN PERCENT FULL

            SCALE.
```

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

```
                                                  LEM-AES VEHICLE LIST
                                                         TRUCK
              CONTRACT NUMBER NAS9-4983                                                                      PAGE NUMBER    4
              REFERENCE TRUCK                                                                                NOVEMBER 8,1965
                                                                                                      C T                              C
                                          INTEREST       FREQ A S S S B G O M MH C F A X    XDCR     FREQ A OSY                REFERENCES  H
    ID               MEASUREMENT           RANGES          OR C C / I I R P C S/ / / / X   RANGES      OR C NIP XDCR XDCR          OR      N
   CODE           NAME AND LOCATION    LOW NORM HIGH UNIT RATE C R S G T D S C SL W L D X LOW HIGH RATE C DGE -PWR  WT.          NOTES     G

 SCR

              TRANSDUCER PROCUREMENT SOURCE CODE.

                   S-SUBCONTRACTOR

                   I-INSTRUMENTATION

                   G-GROUND SUPPORT EQUIPMENT

                   N-NASA(GFE)GOVERNMENT FURNISHED EQUIPMENT.


 S/S

              NUMBER OF SAMPLES PER SECOND.


 SIG

              FORM AND LEVEL OF SIGNAL TO THE PCM EQUIPMENT.

                   L-LOW LEVEL ANALOG (0-40MV)    P-PARALLEL DIGITAL (0 OR 5V)

                   H-HIGH LEVEL ANALOG (0-5V)     E-DISCRETE EVENT (0 OR 5V)

                   S-SERIAL DIGITAL (0 OR 5V)


 BIT

              NUMBER OF BITS PER SAMPLE.


 GRD

              INDICATES THOSE MEASUREMENTS REQUIRED FOR FACTORY TEST OR CHECKOUT.

                A-FACTORY C/O,NON-ACE MONITERED.

                B-FACTORY C/O,ACE MONITERED.
```

```
                                                    LEM-AES VEHICLE LIST
                                                           TRUCK
              CONTRACT NUMBER NAS9-4983                                                           PAGE NUMBER   5
              REFERENCE TRUCK                                                                     NOVEMBER 8,1965
                                                                                        C T                          C
                                                 INTEREST     FREQ A S S S B G O M MH C F A X   XDCR   FREQ A OSY                  REFERENCES   H
        ID            MEASUREMENT                 RANGES       OR  C C / I I R P C S/ / / / X  RANGES   OR  C NIP XDCR XDCR           OR        N
       CODE       NAME AND LOCATION       LOW NORM HIGH UNIT RATE C R S G T D S C SL W L D X LOW HIGH RATE C DGE -PWR  WT.            NOTES      G

  OPS

              INDICATES THOSE MEASUREMENTS REQUIRED FOR PRELAUNCH CHECKOUT

               1-PRELAUNCH C/O,NON-ACE MONITERED.

               2-PRELAUNCH C/O,ACE MONITERED.


  MCC

              INDICATES THAT THE TELEMETERED MEASUREMENT IS REQUIRED BY THE

               MANNED SPACE FLIGHT NETWORK FOR REAL TIME DISPLAY(R).


  MSS

              INDICATES THOSE MEASUREMENTS REQUIRED DURING STORAGE PERIOD.(S)


  H/L

              ASSIGNMENT OF MEASUREMENT

               H-HIGH BIT RATE (51.2K BITS/SEC) TELEMETERED SIGNAL.

               L-LOW BIT RATE (1.6K BITS/SEC) TELEMETERED SIGNAL.

               X-INDICATES ON-BOARD RECORDING.

               *-NOT TELEMETERED DIRECTLY.USED TO FORMULATE THE MEASUREMENT

                 LISTED IN THE ADJACENT NOTES COLUMN.


  C/W

              INDICATES AN INPUT TO A CAUTION(C)OR WARNING(W)LAMP.
```

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

```
                                              LEM-AES VEHICLE LIST
                                                     TRUCK
                                                                                           PAGE NUMBER   6
             CONTRACT NUMBER NAS9-4983                                                     NOVEMBER 8,1965
             REFERENCE TRUCK                                                            C T                        C
                                           INTEREST       FREQ A S S S B G O M MH C F A X   XDCR   FREQ A OSY               REFERENCES H
    ID             MEASUREMENT              RANGES         OR  C C / I I R P C S/ / / / X  RANGES   OR  C NIP XDCR XDCR        OR      N
   CODE         NAME AND LOCATION     LOW NORM HIGH UNIT RATE C R S G T D S C SL W L D X LOW HIGH RATE C DGE -PWR  WT.        NOTES    G

 F/L

             INDICATES AN ADVISORY FLAG(F)OR LIGHT(L).

 A/D

             INDICATES AN INPUT TO AN ANALOG(A)OR DIGITAL(D)DISPLAY.

 XXX

             TIME SHARED SWITCHING CODE 1-9

  XDCR
  RANGES
 LOW HIGH
             SELECTED OR ALLOCATED TRANSDUCER RANGE.

 FREQ
  OR
 RATE
             ALLOCATED EQUIPMENT RESPONSE CAPABILITY.

 ACC
             END-TO-END SYSTEM ACCURACY EXPRESSED IN PERCENT FULL SCALE OF
              ALLOCATED RANGE.
```

```
                                                      LEM-AES VEHICLE LIST
                                                             TRUCK
          CONTRACT NUMBER NAS9-4983                                                                 PAGE NUMBER    7
          REFERENCE TRUCK                                                                           NOVEMBER 8,1965
                                                                                              C T                                       C
                                       INTEREST        FREQ A S S S B G O M MH C F A X   XDCR   FREQ A OSY                 REFERENCES   H
  ID           MEASUREMENT              RANGES          OR  C C / I I R P C S/ / / / X  RANGES   OR  C NIP XDCR XDCR           OR       N
 CODE       NAME AND LOCATION    LOW NORM HIGH UNIT   RATE C R S G T D S C SL W L D X LOW HIGH RATE C DGE -PWR  WT.          NOTES      G

 C T

 OSY

 NIP

 DGE

          SIGNAL CONDITIONING TYPE OF UNITS REQUIRED.

           1-1 REFERS TO SIGNAL CONDITIONER LSP-360-501-1

           1-2 REFERS TO SIGNAL CONDITIONER LSP-360-501-2

 XDCR

 -PWR

          POWER REQUIREMENT FOR TRANSDUCER (IN WATTS)

 XDCR

  WT.

          WEIGHT OF TRANSDUCER ONLY.

            -WEIGHT IN POUNDS(UNMARKED)

           Z-WEIGHT IN OUNCES


 REFERENCES

    OR

   NOTES

          AVAILABLE SPACE FOR REFERENCES OR NOTES.


 CHNG

          REFLECTS LATEST MODIFICATION CODE.
```

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

LEM-AES VEHICLE LIST
TRUCK

CONTRACT NUMBER NAS9-4983
REFERENCE TRUCK

PAGE NUMBER 8
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	FREQ OR RATE	STRUCTURES A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	Δ / D	X X X	XDCR RANGES LOW	HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MA0041-X	LAND GEAR -Y,LS DEPLOY LK	CONTACT CLOSURE				SS		I							*					CC		SS		-	--	--	MA5000	
MA0042-X	LAND GEAR -Y,RS DEPLOY LK	CONTACT CLOSURE				SS		I							*					CC		SS		-	--	--	MA5000	
MA0043-X	LAND GEAR -Z,LS DEPLOY LK	CONTACT CLOSURE				SS		I							*					CC		SS		-	--	--	MA5000	
MA0044-X	LAND GEAR -Z,RS DEPLOY LK	CONTACT CLOSURE				SS		I							*					CC		SS		-	--	--	MA5000	
MA0045-X	LAND GEAR +Z,LS DEPLOY LK	CONTACT CLOSURE				SS		I							*					CC		SS		-	--	--	MA5000	
MA0046-X	LAND GEAR +Z,RS DEPLOY LK	CONTACT CLOSURE				SS		I							*					CC		SS		-	--	--	MA5000	
MA0047-X	LAND GEAR +Y,LS DEPLOY LK	CONTACT CLOSURE				SS		I							*					CC		SS		-	--	--	MA5000	
MA0048-X	LAND GEAR +Y,RS DEPLOY LK	CONTACT CLOSURE				SS		I							*					CC		SS		-	--	--	MA5000	
MA0064-T	TEMP 1,+Z LEG PRI STRUT	32		500	DEGF	SS	1	I	1	H	8				H					0	500	SS		6-2	0	.13		
MA2001-T	TEMP 1,HEAT SHIELD D/S	0		2000	DEGF	SS	1	I	1	H	8				H					0	2500	SS		9-1	0	.18		
MA2002-T	TEMP 2,HEAT SHIELD D/S	0		2000	DEGF	SS	1	I	1	H	8				H					0	2500	SS		9-1	0	.18		
MA5000-U	LAND LEGS DEPLOYED	CONTACT CLOSURE				SS		I	1	H	1	B	2		H					CC		SS		4-5	0	1.00		

LEM-AES VEHICLE LIST
TRUCK

CONTRACT NUMBER NAS9-4983
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ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	ELECTRICAL POWER FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	D P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MC0071-V	VOLTAGE,INVERTER BUS	105	115	125	VRMS	SS	5	S	1	H	8	B	2	R	L					0	130	SS		3-1	--	--		
MC0155-F	FREQ,INVERTER BUS	390	400	410	CPS	SS	.5	S	1	H	8	B	2	R	L					380	420	SS		5-1	--	--		
MC0201-V	VOLTAGE,BATTERY NO.1	20	28	40	VDC	SS	5	S	1	H	8	B	2		L					0	40	SS		2-2	--	--		
MC0301-V	VOLT BUS	20		40	VDC	SS	4	S	1	H	8	B	2	R	L					0	40	SS		2-2	--	--		
MC1201-C	CURRENT,BATTERY NO.1	0		60	AMPS	SS	5	S	1	H	8	B	2		L							SS		-	--	--		
MC3501-T	TEMPERATURE,BATTERY NO.1	0		200	DEGF	SS	5	S	1	H	8	B	2		L					20	200	SS		6-2	0	0		
MC4361-X	HIGH VOLT TAP BATT.NO1	CONTACT CLOSURE				SS		S	1	E	1	B	2	R	H					CC		SS		4-5	0	0		
MC4362-X	LOW VOLT TAP BATT NO1	CONTACT CLOSURE				SS		S	1	E	1	B	2	R	H					CC		SS		4-5	0	0		
MC6311-X	REVERSE/OVER CUR BAT 1	CONTACT CLOSURE						S	1	E	1	B	2	R	H					CC		SS		4-5	0	0		

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

LEM-AES VEHICLE LIST
TRUCK

CONTRACT NUMBER NAS9-4983
REFERENCE TRUCK

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ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	INTEREST RANGES NORM	INTEREST RANGES HIGH	UNIT	ENVIRONMENTAL CONTROL FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	XDCR RANGES HIGH	FREQ OR RATE	A C C	C T OSY NIP OGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MF2021-P	DEL P,PRIM COOLANT PUMP	0	45	50	PSID	SS	5	S	1	H	8	B	2	R	L					0	50	SS		-	.28	.31		
MF2041-X	COOLANT ACC.FLUID LO LVL	CONTACT CLOSURE				SS		S	1	E	1	B	2	R	L					CC		SS		4-5	0	0		
MF2071-X	COOLANT PUMP NO.1 SELECT	CONTACT CLOSURE				SS		S	1	E	1	B	2		L					CC		SS		4-5	0	0		
MF2072-X	COOLANT PUMP NO.2 SELECT	CONTACT CLOSURE				SS		S	1	E	1	B	2		L					CC		SS		4-5	0	0		
MF2581-T	TEMP,MAIN W/B COOL.OUT	30	40	160	DEGF	SS		I												0	160	SS		-	0	.12		
MF2741-P	PRESS,PRIM PUMP DISCHRG	0	50	60	PSIA			I												0	60	SS		-	.28	.28		
MF2931-X	COOLANT PUMP NO.1 FAIL	CONTACT CLOSURE				SS		S	1	E	1	B	2	R	L					CC		SS		4-5	0	0		
MF2932-X	COOLANT PUMP NO.2 FAIL	CONTACT CLOSURE				SS		S	1	E	1	B	2	R	L					CC		SS		4-5	0	0		
MF4511-T	TEMP,MAIN W/B IN WATER	30	70	160	DEGF	SS	5	I	1	H	8				L					0	160	SS		6-2	0	.16		
MF4581-Q	QUANTITY,WATER TANK	0		100	PCT	SS	4	I	1	H	8	B	2	R	L					0	100	SS		-	.50	.75		
MF8019-V	VOLT COOL PUMP SW DK9PO A	0		28	VDC	SS						B	2							0	28	SS		-	--	--		
MF8020-V	VOLT COOL PU SW DK 10PO A	0		28	VDC	SS						B	2							0	28	SS		-	--	--		
MF8024-V	VOLT PUMP DP SW DK 1 LO	0		28	VDC	SS						B	2							0	28	SS		-	--	--		
MF8025-V	VOLT PUMP DP SW DK 2 HI	0		28	VDC	SS						B	2							0	28	SS		-	--	--		
MF8026-V	VOLT PUMP DP SW DK 2 LO	0		28	VDC	SS						B	2							0	28	SS		-	--	--		
MF8027-V	VOLT PUMP DP SW DK 3 HI	0		28	VDC	SS						B	2							0	28	SS		-	--	--		
MF8028-V	VOLT PUMP DP SW DK 3 LO	0		28	VDC	SS						B	2							0	28	SS		-	--	--		

LEM-AES VEHICLE LIST
TRUCK

CONTRACT NUMBER NAS9-4983
REFERENCE TRUCK

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		INTEREST RANGES				NAVIGATION AND GUIDANCE														XDCR RANGES								
ID CODE	MEASUREMENT NAME AND LOCATION	LOW	NORM	HIGH	UNIT	FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	LOW	HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MG0001-X	COMPUTER DIGITAL DATA							N	50S		40B		2	R	H									-	--	--		
MG0117-H	POS,ALTITUDE (LGC)				FT	SS																SS		-	--	--		
MG0118-L	VEL,ALTITUDE RATE (LGC)				F/S	SS																SS		-	--	--		
MG0119-L	VEL,FORWARD (LGC)				F/S	SS																SS		-	--	--		
MG0120-L	VEL,LATERAL (LGC)				F/S	SS																SS		-	--	--		
MG1000-V	VOLT 120 VDC PULSE TOR.REF	0		120	VDC	SS		N	1	H	8	B	2		H					0	120	SS		-	--	--		
MG1020-V	VOLT LGC +14 VDC SUP LEV				VDC	SS			1	H	8	B	2		L							SS		-	--	--		
MG1021-V	VOLT LGC +14VDC SUP NOISE				VRMS	SS			1		8	B	2									SS		-	--	--		
MG1022-X	LGC +14VDC SUP NOISE PEAK				GLT	10			10		1	B	2									10		-	--	--		
MG1030-V	VOLT LGC +4VDC SUP LEVEL				VDC	SS			1	H	8	B	2		L							SS		-	--	--		
MG1031-V	VOLT LGC +4VDC SUP NOISE				VRMS	SS			1		8	B	2									SS		-	--	--		
MG1032-X	LGC +4VDC SUP NOISE PEAK				GLT	10			10		1	B	2									10		-	--	--		
MG1040-V	VOLT CDU +4VDC SUP LEVEL				VDC	SS			1	H	8	B	2		L							SS		-	--	--		
MG1041-V	VOLT CDU +4VDC SUP NOISE				VRMS	SS			1		8	B	2									SS		-	--	--		
MG1042-X	CDU +4VDC SUP NOISE PEAK				GLT	10			10		1	B	2									10		-	--	--		
MG1050-V	VOLT SCA +20VDC SUPPLY				VDC	SS			1	H	8	B	2		L							SS		-	--	--		
MG1100-V	VOLT -27.5 VDC SUPPLY	0		-30	VDC	SS			1	H	8	B	2		L					0	-30	SS		-	--	--		
MG1110-V	VOLT,2.5 VDC TM BIAS PCM				VDC	SS	2	N	1	H	8	B	2		L							SS		-	--	--		
MG1201-V	VOLT IMU 28V 800CPS 1P-OD	0		40	VRMS	SS		N	1	H	8	B	2		H					0	40	SS		-	--	--		
MG1202-V	VOLT IMU 28V 800CPS 5P90D	0		40	VRMS	SS			1		8	B	2							0	40	SS		-	--	--		
MG1203-V	VOLT IMU 28V 800CPS 5P OD	0		40	VRMS	SS			1		8	B	2							0	40	SS		-	--	--		
MG1306-B	PHASE 3.2KC 1-P/LGC SYNC					SS			1		8	B	2									SS		-	--	--		
MG1307-V	VOLT 3.2KC BUTTERFLY REF				VRMS	SS		N	1	H	8	B	2		H							SS		-	--	--		
MG1307-V	VOLT 3.2KC BUTTERFLY REF				VRMS	4KC						A	1									4KC		-	--	--		
MG1341-V	VOLT SELECT PIPA SCOP SIG	0		7	VRMS	4KC	10					A	1							0	7	4KC		-	--	--		

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

LEM-AES VEHICLE LIST
TRUCK

CONTRACT NUMBER NAS9-4983
REFERENCE TRUCK

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NOVEMBER 8,1965

		INTEREST RANGES				NAVIGATION AND GUIDANCE														XDCR RANGES								
ID CODE	MEASUREMENT NAME AND LOCATION	LOW	NORM	HIGH	UNIT	FREQ OR RATE	ACC	SCR	S/S	SIG	BIT	GRD	OPS	MCC	MH S/SL	C/W	F/L	A/D	XXX	LOW	HIGH	FREQ OR RATE	ACC	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
MG1342-V	VOLT SELECT HIGH RATE SIG	0		5	VDC	80C			400		8	B	2									80C		-	--	--		
MG1500-V	VOLT IMU OPER +28VDC LEV				VDC	SS			1	H	8	B	2		L							SS		-	--	--		
MG1501-V	VOLT IMU OPER 28VDC NOISE				VRMS	SS			1		8	B	2									SS		-	--	--		
MG1502-X	IMU OPER 28VDC NOISE PEAK				GLT	10			10		1	B	2									10		-	--	--		
MG1510-V	VOLT IMU STBY 28VDC LEVEL				VDC	SS			1		8	B	2									SS		-	--	--		
MG1511-V	VOLT IMU STBY 28VDC NOISE				VRMS	SS			1		8	B	2									SS		-	--	--		
MG1512-X	IMU STBY 28VDC NOISE				GLT	10			10		1	B	2									10		-	--	--		
MG1513-X	IMU STANDBY/OFF					SS		N	1	E	1			R	H							SS		-	--	--		
MG1520-V	VOLT LGC OPER 28VDC LEVEL				VDC	SS			1	H	8	B	2		L							SS		-	--	--		
MG1521-V	VOLT LGC OPER 28VDC NOISE				VRMS	SS			1	H	8	B	2		L							SS		-	--	--		
MG1522-X	LGC OPER 28VDC NOISE PEAK				GLT	10			10		1	B	2									10		-	--	--		
MG1523-X	LGC OPERATE					SS		N	1	E	1				H							SS		-	--	--		
MG2000-V	VOLT X PIPA MODE CHECK	0		7	VRMS	4KC	10					A	1							0	7	4KC		-	--	--		
MG2001-V	VOLT X PIPA SG OPUT INPH	0		7	VRMS	10C		N	50	H	8	B	2		H					0	7	10		-	--	--		
MG2002-V	VOLT X PIPA SG OPUT QUAD				VRMS	SS		N	1	H	8	B	2		H							SS		-	--	--		
MG2003-V	VOLT X PIPA +28VDC PVR				VDC	SS		N	1	H	8	B	2		L							SS		-	--	--		
MG2020-V	VOLT Y PIPA MODE CHECK	0		7	VRMS	4KC	10					A	1							0	7	4KC		-	--	--		
MG2021-V	VOLT Y PIPA SG OPUT INPH	0		7	VRMS	10C		N	50	H	8	B	2		H					0	7	10		-	--	--		
MG2022-V	VOLT Y PIPA SG OPUT QUAD				VRMS	SS		N	1	H	8	B	2		H							SS		-	--	--		
MG2023-V	VOLT Y PIPA +28VDC PVA				VDC	SS		N	1	H	8	B	2		L							SS		-	--	--		
MG2040-V	VOLT Z PIPA MODE CHECK	0		7	VRMS	4KC	10					A	1							0	7	4KC		-	--	--		
MG2041-V	VOLT Z PIPA SG OPUT INPH	0		7	VRMS	10C		N	50	H	8	B	2		H					0	7	10		-	--	--		
MG2042-V	VOLT Z PIPA SG OPUT QUAD				VRMS	SS		N	1	H	8	B	2		H							SS		-	--	--		
MG2043-V	VOLT Z PIPA +28VDC PVR				VDC	SS		N	1	H	8	B	2		L							SS		-	--	--		
MG2107-V	VOLT IGA SERVO ERROR INPH	0		20	VRMS	20C	5	N	100	H	8	B	2		H					0	20	20C		-	--	--		

LEM-AES VEHICLE LIST
TRUCK

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ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	INTEREST RANGES NORM	INTEREST RANGES HIGH	UNIT	NAVIGATION AND GUIDANCE FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	U P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	XDCR RANGES HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MG2108-V	VOLT IG SERVO ERROR TOTAL	0		20	VRMS	2C	5		10		8	B	2							0	20	2C		-	--	--		
MG2112-V	VOLT,IG 1X RES OUT,SIN	0		28	VRMS	2C		N	10H		8	B	2	R	H					0	28	2C		-	--	--		
MG2113-V	VOLT,IG 1X RES OUT,COS	0		28	VRMS	2C		N	10H		8	B	2	R	H					0	28	2C		-	--	--		
MG2122-V	VOLT,IG 1X RES OUT,SIN	0		28	VRMS															0	28			-	--	--		
MG2123-V	VOLT,IG 1X RES OUT,COS	0		28	VRMS															0	28			-	--	--		
MG2137-V	VOLT MG SERVO ERROR INPH	0		20	VRMS	20C	5	N	100H		8				H					0	20	20C		-	--	--		
MG2138-V	VOLT MG SERVO ERROR TOTAL	0		20	VRMS	2C			10		8	B	2							0	20	2C		-	--	--		
MG2140-C	CURR MG TORQUE MOTOR INPUT				AMP	SS	10		1		8	B	2									SS		-	--	--		
MG2142-V	VOLT,MG 1X RES OUT,SIN	0		28	VRMS	2C		N	10H		8	B	2	R	H					0	28	2C		-	--	--		
MG2143-V	VOLT,MG 1X RES OUT,COS	0		28	VRMS	2C		N	10H		8	B	2	R	H					0	28	2C		-	--	--		
MG2152-V	VOLT,MG 1X RES OUT,SIN	0		28	VRMS															0	28			-	--	--		
MG2153-V	VOLT,MG 1X RES OUT,COS	0		28	VRMS															0	28			-	--	--		
MG2167-V	VOLT OG SERVO ERROR INPH	0		20	VRMS	20C	5	N	100H		8	B	2		H					0	20	20C		-	--	--		
MG2168-V	VOLT OG SERVO ERROR TOTAL	0		20	VRMS	2C			10		8	B	2							0	20	2C		-	--	--		
MG2170-C	CURR OG TOR MOTOR INPUT				AMP	SS	10		1		8	B	2									SS		-	--	--		
MG2172-V	VOLT,OG 1X RES OUT,SIN	0		28	VRMS	2C		N	10H		8	B	2	R	H					0	28	2C		-	--	--		
MG2173-V	VOLT,OG 1X RES OUT,COS	0		28	VRMS	2C		N	10H		8	B	2	R	H					0	28	2C		-	--	--		
MG2182-V	VOLT,OG 1X RES OUT,SIN	0		28	VRMS															0	28			-	--	--		
MG2183-V	VOLT,OG 1X RES OUT,COS	0		28	VRMS															0	28			-	--	--		
MG2205-V	VOLT IG CDU FINE ERROR				VRMS	SS			1		8	B	2									SS		-	--	--		
MG2207-V	VOLT IG CDU COARSE ERROR				VRMS	SS			1		8		2									SS		-	--	--		
MG2214-V	VOLT PITCH CDU DAC OUT				VRMS	2C		N	10H		8	B	2		H							2C		-	--	--		
MG2217-V	VOLT,PITCH ATT ERROR-PGNS	0		10	VRMS															0	10			-	--	--		
MG2235-V	VOLT,MG CDU FINE ERROR				VRMS	SS			1		8	B	2									SS		-	--	--		
MG2237-V	VOLT,MG CDU COARSE ERROR				VRMS	SS			1		8	B	2									SS		-	--	--		

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

LEM-AES VEHICLE LIST
TRUCK

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NAVIGATION AND GUIDANCE

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	HIGH	FREQ OR RATE	A C C	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
MG2244-V	VOLT,ROLL CDU DAC OUT				VRMS	2C		N	10	H	8	B	2		H							2C		-	--	--		
MG2247-V	VOLT,ROLL ATT ERROR-PGNS	0		10	VRMS															0	10			-	--	--		
MG2265-V	VOLT,OG CDU FINE ERROR				VRMS	SS			1		8	B	2									SS		-	--	--		
MG2267-V	VOLT,OG CDU COARSE ERROR				VRMS	SS			1		8	B	2									SS		-	--	--		
MG2274-V	VOLT,YAW CDU DAC OUT				VRMS	2C		N	10	H	8	B	2		H							2C		-	--	--		
MG2277-V	VOLT,YAW ATT ERROR-PGNS	0		10	VRMS															0	10			-	--	--		
MG2300-T	TEMP,PIPA	0		140	DEGF	SS	2	N	1	H	8	B	2		L					0	140	SS		-	--	--		
MG2301-T	TEMP,IRIG				DEGF	SS			1		8	B	2									SS		-	--	--		
MG2302-X	IMU HEATER ON					SS			1		1	B	2									SS		-	--	--		
MG2303-X	IMU BLOWER ON					SS			1		1	B	2									SS		-	--	--		
MG4300-T	TEMP,LGC				DEGF	SS		N	1		8	B	2									SS		-	--	--		
MG6020-T	TEMP,PIPA CAL MOD				DEGF	SS			1		8	B	2									SS		-	--	--		
MG6022-T	TEMP,PSA				DEGF	SS			1		8	B	2									SS		-	--	--		
MG9000-X	IMU CAGE	CONTACT CLOSURE				SS			1	E	1	B	2		H					CC		SS		4-5	0	0		
MG9001-X	LGC (WARNING)	CONTACT CLOSURE				SS			1	E	1	B	2		L					CC		SS		4-5	0	0		
MG9002-X	INRTL REF (WARNING)	CONTACT CLOSURE				SS			1	E	1	B	2		L					CC		SS		4-5	0	0		
MG9003-X	PGNS (CAUTION)	CONTACT CLOSURE				SS			1	E	1	B	2		L					CC		SS		4-5	0	0		

LEM-AES VEHICLE LIST
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CONTRACT NUMBER NAS9-4983
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ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	INTEREST RANGES NORM	INTEREST RANGES HIGH	UNIT	STABILITY AND CONTROL-CES FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	XDCR RANGES HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MH1211-V	VOLT AUTO TH INCR 3,2KPPS	0		2-5	VDC	SS						B	2							0	5	SS		-	--	--		
MH1212-V	VOLT AUTO TH DECR 3,2KPPS	0		2-5	VDC	SS						B	2							0	5	SS		-	--	--		
MH1214-X	AUTO ENG ON COMMAND	0	OR	15	VDC	SS			1	E	1	B	2		L					0	OR15	SS		4-2	0	0		
MH1217-X	AUTO ENG OFF COMMAND	0	OR	15	VDC	SS			1	E	1	B	2		L					0	OR15	SS		4-2	0	0		
MH1229-X	DESC ENG ARM CMD (PNL)					SS			1	E	1	B	2		H							SS		4-2	0	0		
MH1230-X	ASC.ENG ARM (FROM PNL)					SS			1	E	1	B	2		H							SS		2-2	0	0		
MH1240-V	VOLT,'X' TRANS.CMD	-10	OR	+10	VDC	2C			10	H	8	B	2	R	H					-10	+10	2C		2-2	0	0		
MH1241-V	VOLT,'Y' TRANS.CMD	-10	OR	+10	VDC	2C			10	H	8	B	2	R	H					-10	+10	2C		2-2	0	0		
MH1242-V	VOLT,'Z' TRANS.CMD	-10	OR	+10	VDC	2C			10	H	8	B	2	R	H					-10	+10	2C		2-2	0	0		
MH1247-V	VOLT,PULSE YAW CMD	-13	+.5	+13	VDC	2C	2		10	H	8	B	2		H					-13	+13	2C		2-2	0	0		
MH1248-V	VOLT,PULSE PITCH CMD	-13	+.5	+13	VDC	2C	2		10	H	8	B	2		H					-13	+13	2C		2-2	0	0		
MH1249-V	VOLT,PULSE ROLL CMD	-13	+.5	+13	VDC	2C	2		10	H	8	B	2		H					-13	+13	2C		2-2	0	0		
MH1260-X	A.E. ON/CFF TO PROP	0		28	VDC	SS			1	E	1	B	2	R	H					0	28	SS		-	--	--		
MH1301-X	DESC ENG -ON/OFF- TO PROP	0		28	VDC	SS			1	E	1	B	2	R	L					0	28	SS		-	--	--		
MH1313-V	VOLT,PITCH GDA POS (.4KC)	-15	+.05	+15	VRMS	1C	2			H	8	B	2	R	H					-15	+15	1C		7-1	0	0		
MH1314-V	VOLT,ROLL GDA POS (.4KC)	-15	+.05	+15	VRMS	1C	2			H	8	B	2	R	H					-15	+15	1C		7-1	0	0		
MH1318-	PITCH GDA EXTEND FROM LGC	TBA										B	2											-	--	--		
MH1319-	PITCH GDA RETRAC FROM LGC	TBA										B	2											-	--	--		
MH1320-X	PITCH GDA EXT/RET(.4KC)	0	OR	90	DEG	SS						B	2									SS		-	--	--		
MH1323-X	PITCH TRIM FAIL	TBA				SS			1	E	1	B	2	R	L							SS		4-5	0	0		
MH1330-X	ROLL TRIM FAIL	TBA				SS			1	E	1	B	2	R	L							SS		4-5	0	0		
MH1331-V	VOLT,AUTO THRUST CMD	0	.015	12	VDC	1C	2		10	H	8	B	2	R	H					0	15	1C		2-2	0	0		
MH1332-V	VOLT,AUTO/MAN THRUST	0		5	VDC	SS														0	5	SS		-	--	--		
MH1343-	ROLL GDA EXTEND FROM LGC	TBA										B	2											-	--	--		
MH1344-	ROLL GDA RETRACT FROM LGC	TBA										B	2											-	--	--		

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

LEM-AES VEHICLE LIST
TRUCK

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STABILITY AND CONTROL-CES

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	INTEREST RANGES NORM	INTEREST RANGES HIGH	UNIT	FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	XDCR RANGES HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MH1345-X	ROLL GDA EXT/RET (.4KC)	0	OR	90	DEG	SS						B	2									SS		-	--	--		
MH1348-X	DESC ENG ARM (DECA OUT)	0	OR	28	VDC	SS							2							0 /	28	SS		-	--	--		
MH1406-V	VOLT +15V DC SUPPLY			+15	VDC																			2-2	0	0		
MH1407-V	VOLT -15V DC SUPPLY	-15			VDC																			2-2	0	0		
MH1408-V	VOLT +4V DC SUPPLY			+4	VDC																			4-1	0	0		
MH1418-V	VOLT,JET 1 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H					0 /	28			4-2	0	0		
MH1419-V	VOLT,JET 2 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H					0 /	28			4-2	0	0		
MH1420-V	VOLT,JET 3 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H					0 /	28			4-2	0	0		
MH1421-V	VOLT,JET 4 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H					0 /	28			4-2	0	0		
MH1422-V	VOLT,JET 5 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H					0 /	28			4-2	0	0		
MH1423-V	VOLT,JET 6 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H					0 /	28			4-2	0	0		
MH1424-V	VOLT,JET 7 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H					0 /	28			4-2	0	0		
MH1425-V	VOLT,JET 8 DRIVER OUT,28V	6PPS	MAX,10-400		MS				200E		1	B	2	R	H					0 /	28			4-2	0	0		
MH1434-V	VOLT LGC JET CMD NO 1	TBA										B	2											-	--	--		
MH1435-V	VOLT LGC JET CMD NO 2	TBA										B	2											-	--	--		
MH1436-V	VOLT LGC JET CMD NO 3	TBA										B	2											-	--	--		
MH1437-V	VOLT LGC JET CMD NO 4	TBA										B	2											-	--	--		
MH1438-V	VOLT LGC JET CMD NO 5	TBA										B	2											-	--	--		
MH1439-V	VOLT LGC JET CMD NO 6	TBA										B	2											-	--	--		
MH1440-V	VOLT LGC JET CMD NO 7	TBA										B	2											-	--	--		
MH1441-V	VOLT LGC JET CMD NO 8	TBA										B	2											-	--	--		
MH1450-V	VOLT PITCH TRIM ERROR	-14		+14	VDC							B	2							-14	+14			-	--	--		
MH1452-V	VOLT ROLL TRIM ERROR	-14		+14	VDC							B	2							-14	+14			-	--	--		
MH1455-V	VOLT,YAW ATT ERROR (.8KC)	TBA				2C			10H		8	B	2	R	H							2C		7-1	0	0		
MH1456-V	VOLT,PITCH ATT ERROR(.8KC)	TBA				2C			10H		8	B	2	R	H							2C		7-1	0	0		

LEM-AES VEHICLE LIST
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		INTEREST				STABILITY AND CONTROL-CES																						
ID CODE	MEASUREMENT NAME AND LOCATION	RANGES LOW	NORM	HIGH	UNIT	FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MH1457-V	VOLT,ROLL ATT ERROR(.8KC)	TBA				2C			10	H	8	B	2	R	H							2C		7-1	0	0		
MH1461-V	VOLT,YAW RG SIG (.8KC)	-3.5		+3.5	VRMS	2C	2		10	H	8	B	2	R	L					-3.5	+3.5	2C		7-1	0	0		
MH1462-V	VOLT,PITCH RG SIG (.8KC)	-3.5		+3.5	VRMS	2C			10	H	8	B	2	R	L					-3.5	+3.5	2C		7-1	0	0		
MH1463-V	VOLT,ROLL RG SIG (.8KC)	-3.5		+3.5	VRMS	2C	2		10	H	8	B	2	R	L					-3.5	+3.5	2C		7-1	0	0		
MH1492-V	VOLT -4VDC SUPPLY	-4			VDC	SS																SS		4-1	0	0		
MH1493-V	VOLT +6VDC SUPPLY			+6	VDC	SS																SS		2-2	0	0		
MH1494-V	VOLT -6VDC SUPPLY	-6			VDC	SS																SS		2-2	0	0		
MH1603-X	DEADBAND SELECT	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
MH1608-X	SCS MODE SELECT (AUTO)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
MH1609-X	SCS MODE SELECT(ATT HOLD)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
MH1615-X	ROLL ATT CONT SEL(PULSED)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
MH1616-X	PITCH ATT CONT SEL(PULSED)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
MH1617-X	YAW ATT CONT SEL(PULSED)	TBA				SS			1	E	1	B	2	R	H							SS		4-5	0	0		
MH1896-X	UNBALANCED COUPLES	TBA				SS			1	E	1	B	2		H							SS		4-5	0	0		

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

LEM-AES VEHICLE LIST
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ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	INSTRUMENTATION FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
ML0300	FRAME SYNCH + ID								1	P	32	B	2	R	L									-	--	--		
ML0300-	FRAME SYNCH + ID								50	P	32	B	2	R	H									-	--	--		
ML0302	FORMAT ID								1	P	8	B	2	R	L									-	--	--		
ML0401	CALIB 85 PCT HL	4.24	4.25	4.26	VDC	SS			1	H	8	B	2	R	L					0	5	SS		-	--	--		
ML0401-	CALIB 85 PCT HL	4.24	4.25	4.26	VDC	SS			10	H	8	B	2	R	H					0	5	SS		-	--	--		
ML0402-	CALIB 15 PCT HL	.741	.75	.759	VDC	SS			10	H	8	B	2	R	L					0	1	SS		-	--	--		
ML0402	CALIB 15 PCT HL	.741	.75	.759	VDC	SS			1	H	8	B	2	R	H					0	1	SS		-	--	--		
ML0411	OUTPUT REG ALL ZERO CK								1	P	8	B	2		L									-	--	--		
ML0501-W	TIME,GREEMWICH MEAN		TIME						10	P	32	B	2	R	H									-	--	--		
ML0501-W	TIME,GREEMWICH MEAN		TIME						1	P	32	B	2	R	L									-	--	--		
ML0801-V	VOLT PCMTE 1024KC TIM SIG					SS						B	2											-	--	--		

Grumman

LEM-AES VEHICLE LIST
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ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	INTEREST RANGES NORM	INTEREST RANGES HIGH	UNIT	FREQ OR RATE	RADARS A C C	RADARS S C R	RADARS S / S	RADARS S I G	RADARS B I T	RADARS G R D	RADARS O P S	RADARS M C C	RADARS MH S/ SL	RADARS C / W	RADARS F / L	RADARS A / D	RADARS X X X	XDCR RANGES LOW	XDCR RANGES HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MN7521-X	LR RANGE DATA NO GOOD	CONTACT CLOSURE				SS			1	E	1	B	2		H					CC		SS		4-5	0	0		
MN7523-L	VEL LR V'XA VEL(ALT RATE)	TBA			FT/S																			-	--	--		
MN7524-L	VEL LR V'YA VEL	TBA			FT/S																			-	--	--		
MN7525-L	VEL LR V'ZA VEL	TBA			FT/S																			-	--	--		
MN7527-H	POS LR RANGE DATA (DISP)				FEET																			-	--	--		
MN7529-V	VOLT LR RANGE GATE STROBE	4	7	10	VDC	3.2K						A	1							0	10			-	--	--		
MN7530-V	VOLT LR VXA GATE STROBE	4	7	10	VDC	3.2K						A	1							0	10			-	--	--		
MN7531-V	VOLT LR VYA GATE STROBE	4	7	10	VDC	3.2K						A	1							0	10			-	--	--		
MN7532-V	VOLT LR VZA GATE STROBE	4	7	10	VDC	3.2K						A	1											-	--	--		
MN7533-V	VOLT LR LGC ANT POS CMD	TBA										A	1											-	--	--		
MN7534-V	VOLT LR RESET STROBE	4	7	10	VDC	3.2K						A	1							0	10			-	--	--		
MN7535-V	VOLT LR COUNT READOUT CMD	4	7	10	VDC	3.2K						A	1							0	10			-	--	--		
MN7536-V	VOLT LR COUNTER OUTPUT 0	4	7	10	VDC	3.2K						A	1							0	10			-	--	--		
MN7537-V	VOLT LR COUNTER OUTPUT 1	4	7	10	VDC	3.2K						A	1							0	10			-	--	--		
MN7540-X	VOLT LR LOW SCALE FACTOR	17	TBA	39	VDC	SS						B	2							0	40	SS		-	--	--		
MN7545-E	PWR LR VEL XMTR RF PWROUT				MW																			-	--	--		
MN7546-E	PWR LR ALT XMTR RF PWROUT				MW																			-	--	--		
MN7557-X	LR VEL.DATA NO GOOD	CONTACT CLOSURE				SS		S	1	E	1	B	2	R	H					CC		SS		4-5	--	--		
MN7562-X	LR HEATER CAUTION	CONTACT CLOSURE				SS		S	1	E	1	B	2		H					CC		SS		4-5	--	--		
MN7567-V	VOLT LR GAIN STATE D1	-1		+6	VDC	SS						B	2							-1	+6	SS		-	--	--		
MN7568-V	VOLT LR GAIN STATE D2	-1		+6	VDC	SS						B	2							-1	+6	SS		-	--	--		
MN7569-V	VOLT LR GAIN STATE D3	-1		+6	VDC	SS						B	2							-1	+6	SS		-	--	--		
MN7570-V	VOLT LR GAIN STATE D4	-1		+6	VDC	SS						B	2							-1	+6	SS		-	--	--		
MN7571-V	VOLT LR -25 VDC	-27	-25	0	VDC	SS						B	2							-28	0	SS		-	--	--		
MN7572-V	VOLT LR +25 VDC	0	25	27	VDC	SS						B	2							0	28	SS		-	--	--		

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

LEM-AES VEHICLE LIST
TRUCK

CONTRACT NUMBER NAS9-4983
REFERENCE TRUCK

PAGE NUMBER 20
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	INTEREST RANGES NORM	INTEREST RANGES HIGH	UNIT	FREQ OR RATE	RADARS A C C	RADARS S C R	RADARS S / S	RADARS S I G	RADARS B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	XDCR RANGES HIGH	FREQ OR RATE	A C C	C T DSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MN7573-V	VOLT LR +25 VDC (SSC)	0	25	27	VDC	SS						B	2							0	28	SS		-	--	--		
MN7574-V	VOLT LR +4 VDC	0	4	6	VDC	SS						B	2							0	10	SS		-	--	--		
MN7575-V	VOLT LR -2 VDC	-4	-2	0	VDC	SS						B	2							-5	0	SS		-	--	--		
MN7576-X	LR ANTENNA POSIT 1 IND	TBA			VDC	SS						B	2									SS		-	--	--		
MN7577-X	LR ANTENNA POSIT 2 IND	TBA			VDC	SS						B	2									SS		-	--	--		
MN7582-E	PWR LR VEL XMTR RF PWROUT				MW							B	2											-	--	--		
MN7583-E	PWR LR ALT XMTR RF PWROUT				MW							B	2											-	--	--		
MN7584-X	LR MODE CONTRCL	TBA										B	2											-	--	--		
MN7585-F	FREQ LR SELF TEST	TBA										B	2											-	--	--		
MN7586-F	FREQ LR RA TRAN BLANK SIG	TBA										B	2											-	--	--		
MN7589-V	VOLT D1 AT ANGLE 0 DEG	TBA										B	2											-	--	--		
MN7590-V	VOLT D2 AT ANGLE 0 DEG	TBA										B	2											-	--	--		
MN7591-V	VOLT D3 AT ANGLE 0 DEG	TBA										B	2											-	--	--		
MN7592-V	VOLT FR AT ANGLE 0 DEG	TBA										B	2											-	--	--		
MN7593-V	VOLT D1 AT ANGLE 90 DEG	TBA										B	2											-	--	--		
MN7594-V	VOLT D2 AT ANGLE 90 DEG	TBA										B	2											-	--	--		
MN7595-V	VOLT D3 AT ANGLE 90 DEG	TBA										B	2											-	--	--		
MN7596-V	VOLT FR AT ANGLE 90 DEG	TBA										B	2											-	--	--		
MN7597-F	FREQ LR ALT TRAN TES CPLR	TBA										A	1											-	--	--		
MN7598-F	FREQ LR VEL TRAN TES CPLR	TBA										A	1											-	--	--		
MN9001	GYRO TEST INPUT SIG																							-	--	--		
MN9002	RCVR(SHAFT ERROR)INPT SIG																							-	--	--		
MN9003	RCVR(SUM)INPUT SIG																							-	--	--		
MN9004	RCVR(TRUN ERROR)INPUT SIG																							-	--	--		
MN9005	SHAFT CHANNEL INPUT SIG																							-	--	--		

LEM-AES VEHICLE LIST
TRUCK

CONTRACT NUMBER NAS9-4983
REFERENCE TRUCK

PAGE NUMBER 21
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ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	FREQ OR RATE	RADARS A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MN9006	SUM CHANNEL INPUT SIG																							-	--	--		
MN9007	TRUNNION CHANNEL INPT SIG																							-	--	--		
MN9008	VELOCITY RCVR NO1 INPUT																							-	--	--		
MN9009	VELOCITY RCVR NO2 INPUT																							-	--	--		
MN9010	VELOCITY RCVR NO3 INPUT																							-	--	--		
MN9011	ALTIMETER RCVR INPUT																							-	--	--		

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

LEM-AES VEHICLE LIST
TRUCK

CONTRACT NUMBER NAS9-4983
REFERENCE TRUCK

PAGE NUMBER 22
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	PROPULSION-DESCENT FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MQ3001-P	PRESS,HE SUPPLY TANK	190		1398	PSIA	SS		I	1	H	8	B	2	R	L					0	4000	SS		-	.28	.25		
MQ3018-P	PRESS,HE REG OUT MANIFOLD	210	235	270	PSIA	SS		I	1	H	8	B	2	R	H					0	300	SS		-	.28	.25		
MQ3018-P	PRESS HE REG OUT MANIFOLD	210	235	270	PSIA	100C						A	1							0	300	100C		-	.28	.25		
MQ3201-T	TEMP,HE SUPPLY TANK	-445		-335	DEGF	SS		I	1	H	8	B	2	R	L					-450	-300	SS		-	.25	.25		
MQ3309-X	HE PRI SOL VLV CLOSED	CONTACT	CLOSURE			SS		S	1	E	1	B	2	R	H					CC		SS		4-5	0	Z.05		
MQ3310-X	HE SEC SOL VLV CLOSED	CONTACT	CLOSURE			SS		S	1	E	1	B	2	R	H					CC		SS		4-5	0	Z.05		
MQ3718-T	TEMP,FUEL TANK 1,BULK	40	70	100	DEGF	SS		I	1	H	8	B	2	R	L					40	100	SS		6-2	0	.16		
MQ3719-T	TEMP,FUEL TANK 2,BULK	40	70	100	DEGF	SS		I	1	H	8	B	2	R	L					40	100	SS		6-2	0	.16		
MQ3909-X	FUEL TANK 1 LQD LEVEL LOW	CONTACT	CLOSURE			SS		I	1	E	1	B	2	R	H					CC		SS		4-5	*	*	SS WT./PWR.	
MQ3910-X	FUEL TANK 2 LQD LEVEL LOW	CONTACT	CLOSURE			SS		I	1	E	1	B	2	R	H					CC		SS		4-5	*	*	SS WT./PWR.	
MQ4218-T	TEMP,OX TANK 1,OX BULK	40	70	100	DEGF	SS		I	1	H	8	B	2	R	L					40	100	SS		6-2	0	.16		
MQ4219-T	TEMP,OX TANK 2,OX BULK	40	70	100	DEGF	SS		I	1	H	8	B	2	R	L					40	100	SS		6-2	0	.16		
MQ4409-X	OX TANK 1,LQD LEVEL LOW	CONTACT	CLOSURE			SS		S	1	E	1	B	2	R	H					CC		SS		4-5	*	*	SS WT./PWR.	
MQ4410-X	OX TANK 2,LQD LEVEL LOW	CONTACT	CLOSURE			SS		S	1	E	1	B	2	R	H					CC		SS		4-5	*	*	SS WT./PWR.	
MQ6001-P	PRESS FUEL CONTROL VLV IN	50	210	270	PSIA	SS		I	1	H	8	B	2	R	L					0	300	SS		-	--	--		
MQ6001-P	PRESS,FUEL CONTROL VLV IN	50	210	270	PSIA	150C		I				A	1							0	300	150C		-	.28	.25		
MQ6002-P	PRESS,OX CONTROL VLV IN	50	210	270	PSIA	SS		I	1	H	8	B	2	R	L					0	300	SS		-	.28	.25		
MQ6301-H	POS MIXTURE RATIO ACTUAT	-15		+15	DEG	SS		S												-15	+15	SS		-	--	--		
MQ6306-X	SHUTOFF VLV A NOT OPEN	CONTACT	CLOSURE			SS		S							*					CC		SS		-	0	Z.05	MQ7498	
MQ6307-X	SHUTOFF VLV A NOT CLOSED	CONTACT	CLOSURE			SS		S							*					CC		SS		-	0	Z.05	MQ7498	
MQ6308-X	SHUTOFF VLV B NOT OPEN	CONTACT	CLOSURE			SS		S							*					CC		SS		-	0	Z.05	MQ7498	
MQ6309-X	SHUTOFF VLV B NOT CLOSED	CONTACT	CLOSURE			SS		S							*					CC		SS		-	0	Z.05	MQ7498	
MQ6314-X	SHUTOFF VLV C NOT OPEN	CONTACT	CLOSURE			SS		S							*					CC		SS		-	0	Z.05	MQ7499	
MQ6315-X	SHUTOFF VLV C NOT CLOSED	CONTACT	CLOSURE			SS		S							*					CC		SS		-	0	Z.05	MQ7499	
MQ6316-X	SHUTOFF VLV D NOT OPEN	CONTACT	CLOSURE			SS		S							*					CC		SS		-	0	Z.05	MQ7499	

LEM-AES VEHICLE LIST
TRUCK

CONTRACT NUMBER NAS9-4983
REFERENCE TRUCK

PAGE NUMBER 23
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ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	PROPULSION-DESCENT FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MQ6317-X	SHUTOFF VLV D NOT CLOSED	CONTACT CLOSURE				SS		S							*					CC		SS		-	0	Z.05	MQ7499	
MQ6510-P	PRESS,THRUST CHAMBER	11	110	121	PSIA	SS		S	1	H	8			R	L					0	100	SS		-	--	--		
MQ6806-H	POS,VARIABLE INJ.ACTUATOR	10		100	PCT	SS		S	1	H	8	B	2	R	H					0	100	SS		-	--	--		
MQ7498-U	SHUTOFF VLVS A/B MID POS.	CONTACT CLOSURE				SS			1	E	1	B	2	R	L					CC		SS		4-5	--	--		
MQ7498-U	SHUTOFF VLVS A/B MID POS.	CONTACT CLOSURE				1MS						A	1							CC		--		-	--	--		
MQ7499-U	SHUTOFF VLVS C/D MID POS.	CONTACT CLOSURE				SS			1	E	1	B	2	R	L					CC		SS		4-5	--	--		
MQ7499-U	SHUTOFF VLVS C/D MID POS.	CONTACT CLOSURE				1MS						A	1							CC		--		-	--	--		

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

LEM-AES VEHICLE LIST
TRUCK

CONTRACT NUMBER NAS9-4983
REFERENCE TRUCK

PAGE NUMBER 24
NOVEMBER 8,1965

ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	INTEREST RANGES NORM	INTEREST RANGES HIGH	UNIT	REACTION CONTROL FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X / X	XDCR RANGES LOW	XDCR RANGES HIGH	FREQ OR RATE	A C C	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
MR1102-P	PRESSURE,HELIUM TANK B	3000	3050	3250	PSIA	SS	3	I	1	H	8	B	2	R	L					0	3500	SS		-	.28	.25		
MR1122-T	TEMP,HELIUM TANK B	40	70	100	DEGF	SS	3	I	1	H	8	B	2	R	L					20	120	SS		6-2	0	.16		
MR1202-P	PRESS,HE REGULATOR B OUT	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	L					0	350	SS		-	.28	.25		
MR1463-X	HE SHUTOFF VLV B-1 CLOSE	CONTACT CLOSURE				SS		S	I	E	I	B	2	R	H					CC		SS		4-5	0	Z.05		
MR1464-X	HE SHUTOFF B-2 NOT CLOSED	CONTACT CLOSURE				SS		S	I	E	I	B	2	R	L					CC		SS		4-5	0	Z.05		
MR2102-P	PRESSURE,FUEL TANK B	171	191	250	PSIA	SS		I	1	H	8	B	2	R	L					0	350	SS		-	.28	.25		
MR2122-T	TEMPERATURE,FUEL TANK B	40	70	100	DEGF	SS		I	1	H	8	B	2	R	L					20	120	SS		6-2	0	.16		
MR2142-Q	QUANTITY,FUEL TANK B	0		99	PCT	SS		S	1	P	8	B	2	R	L					0	99	SS		-	--	--		
MR2202-P	PRESS,B FUEL MANIFOLD	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	H					0	350	SS		-	.28	.25		
MR2462-X	FUEL MAIN FEED S/O B CL	CONTACT CLOSURE				SS		S							*					CC		SS		-	0	Z.05	MR9610	
MR3102-P	PRESSURE,OXIDIZER TANK B	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	L					0	350	SS		-	.28	.25		
MR3122-T	TEMP,OXIDIZER TANK B	40	70	100	DEGF	SS	3	I	1	H	8	B	2	R	L					20	120	SS		6-2	0	.16		
MR3142-Q	QUANTITY,OXID.TANK B	0		99	PCT	SS	3	S	1	P	8	B	2	R	L					0	99	SS		-	--	--		
MR3202-P	PRESSURE,OXID.MNFLD B	171	191	250	PSIA	SS	3	I	1	H	8	B	2	R	H					0	350	SS		-	.28	.25		
MR3462-X	OXID MAIN FEED S/O B CLSD	CONTACT CLOSURE				SS		S							*					CC		SS		-	0	Z.05	MR9610	
MR5002-X	O/F RATIO B OUT,TOLER	CONTACT CLOSURE				SS		S	I	E	I	B	2	R	H					CC		SS		4-5	0	Z.05		
MR6001-T	TEMP,QUAD CLUSTER NO.1	0		200	DEGF	SS	3	I	1	H	8	B	2	R	H					0	200	SS		6-2	0	.08		
MR6002-T	TEMP,QUAD CLUSTER NO.2	0		200	DEGF	SS	3	I	1	H	8	B	2	R	H					0	200	SS		6-2	0	.08		
MR6003-T	TEMP,QUAD CLUSTER NO.3	0		200	DEGF	SS	3	I	1	H	8	B	2	R	H					0	200	SS		6-2	0	.08		
MR6004-T	TEMP,QUAD CLUSTER NO.4	0		200	DEGF	SS	3	I	1	H	8	B	2	R	H					0	200	SS		6-2	0	.08		
MR7121-V	VOLT SEC FUEL + OX INJT 1	0	28	32	VDC							B	2							0	35			-	--	--		
MR7123-V	VOLT SEC FUEL + OX INJT 3	0	28	32	VDC							B	2							0	35			-	--	--		
MR7126-V	VOLT SEC FUEL + OX INJT 6	0	28	32	VDC							B	2							0	35			-	--	--		
MR7127-V	VOLT SEC FUEL + OX INJT 7	0	28	32	VDC							B	2							0	35			-	--	--		
MR7129-V	VOLT SEC FUEL + OX INJT 9	0	28	32	VDC							B	2							0	35			-	--	--		

LEM-AES VEHICLE LIST
TRUCK

CONTRACT NUMBER NAS9-4983
REFERENCE TRUCK

PAGE NUMBER 25
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ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	INTEREST RANGES NORM	INTEREST RANGES HIGH	UNIT	REACTION CONTROL FREQ OR RATE	A C C	S C R	S / S	S I G	B I T	G R D	O P S	M C C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	XDCR RANGES HIGH	FREQ OR RATE	A C C	C T OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MR7132-V	VOLT SEC FUEL + OX INJT12	0	28	32	VDC							B	2							0	35			-	--	--		
MR7134-V	VOLT SEC FUEL + OX INJT14	0	28	32	VDC							B	2							0	35			-	--	--		
MR7136-V	VOLT SEC FUEL + OX INJT16	0	28	32	VDC							B	2							0	35			-	--	--		
MR9610-U	MAIN PROP.VALVE B CLOSED	CONTACT CLOSURE				SS			1	E	1	B	2	R	H					CC		SS		4-5	--	--		

Table 5.6-4 OPERATIONAL MEASUREMENTS LIST

LEM-AES VEHICLE LIST
TRUCK

CONTRACT NUMBER NAS9-4983
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ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	INTEREST RANGES NORM	INTEREST RANGES HIGH	UNIT	COMMUNICATIONS FREQ OR RATE	ACC	SCR	S/S	SIG	BIT	GRD	OPS	MCC	MH S/SL	C/W	F/L	A/D	XXX	XDCR RANGES LOW	XDCR RANGES HIGH	FREQ OR RATE	ACC	CT OSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	CHNG
MT0105	PCM NRZ DATA INPUT		TBA									A	1											-	--	--		
MT0106	TE 512KC SYNC IN		TBA									A	1											-	--	--		
MT0107	PCM SPLIT PHASE IN		TBA									A	1											-	--	--		
MT0108	512KC SUBCARRIER REF IN		TBA									A	1											-	--	--		
MT0145-V	VOLT,SPS AVC RCVD VHF B	0		5	VDC	SS						B	2							0	5	SS		-	--	--		
MT0161-V	VOLT,PMP EMS VOICE LINE		TBA									A	1											-	--	--		
MT0163	VHF RCVD VOICE IN A		TBA									A	1											-	--	--		
MT0164	VHF RCVD VOICE IN B		TBA									A	1											-	--	--		
MT0201-E	POWER,SBAND PA RF PWR OUT	0	18	25	WATTS	SS		S	1	H	8	B	2	R	L							SS		-	--	--		
MT0202-E	PWR,SBAND PA RF REFLECTED	0	.3	.5	WATTS	SS		S	1	H	8	B	2		H							SS		-	--	--		
MT0206-X	PA RECYCLING SIG NO 1											B	2											-	--	--		
MT0207-X	PA RECYCLING SIG NO 2											B	2											-	--	--		
MT0224-C	CURR, SBAND PWR AMP AN 1	20	25	30	MA	SS						B	2							0	30	SS		-	--	--		
MT0225-C	CURR, SBAND PWR AMP AN 2	20	25	30	MA	SS						B	2							0	30	SS		-	--	--		
MT0226-E	PWR VHF XMTR A+B RF OUT		TBA									B	2											-	--	--		
MT0451-H	POS GIMBAL PICOFF OPUT Y	-60		+240	DEG																			-	--	--		
MT0452-H	POS GIMBAL PICOFF OPUT X	-75		+75	DEG																			-	--	--		
MT0453-X	SBAND STEER ANT NO TRACK	CONTACT		CLOSURE		SS														CC		SS		-	--	--		
MT0504-V	VOLT,SBAND RCVR AGC	0		4.2	VDC															0	5			-	--	--		
MT0511	SBAND XPNDR FM INPUT		TBA									A	1											-	--	--		
MT0513	SBAND XPNDR PM INPUT		TBA									A	1											-	--	--		
MT0555	S BD RCVR SBCAR WVFORM OT		TBA									A	1											-	--	--		
MT0604-V	VOLT,VHF RCVR A AGC	0		4.2	VDC	SS						B	2							0	5	SS		-	--	--		
MT0605-V	VOLT,VHF RCVR B AGC	0		4.2	VDC	SS						B	2							0	5	SS		-	--	--		
MT0660-V	VOLT,ST ANT SERV ERR INP		TBA									A	1															

LEM-AES VEHICLE LIST
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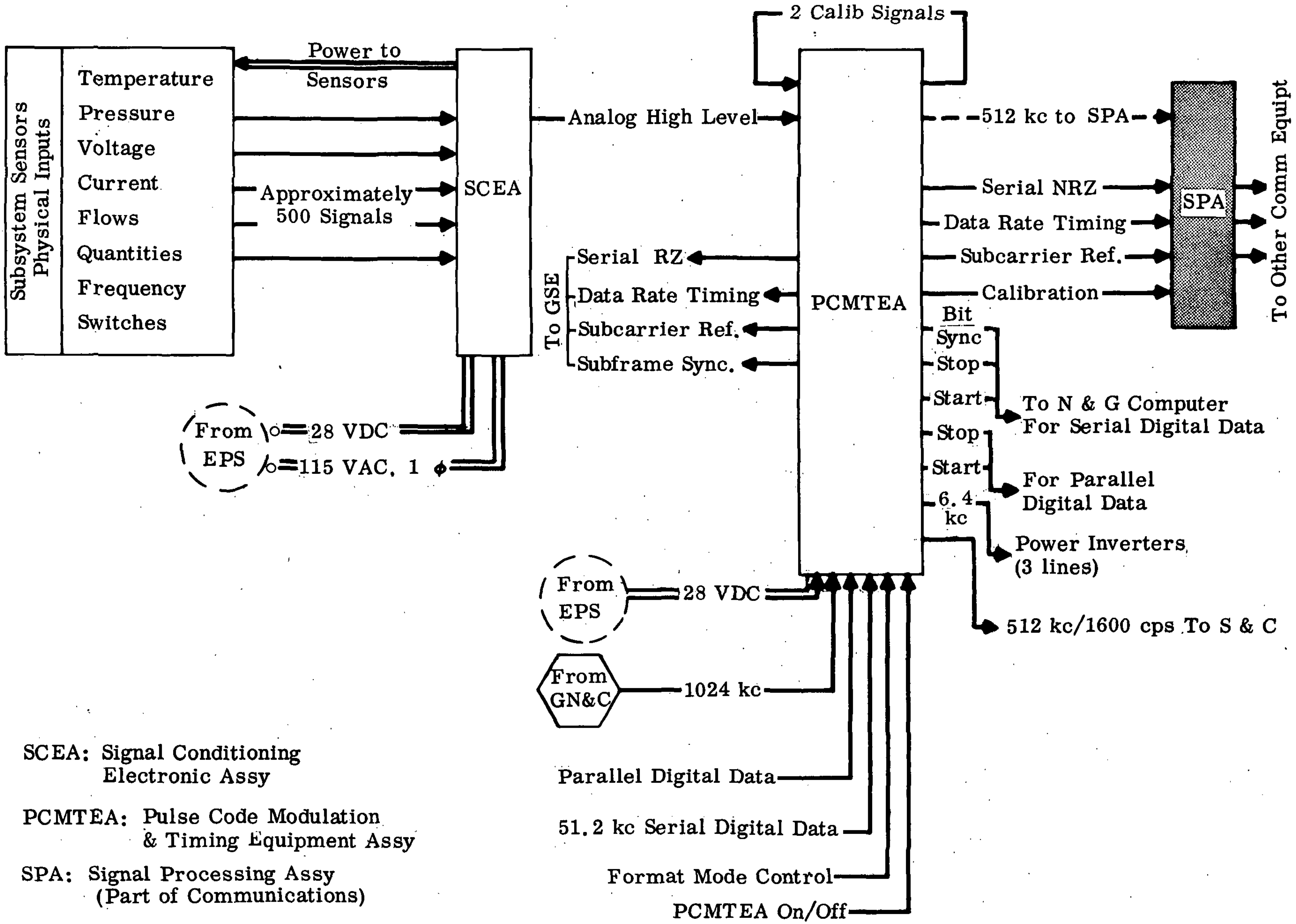
ID CODE	MEASUREMENT NAME AND LOCATION	INTEREST RANGES LOW	NORM	HIGH	UNIT	COMMUNICATIONS FREQ OR RATE	A C C	S C R	S C / S	S / I G	B I T	G I R D	O R P S	M P C C	M C S C	MH S/ SL	C / W	F / L	A / D	X X X	XDCR RANGES LOW	HIGH	FREQ OR RATE	A C C	C T DSY NIP DGE	XDCR -PWR	XDCR WT.	REFERENCES OR NOTES	C H N G
MT0992-B	PHASE,ST PH ER,SLCTD S/B	-15	0	+15	DEG	2C		S	10	H	8	B	2	R	L								2C		-	--	--		
MT0993-E	PWR,SLCTD SBAND XMTR RF	.5	.75	1	WATT	SS		S	1	H	8	B	2	R	L								SS		-	--	--		
MT0994-V	VOLT,SLCTD SBAND RCVR AGC	0		4.2	VDC	2C		S	10	H	8	B	2	R	L						0	5	2C		-	--	--		
MT8001	VHF XMTR A CW CONTROL																								-	--	--		
MT8002	VHF XMTR B CW CONTROL																								-	--	--		
MT8003-V	VOLT,PRIM PWR SUPP CONTR																								-	--	--		
MT8005-V	VOLT,SEC PWR SUPP CONTR																								-	--	--		



SCEA: Signal Conditioning Electronic Assy

PCMTEA: Pulse Code Modulation & Timing Equipment Assy

SPA: Signal Processing Assy (Part of Communications)

Figure 5.6-1 Instrumentation Subsystem Reference Truck Vehicle Support Configuration

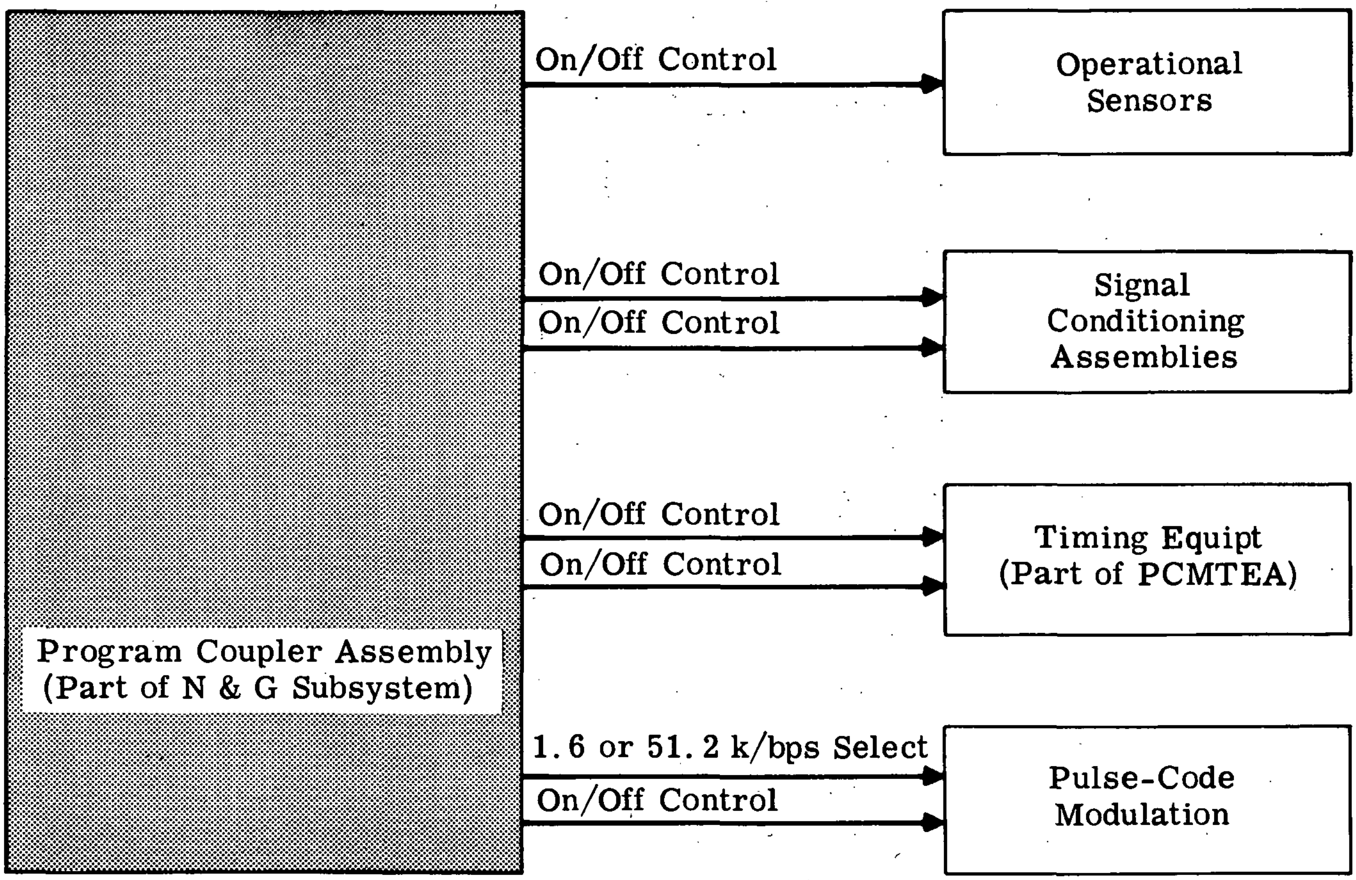


Fig. 5.6-2 Instrumentation Subsystem Ground Command Control

6. VEHICLE DESIGN AND INTEGRATION

6.1 SPACECRAFT DESIGN

6.1.1 Ground Rules

There are no ground rules unique to the spacecraft design. The overall vehicle ground rules which most closely concern the design of the structure are those specifying the maximum use of Apollo hardware, the independence of the Truck from the payload, and the prohibition of changes to the Spacecraft LEM Adapter (SLA).

6.1.2 Assumptions

- For the Reference configuration, the payload fills the available volume around the entire periphery (no "cutouts")
- It is possible to connect an electrical umbilical between the CSM and Truck after docking
- For translunar injection, the Truck and CSM must dock along their centerlines and use the same hardware and techniques employed in the Apollo mission.

6.1.3 Reference Configuration

The Reference Truck general arrangement (Fig. 6.1-1) consists of the basic LEM descent stage with the necessary modifications to incorporate additional equipment required for the mission. The primary structure consists of four main beams, approximately 64 in. deep, arranged as a cruciform and interconnected by diagonal members. A tubular truss structure at each end of the cruciform beams transfers the Truck and payload platform loads to the SLA.

The four main attachment fittings normally used for the ascent stage are available for support of the payload. The magnitude and direction of the allowable loads on these attachments are tabulated on Fig. 6.1-1.

The LEM RCS thruster assemblies are attached to the descent stage by trusses connected to the primary structural hard points used to support the landing gear. Because of the extraction angle of the Truck from the SLA, the nominal radius of the clusters is 107 in. Fig. 6.1-1 shows the RCS thruster locations only; the possible nozzle arrangements are illustrated in Section 5.4. For the Reference configuration, the eight nozzle arrangement with canted upward-firing nozzles is used, to satisfy the working assumption of a payload without "cutouts". Ultimately, it may prove worthwhile to make the choice of nozzle arrangement payload-dependent. Many of the specific payloads to be carried by the Truck will clear the plume of vertical upward-firing thrusters, permitting retention of either the present LEM nozzle arrangement (and computer logic) or the eight-jet RCS developed for the Shelter.

The IMU and Automatic Star Tracker are located on top of the landing gear truss; this provides the rigidity required for proper alignment of the units and a viewing field of 120 deg in elevation, ± 90 deg in azimuth.

A docking ring is located on the Reference configuration (Fig. 6.1-1) to indicate that one is always required. However, no supporting members are shown because of the payload-dependence of such structure. Certain payloads will have integral docking provisions. For those which do not, alternate concepts for providing the docking structure are offered; these are discussed in the following paragraphs and illustrated in Fig. 6.1-2.

6.1.4 Alternate Configuration - "Central Tube" Docking Structure

For payloads made up of a number of small objects or otherwise not requiring an unobstructed volume, the central tube docking structure offers the lightest approach (approximately 90 lb). The payload volume is basically a flat-edged torus, but the volume inside the docking structure is also accessible, since the "tube" has four triangular openings. These two volumes total approximately 1900 cu ft. One concept for mounting communications antennas on a shelf extending from the docking ring is illustrated in Fig. 5.5-4.

6.1.5 Alternate Configuration - "Outer Structure" Docking Support

For payloads which do not allow passage of a central tube, a structure can be provided which carries the docking loads around the outside of the payload. It consists of a circular bulkhead at LEM Sta X 312.5 and a skirt and leg structure connected to the descent stage landing gear truss. A completely unobstructed payload volume of approximately 1700 cu ft is provided. The conceptual design shown in Fig. 6.1-2 weighs approximately 360 lb.

As indicated in the illustration, this concept offers a location for mounting the IMU and Star Tracker which closely approximates that in the Shelter and which provides excellent viewing angles. The upper bulkhead can also be used for communications antennas as shown in Fig. 5.5-3.

6.2 STRUCTURAL ANALYSIS

6.2.1 Assumptions and Background Data

The applicable structural design criteria and environments established for the LEM will not be exceeded when the final requirements for the Truck are defined. The pertinent design requirements used to establish the integrity of the basic vehicle and subsystems are tabulated below. A safety factor of 1.50 is applied to the limit conditions to obtain ultimate loads.

Limit Accelerations

Axis / Mission Phase	X		Y or Z	
	g	rad/sec^2	g	rad/sec^2
Launch and Boost, S-V				
Lift-off	+1.60	---	±.65	---
Max q (S-IC)	±2.07	---	±.30	---
Boost (S-IC)	+4.90	---	±.10	---
Cut-off (S-IC)	-1.70	---	±.10	---
Engine Hard Over (S-II)	+2.15	---	±.40	---
Earth Orbit	0	0	0	0
Space Flight				
SM Prop. Syst. Operating	-.36	---	±.062	±1.99
SM Prop Syst. not Operating	0	0	0	0

The mission vibration environment is represented by the following random and sinusoidal envelopes considered separately:

Input To Equipment Supports, Launch and Boost

Freq., cps	Random	Freq. cps	Sinusoidal
From Exterior Primary Structure			
10 to 23	12 db/octave rise to		
23 to 80	0.0148 g^2/cps		
80 to 105	12 db/octave rise to	5 to 18.5 cps	0.154 in. D.A.
105 to 950	0.0444 g^2/cps	18.5 to 100 cps	2.69 g peak
950 to 1250	12 db/octave decrease to		
1250 to 2000	0.0148 g^2/cps		
From Interior Primary Structure			
10 to 23	12 db/octave rise to		
23 to 80	0.0148 g^2 cps	5 to 16 cps	0.154 in. D.A.
80 to 100	12 db/octave rise to	16 to 100 cps	1.92 g peak
100 to 1000	0.0355 g^2/cps		
1000 to 1200	12 db/octave decrease to		
1200 to 2000	0.0148 g^2/cps		

For design purposes, the above random spectrum applied for five minutes along each of the three mutually perpendicular axes (X, Y, Z), in addition to the corresponding sinusoidal spectrum acting for five seconds at the natural frequency of the equipment being designed, will adequately represent the environment.

Acoustics

Sound Pressure Levels in db External to LEM

(Re. 0.0002 dynes/cm^2)

Octave Band, cps	S-V at max level, db
9 to 18.8	136
18.8 to 37.5	142
37.5 to 75	146
75 to 150	143
150 to 300	139
300 to 600	135
600 to 1200	130
1200 to 2400	125
2400 to 4800	119
4800 to 9600	113
Overall	150

Docking - Typical Conditions

Axial velocity, 0.1 to 1.0 fps
Radial velocity, 0.0 to ±0.5 fps
Angular misalignment, ±10 deg
Angular velocity, ±1.0 deg/sec
Miss distance at probe, ±1 ft.

Lunar Landing Conditions

- Descent Maneuvers - Dynamic loads during descent are due to operation of the main descent engine and the RCS. Significant loads calculated occur at separation, at start of hover, and just prior to touchdown. Accelerations are calculated assuming maximum thrust at any time during the 1030 sec engine duty time.

Phase	Vertical Accel, Earth g X	Lateral Accel, Earth g Y & Z	rad/sec^2 Abort Y & Z	rad/sec^2 Abort X
At separation	+0.368	±0.0378	±0.192	±0.091
Elliptic orbit	+0.372	±0.0383	±0.193	±0.092
Start of hover	+0.707	±0.0728	±0.448	±0.166
End of hover	+0.815	±0.084	±0.645	±0.189
Transfer orbit	0	0	0	0

- Landing - At touchdown, the propulsion and reaction control systems are capable of producing the accelerations given above. In addition, the RCS combined with the descent engine must bring the Truck attitude within 3 deg of the local vertical and must hold the Truck motion within the following limits at impact on the lunar surface:

Local Vertical Velocity ≤10 fps	Local Horizontal Velocity ≤ 4 fps		Pitch/Roll Rate ≤ 3 deg/sec		Yaw Rate ≤ 3 deg/sec	
Landing Accelerations at LEM cg	X		Y		Z	
	g	rad/sec^2	g	rad/sec^2	g	rad/sec^2
Case 1	.798	±0.036	±1.778	-0.016	0	±14.56
Case 2	.798	0	0	17.60	1.778	0
Case 3	.857	±15.82	±0.095	9.05	-0.421	+ 0.573
Case 4	2.74	0	0	±28.1	±0.514	0
Case 5	2.74	± 0.01	±0.514	- 0.055	0	±23.3

- Interstage Allowable Loads

  The ultimate allowable interstage loads as derived from the LEM analysis are tabulated below. (Loads shown in pounds acting on descent stage.)

Location (Ref. Dwg. No. LDW 280-30510A	Launch			Landing		
	X	Y	Z	X	Y	Z
1. Fwd Left x = +211.30 y = - 22.00 z = + 66.20	-11,154	+2703	-179	-27,429	+14,643	+16,709
2. Fwd Right x = +211.30 y = + 22.00 z = + 66.20	-11,108	-2524	-247	-29,560	+16,169	+31,821
3. Aft Left x = +202.00 y = - 65.00 z = - 27.03	-27,309	-17,236	-769	-51,379	-26,045	-767
4. Aft Right x = +202.00 y = + 65.00 z = - 27.03	-27,071	+16,440	+759	-51,700	+26,023	-788

6.2.2 Reference Configuration

The basic structural components of the present LEM descent stage have been utilized without modification to the primary members. Minor structural changes which must be incorporated do not result in substantial revisions to the primary structure of the descent stage; these modifications are caused primarily by the integration of additional subsystems into the descent stage and removal of unused components. Where necessary, additional localized strength is incorporated to provide the required hardpoint strengths and rigidity for equipment support loads. The navigation base structure must provide adequate restraint for distortions.

The planned utilization of the descent stage without primary structural modification is a result of an analysis which shows that the critical structural design conditions and the integrated payload/Truck weight configurations lie within the design load envelope of the present LEM.

The equipment and experiment component supports are integrated into the primary structure and satisfy the design requirements. In addition to providing adequate strength, the equipment support structures must be designed to satisfy applicable heat conduction requirements between the vehicle structure and the equipment and/or experiments. Thermal isolation of equipment from the structure would be achieved by the use of proper structural design techniques, such as the use of trusses and the selection of efficient structural materials which possess low thermal conductivity.

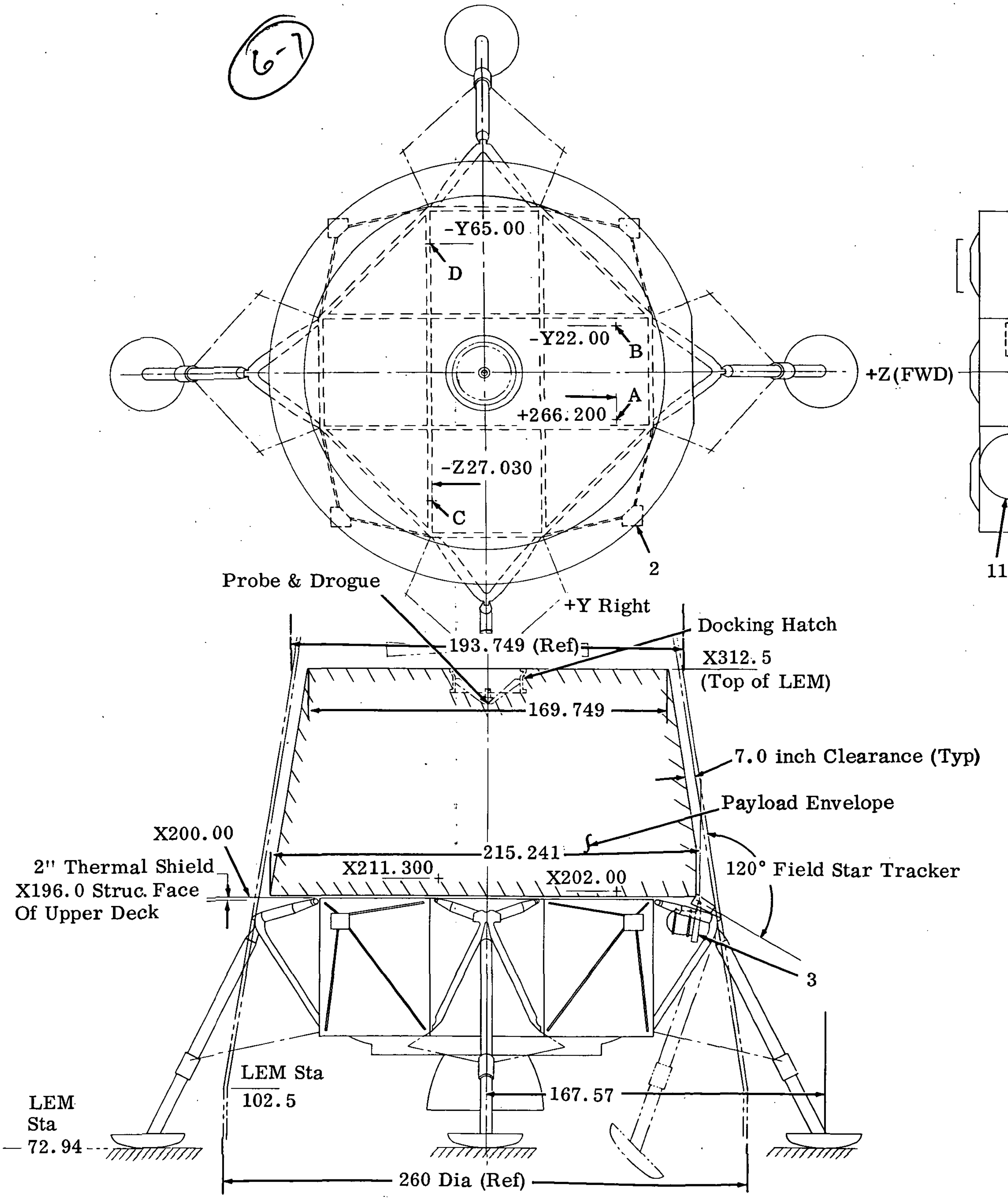
6.2.3 Alternate Configurations - Docking Structure

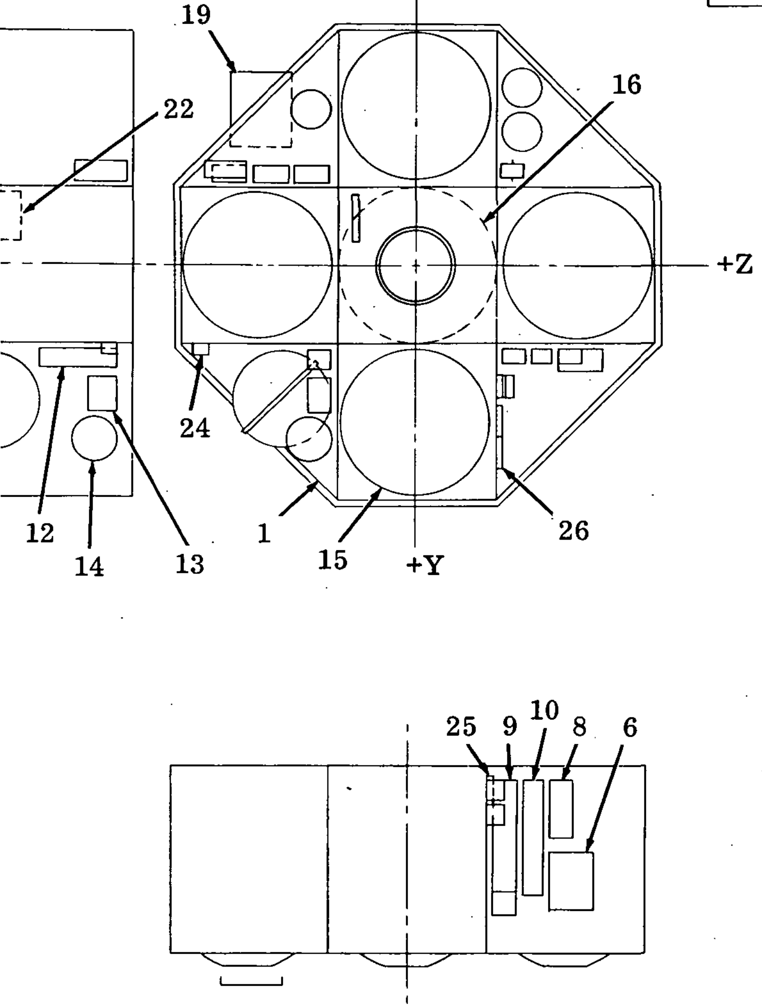
Two structural concepts were studied for docking the CSM and Truck independent of the payload. They are illustrated in Section 6.1; sketches indicating design ultimate loading appear in Fig. 6.2-1.

The "outer structure" docking arrangement consists of a 12 in. deep, box-beam type, double skinned structure, located over the top of the payload. It contains eight vertical ribs extending vertically from the docking ring to the outer diameter of the box beam. An outer ring provides the end bulkhead of each box beam, as well as a flange for attaching the peripheral skirt and the four honeycomb legs. These legs support the entire docking structure at the descent stage pickup points.

In the "central tube" docking arrangement, the docking ring is supported by four vertical members which deliver the reactions from the docking load into the descent stage structure as shown.

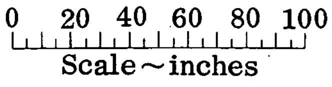
6-7


-Y65.00
D
-Y22.00
B
+Z(FWD)
A
+266.200
-Z27.030
C
2
11
Probe & Drogue
+Y Right
Docking Hatch
193.749 (Ref)
X312.5
(Top of LEM)
169.749
7.0 inch Clearance (Typ)
Payload Envelope
X200.00
215.241
2" Thermal Shield
X196.0 Struc. Face
Of Upper Deck
X211.300
X202.00
120° Field Star Tracker
3
LEM Sta
102.5
167.57
LEM
Sta
72.94
260 Dia (Ref)



Key

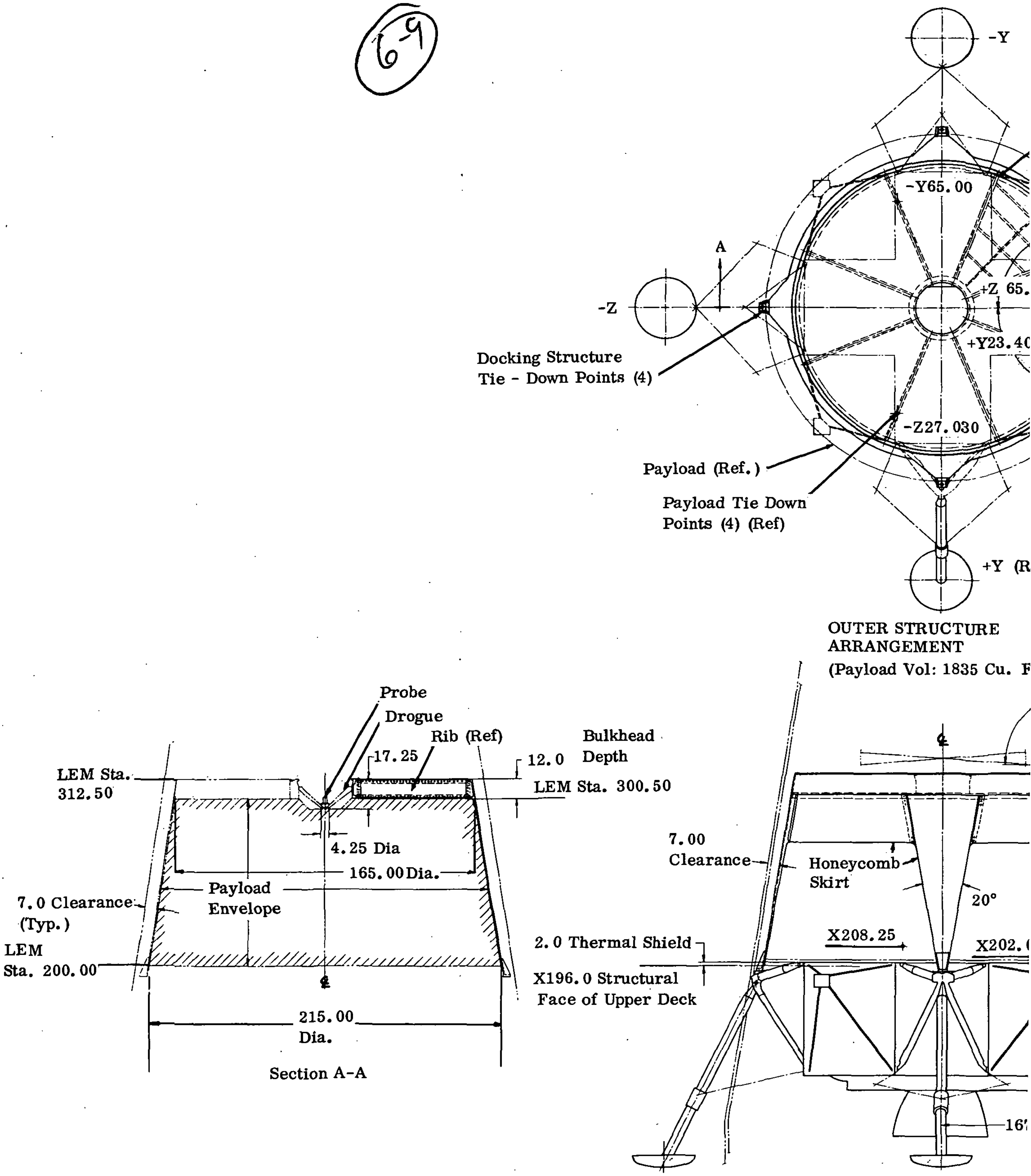
1 LEM Descent Stage Structure
2 RCS Thruster Assy (See Text)
3 IMU & Star Tracker
4 Battery
5 RCS Helium
6 RCS Valves
7 RCS Fuel
8 S-Band Era
9 Signal Conditioner
10 PCMTEA
11 Super Critical Helium Storage
12 ECS Coolant Evaporator
13 ECS Equipment
14 ECS Water
15 Descent Engine Fuel Tanks
16 Descent Engine
17 S & C & RCS Sub Systems
18 Guidance Computer
19 Landing Radar Ant
20 Landing Radar Sub System
21 RCS Oxidizer
22 Super Critical Helium Heat Exchanger
23 Helium Pressure Manifold
24 DECA
25 PYRO Relay Box
26 PYRO Batteries
Note: For Antennas See Sect 5.5



Location		X	Y	Z
FWD	Right	+12,778	+16,169	+31,821
	A	-29,560	- 8,428	-22,865
	Left	+12,234	+14,643	+16,704
	B	-27,429	-12,386	-15,952
AFT	Right	+ 9,817	+26,023	+ 345
	C	-51,700	-14,475	- 788
	Left	+ 9,861	+14,443	+ 344
	D	-51,379	-26,045	- 767

Fig. 6-1 General Arrangement
- Reference Truck

6-9



OUTER STRUCTURE ARRANGEMENT
(Payload Vol: 1835 Cu. F

Section A-A

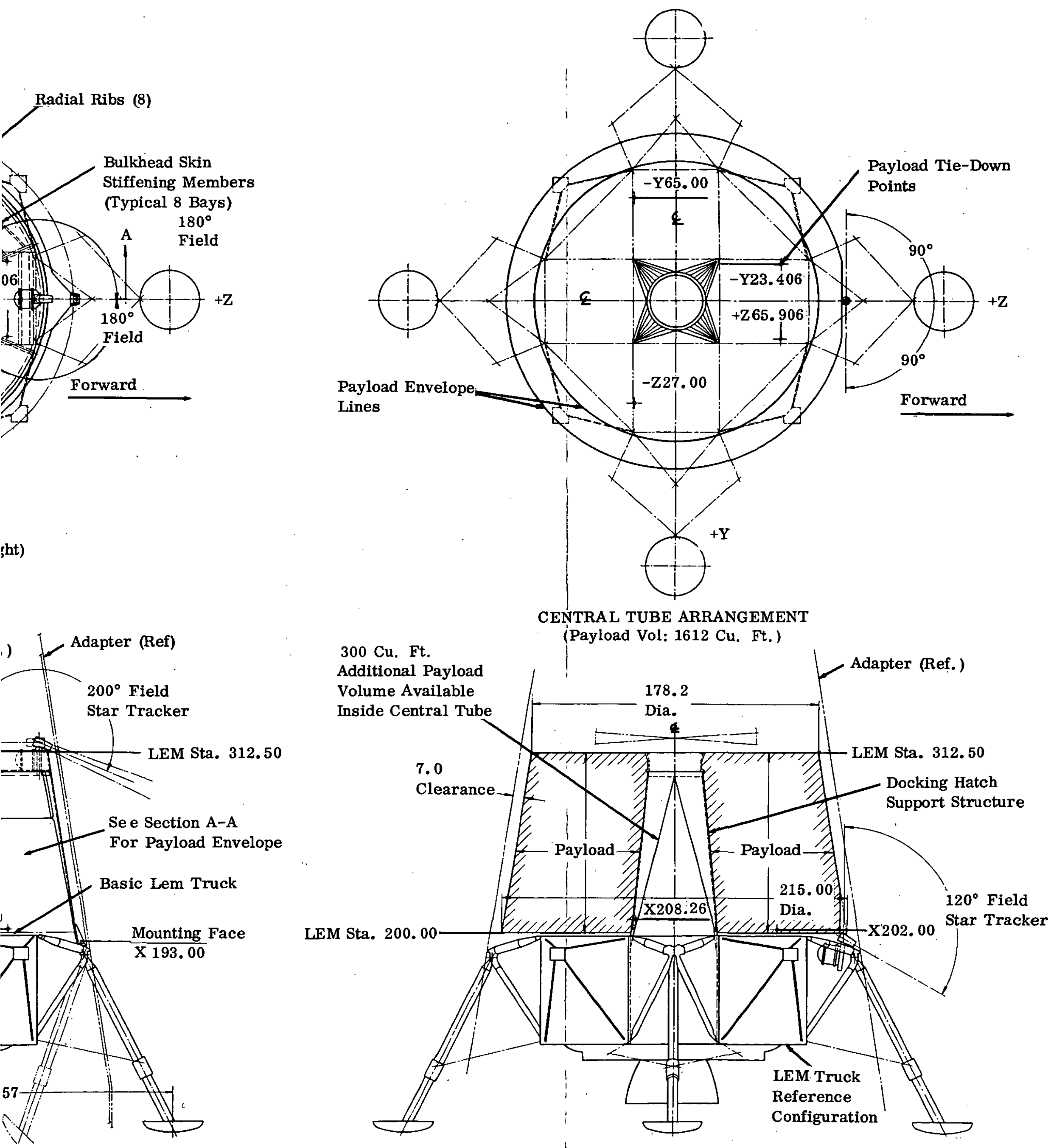
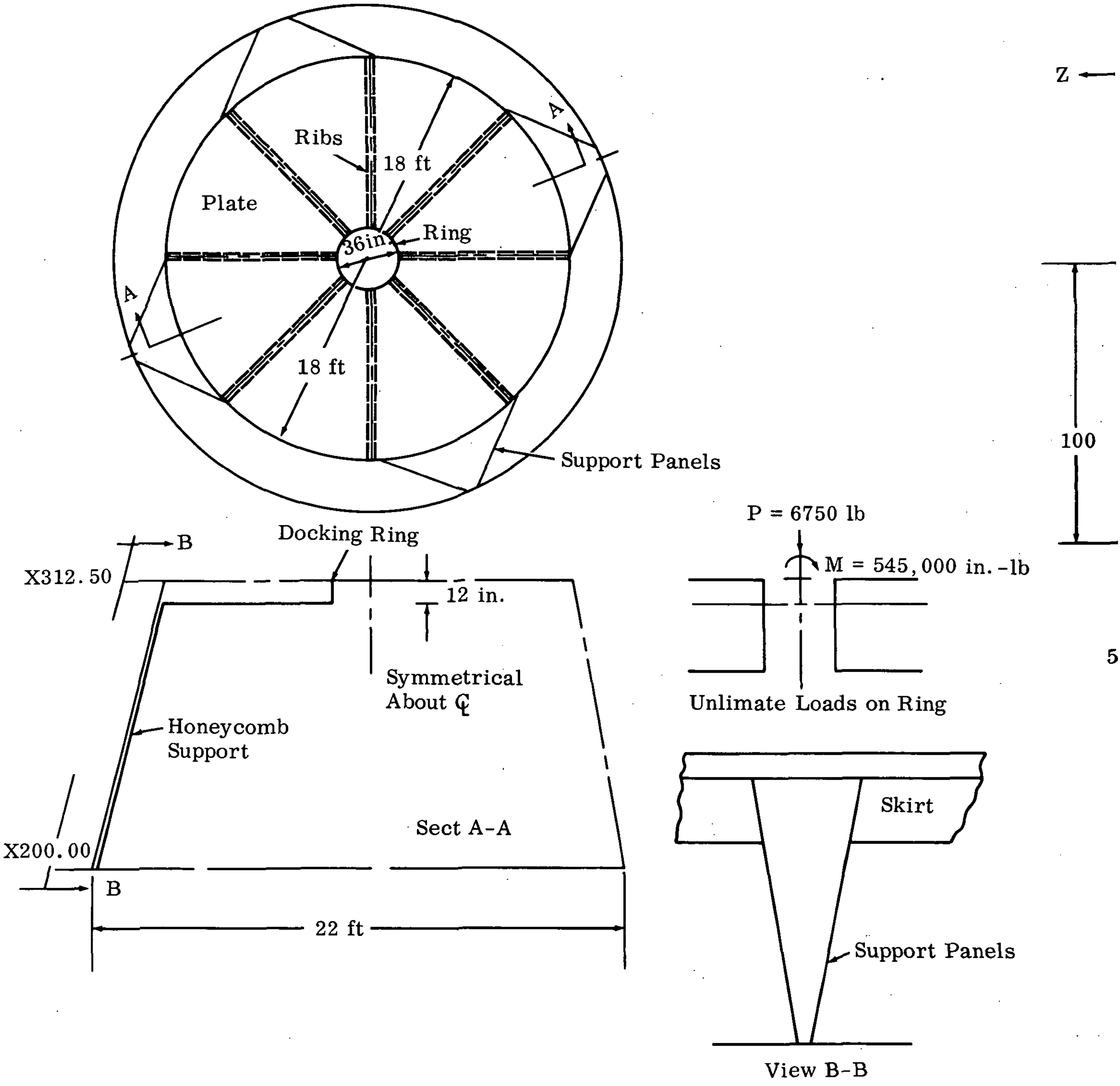
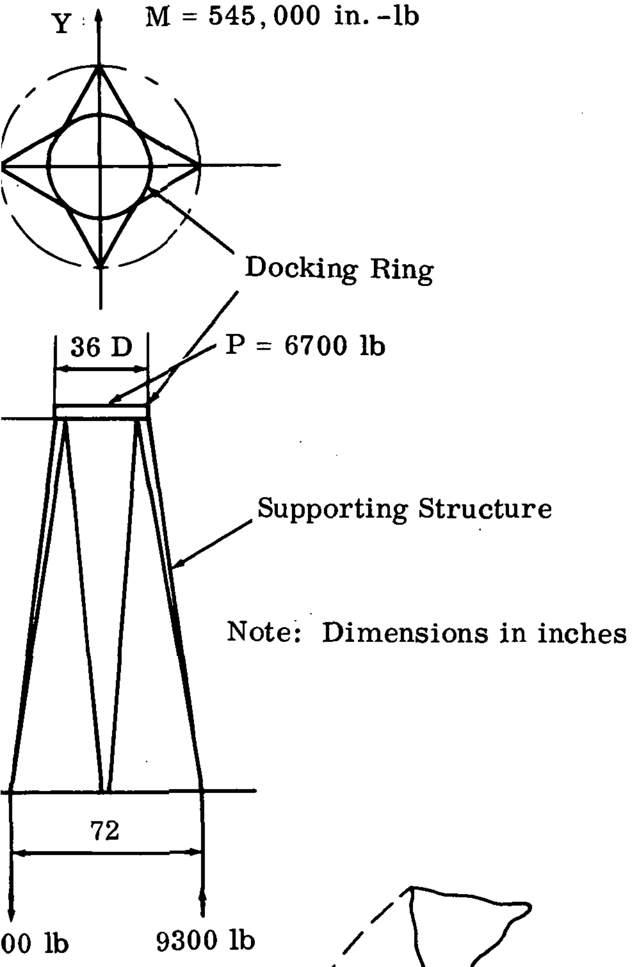


Fig. 6-2 Truck Docking Structure Design Concepts

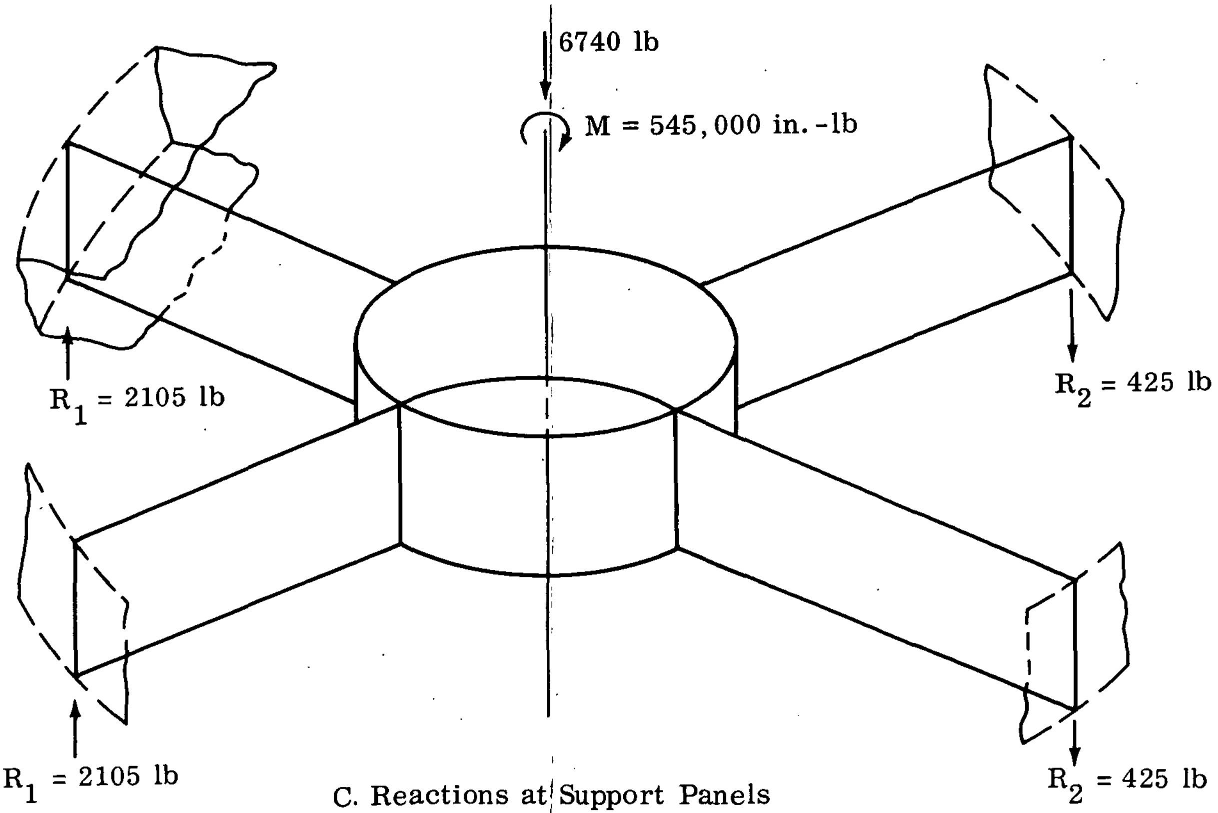
6-11



A. Outer Structure
Docking Concept



B. Central Tube Docking Concept



C. Reactions at Support Panels

Fig. 6-3 Docking Structure Design Ultimate Loading

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